ERDC TN-DOER-T10
September 2011

Physical Separation Process Demonstrations-- A Review of Three Dredging Projects

by *Daniel E. Averett and Trudy J. Estes*

INTRODUCTION: The Dredging Operations and Environmental Research (DOER) Program and the Dredging Operations Technical Support (DOTS) Program include a work unit titled "Diffusion of Innovative Technologies." The purpose of this work unit is to identify and evaluate:

> *…mature innovative technologies that exhibit potential application to reduce dredging costs, address U.S. Army Corps of Engineers (USACE) problems related to dredging, or improve dredging-related measurement, assessment, and management capabilities. Results of these evaluations will be used to foster USACE and industry-wide (where applicable) implementation of innovative technology solutions for navigation dredging projects.*

This technical note documents the application of physical separation technologies for two maintenance dredging projects and for one remediation dredging project.

Increasingly stringent restrictions on placement or disposal of contaminated dredged material and enhanced interest in finding ways to beneficially use dredged material have drawn attention to alternative management strategies, including the use of innovative treatment technologies to remove or destroy contaminants. Clean dredged material has the potential for a wide range of beneficial uses—the sandy fraction in particular. Contaminant destruction technologies, common to environmental remediation projects, have generally proven to be complex and too expensive for navigation dredging projects, where dredged material volumes and production rates are high and lower-cost disposal alternatives are usually available. Treatment technologies developed or adapted for removal of contaminants from sediment include physical separation, soil washing, solvent extraction, and thermal processes; several of these processes are described in detail in Estes et al. (2011). Of this group, physical separation perhaps offers the best chance for cost-effective application to maintenance dredging projects; contaminant reduction is achieved by segregation of the most contaminated sediment fractions, rather than by contaminant destruction. Because contaminants are not destroyed by separation processes, careful material characterization is required to inform equipment selection in order to successfully achieve processing objectives.

This technical note describes the innovative use of physical separation technologies at two USACE maintenance dredging projects—one for the Miami River Navigation Channel, FL, and the other for the Marina del Rey Harbor, CA. Both of these projects included sediments contaminated with organics and metals that were unsuitable for open-water placement; both used similar physical separation unit operations; both produced a product that was easier to handle physically for beneficial use, and both were located in a congested urban/commercial setting. The coarse products produced by the projects were not clean enough to allow unrestricted beneficial use, however. The projects differed in size and duration, in the type of dredging technology, the method of contracting the project, and final beneficial use of the recovered product. A third project, which is briefly described in this technical note based on published information, is a sediment remediation project for the Fox River, WI, where physical separation and dewatering technologies are used to prepare contaminated material for landfill disposal and collect relatively uncontaminated sand for beneficial use.

PURPOSE: The objective of this technical note is to document the field implementation of two USACE maintenance dredging projects where physical separation was employed to recover material that was used beneficially. The overall effectiveness, logistical issues and lessons learned are documented in order to inform project managers considering these technologies of the requirements and limitations of the processes.

PHYSICAL SEPARATION: Physical separation technologies are designed to separate soil or sediment into different size or density fractions based on differences in their physical properties. In some cases, physical separation produces the additional advantage of separating contaminants attached to sediment particles into a dirty fraction while also producing a clean fraction for potential beneficial use. Sediment contaminants are generally expected to be associated with either (Estes 2005):

- the clay fraction, having the properties of small particle size (<5 μm), high surface area, charged surfaces, and interlayers where contaminant molecules may be trapped

- organic materials, which are less dense than the mineral fraction of the sediment, but which may vary in size from very fine to coarser than sand particles (>4.75 mm).

The sand fraction is commonly expected to be uncontaminated because the surface of the primary minerals of which sand is composed is relatively unreactive, and has a low affinity for contaminants. There are many uses for sand, such as beach nourishment and fill, which make it a desirable commodity. For physical separation to be economically favorable, the contaminated fraction, which will likely require subsequent treatment or long-term disposal, must be relatively small compared to the reusable uncontaminated fraction.

Using physical separation technologies for dredged material is not a new idea. Mallory and Nawrocki (1974) considered the feasibility of sand and gravel beneficiation using scalping pump boxes, vibrating screens, hydraulic scalpers and classifiers, hydrocyclones, and other technologies as a study topic under the Dredged Material Research Program. They suggested that these processes were feasible, but recommended demonstration projects for dredged material slurries. Physical separation technology demonstrations at Saginaw Bay (U.S. Environmental Protection Agency (USEPA) 1994), Erie Pier confined disposal facility at Duluth/Superior Harbor (Olin and Bowman 1996), Green Bay, WI (Olin-Estes et al. 2002), and Fort Myers, FL (Granat 1998) reported successful application of numerous technologies. New England District has been using physical (mechanical) separation as part of the dewatering effort for the New Bedford Harbor Superfund site, and other U.S. remediation sites have applied physical separation technologies to contaminated sediments. In Europe, full-scale physical separation systems for contaminated sediments are more common than in the United States and have been used for a number of years. Despite successful demonstrations on some level at these locations and continued interest in the technology, physical separation using mechanical equipment has not been implemented as a standard operational practice in the United States for dredged material. The two navigation projects summarized in this document will be useful in establishing a baseline for this type of operation where the overall success or failure may be measured by production of beneficial use products, simplicity, contaminant removal, and cost compared to other alternatives.

MIAMI RIVER: The Miami River, located within the City of Miami in Miami-Dade County, FL, a natural river, flows from the Everglades in a southeasterly direction and discharges into Biscayne Bay near the present-day Port of Miami. The Federal Navigation Channel, originally authorized and constructed in 1934, consists of the 5.5 miles upstream of the river's confluence with Biscayne Bay, ending at a salinity dam near the Miami International Airport. The authorized project depth is 15 ft with a bottom width of 150 ft near the Bay, narrowing to 90 ft at the uppermost section. In addition to recreational boats, the channel is used by shallow-draft shipping vessels transporting goods from Caribbean ports to dozens of private terminals located at the upper end of the channel (Landers 2008). Left un-dredged, by 2004 shoaling in the channel had reduced water depths to 9 ft or less, requiring cargo vessels to reduce their load to half of capacity.

The river has a history of pollution from both point and non-point sources, including agricultural, industrial, commercial, residential, and maritime activities. As a result of these discharges, Miami River sediments contain elevated concentrations of trace metals (cadmium, chromium, copper, mercury, lead, and zinc) and petroleum hydrocarbons (USACE 2002). Pesticides, PCBs, and PAHs have also been found in some area sediments. With the successful implementation of pollution abatement programs to reduce contaminant loadings from the watershed, the contribution of contaminants from the sediments and their impact on water quality of the river and bay began to assume more importance. Elutriate tests and bioassays showed sediment contaminants to be bio-available and led to the conclusion that dredged material from the Miami River project would not be suitable for disposal at the designated offshore disposal site near Miami. The congested urban area and sensitive environmental areas precluded the use of a conventional diked confined disposal facility, where the material could be stored indefinitely or where it could be passively dewatered to a moisture content suitable for transport and landfill disposal. The local sponsor made available an 8.5-acre staging area for dredged material rehandling, but specified it could not be used for open-air drying of the dredged material. Although the dredged material is not a hazardous waste, nor a solid waste from a regulatory perspective, the Miami-Dade Department of Environmental Resources Management (DERM) ruled the material unsuitable for clean soil or backfill uses. However, the DERM indicated that the material was suitable for disposal at an approved solid waste landfill (USACE 2002).

Contracting approach: In developing the Dredged Material Management Plan (DMMP) (USACE 2002) for this project, the USACE Jacksonville District recognized that traditional means of dredged material disposal were not feasible. The District first issued a Request for Information (RFI) to dredging, environmental/remediation, and waste management companies soliciting industry comments on the most environmentally and economically feasible method for dredging the Miami River and disposing of the dredged material. The consensus of the responders to the RFI was that contractors preferred the flexibility to identify alternatives for dredging and permanent disposal or beneficial use of the dredged material. To accommodate this recommendation and to encourage the use of innovative technology, the District issued a Request for Proposal (RFP) and awarded the contract based on Army guidance found in the *Army Source Selection Manual* (ASAALT 2007). This process allows for awarding a contract that provides the overall best value to the government including but not limited to efficiency, technical experience, neighborhood and environmental protection, as well as cost (USACE 2002). The method of material processing and final destination of the dredged material were not specified by the contract; those two issues (processing method and final destination) were to be answered by the bidders in their proposal. The government then selected the "best value" from among the various proposals that were submitted.[1]

The contract solicitation for the project (USACE 2003) describes the river sediments as a combination of sand, silty sand, clay, silt, and gravel overlying soft to moderately hard limestone rock. Silty, very fine to medium-grained sand comprised the majority of the sediments, followed by apparently discontinuous sandy clay lenses. Also present were a wide variety of mostly man-made debris, including tires, boats, cars, motorcycles, handguns, heavy industrial debris, and assorted trash. Operations for the dredging project had to be suspended in several locations because of the discovery of discarded military munitions in sediments near a WWII-era Navy facility.

Physical separation was evaluated as a management option by PPB Environmental Laboratories, Inc. in 1997. Four grab samples of bottom sediments from the Miami River were collected, composited, and sieved through 100-, 200-, and 315-mesh screens. Analysis of the sieve fractions indicated that metal concentrations increased as grain size decreased. These data established operational parameters for a hydrocyclone/maximum density separator bench test. This test yielded a fine fraction with 10 times the metal concentration of the coarse fraction. However, the DERM noted that the coarse fraction failed to meet its definition of “clean” and that the supernatant water might require treatment beyond particulate removal (USACE 2002).

The Jacksonville District issued its RFP in October 2003 and awarded a contract in April 2004 to a joint venture of Weston Solutions, Inc., and Bean Environmental, LLC. Bean used a newly designed and built precision backhoe dredger to excavate sediment from the river and place it in conventional barges for river transport to the processing/rehandling site. Weston provided project management, environmental monitoring, and land-based logistics including transport and placement at two separate landfills. In partnership with the joint venture, Boskalis-Dolman furnished and operated a mobile soil washing plant, which was set up at the processing area.

Schedule and cost: Dredging began in September 2004 and was completed in October 2008. The project was divided into 15 sections of the river. Local sponsors furnished 20% of the cost of the Federal channel as well as 100% of the cost for removal of bank materials outside the Federal channel. Federal funds paid 80% of the cost for the Federal channel. Timely funding was an issue. The project was suspended from November 2005 until February 2008, when adequate funds were appropriated. An estimated total of 550,000 yd^3 of sediment was removed at a cost of approximately $80 million. Final total cost has not yet been determined pending settlement of contractor claims.

[1] Personal Communication. 2010. John Bearce, Project Engineer, U.S. Army Corps of Engineers, Jacksonville District, FL.

Dredge: The Florida Department of Environmental Protection established turbidity limits in the vicinity of the dredge to protect the endangered West Indian manatee and submerged archeological resources; air quality and noise were also environmental protection concerns. Bean's dredge *Barredor del Rio* was equipped with state-of-the-art positioning and operational controls providing dredging accuracy within 6 in. in the x, y, and z planes (Taylor et al. 2006). The dredge's bucket holds 4.5 yd^3, can extend 33 ft for 17 ft of depth, and can dredge 150 yd^3 per hour. The average production for this project was about 1,500 yd^3 per day (Kelly 2008).

Physical separation process: Boskalis/Dolman's mobile soil washing plant was packaged in 38 containers and transported from England and the Netherlands to the Miami River site. Assembly and startup of the 150 ton/hour plant required 3 weeks (Taylor et al. 2006). The plant was able to keep pace with the dredging operation with only four barges to equalize the feed to the plant. The overall objective of the soil washing plant was to separate the dredged material into size fractions allowing for beneficial use, and to reduce volume and mass by dewatering the materials. Because the landfills charge on the basis of weight rather than volume, removing as much water as possible saved on landfill tipping fees.

A block flow diagram for the soil washing plant is shown in Figure 1, and photographs of the processing plant are shown in Figures 2 and 3. Dredged material from the barges was offloaded with an excavator, which placed the material on top of a stationary grizzly screen. Oversize debris retained on the screen was segregated by type (metal, rocks, trash, etc.) and placed in dumpsters for transport to disposal. The grizzly underflow discharged into a rotary wash-and-sieve drum or trommel, which screened out particles 3-25 cm in size. These rocks and small debris, which were relatively dry, fell onto a conveyor belt for movement to a temporary storage pile.

Material in the under flow from the trommel with a size range of ≤ 3 cm was collected, spray washed, and dewatered on a linear shaking screen, where the oversize material (0.3 to 3 cm) was then moved by conveyor to a covered storage area. The remaining dredged material was slurried with water recycled from downstream unit processes and pumped through a bank of hydrocyclones separating sand from silt and clay at a cut size of approximately 40 to 60 microns. Sand exiting the apex of the cone dropped into a counter current washer, which removed additional fine-grained and organic materials from the sand stream. The polished sand was dewatered on a shaking screen and conveyed to the storage area.

The fine slurry from the hydrocyclone overflow, as well as the underflow from the sand dewatering screen, were discharged to a pre-thickener tank. Polymer was added upstream of the pre-thickener tank to enhance flocculation. Underflow from the thickener tank was further conditioned with flocculent and pumped to a belt filter for dewatering. The influent to the filter was about 20% dry solids by weight; the filter cake was >50% solids. Water from the thickener and filter press was recycled for use in the upstream unit processes as much as possible. Excess water from the original dredged material was treated by sand filtration and released to the river. The soil washing system was fully automated and the operator monitored flows, fluid levels, and controlled operations from the control room.

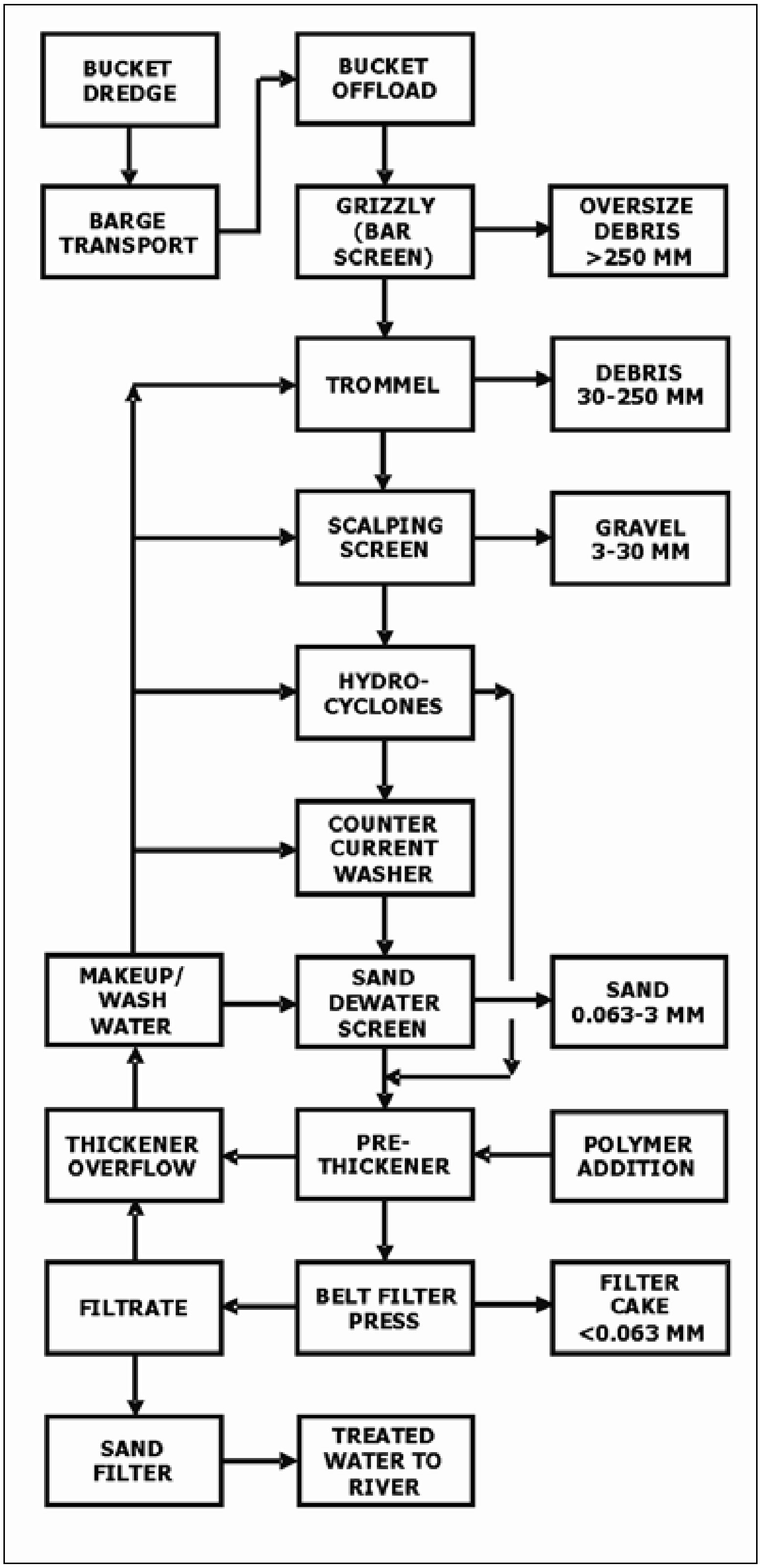

Figure 1. Block flow diagram for Miami River physical separation processes.

Figure 2. Photograph of Boskalis-Dolman physical separation system, Miami River, FL (Courtesy Bastiaan Lammers, Boskalis Dolman).

Figure 3. Photograph of Boskalis-Dolman vibrating screens, hydrocyclones, and washing system, Miami River, FL (Courtesy Bastiaan Lammers, Boskalis Dolman).

Products: A mass balance for the major product streams is given in Table 1. More than 38% of the material was classified as sand. After being processed, almost all (93%) of the separated sand was suitable for use beneficially as a final landfill cover (Table 2) (Van Dam et al. 2009). Although not suitable for final cover, the filter cake was found acceptable for use as daily landfill cover.

Table 1. Separated fractions for Miami River project (Van Dam et al. 2009).

Process Unit	Fraction	Size	Mass Balance (2009 update)	Remarks
Trommel & shaker screen	Coarse	3-250 mm	28%	Gravel/small debris
Hydrocyclone, counter current washer & dewatering screen	Sand	0.063-3 mm	38%	Sand
Belt filter press	Filter cake	<0.063 mm	34%	Silt/clay -- up to 54% dry solids

Table 2. Beneficial use of materials separated from Miami River sediment (Kelly 2008).

Material	Use
Coarse stone	Roads
Contaminated sand	Daily covers at Waste Management Landfill
Clean sand	Final cover at Waste Management Landfill
Filter cakes (silts/clays)	Daily cover at Waste Management Landfill
Trash and large rocks	Disposal at Waste Management Landfill
Metals	Recycled
Tires	Washed and recovered

MARINA DEL REY: Marina del Rey Harbor, California, is located on the Pacific coast 2 miles north of Los Angeles International Airport and is noted for being the Nation's largest small-craft harbor. More than 5,000 recreational boats are berthed at this facility. Congress authorized Marina del Rey as a Federal navigation project in 1954, but its current configuration with an outer breakwater was not completed until 1965. Since that time, periodic maintenance dredging has been required to remove shoals and maintain navigational depths. In 2008, the USACE Los Angeles District, in cooperation with the Los Angeles County Beaches and Harbors Commission, awarded a contract to dredge portions of the harbor's entrance and main channel where shoaling had reduced water depths from an authorized 6.1 m to less than 3 m in some places.

Marina del Rey sediment is relatively coarse-grained material with generally less than 30% passing a No. 200 sieve (75 microns). Contaminants of concern in the sediment include polychlorinated biphenyls (PCBs), pesticides, and heavy metals. These contaminants are primarily transported into the harbor by Ballona Creek, which empties into the Pacific alongside the marina channel and inside the breakwater. Per environmental regulations these contaminants preclude the sediment from being disposed in the open water and require consideration of other management and disposal options. One option is to use the sandy fraction of the sediment for beach nourishment. There are a number of sand beaches and recreational areas adjacent to the harbor, and there is a recurring need to replace sand that erodes along the shoreline.

Contract: The Los Angeles District contracted with CJW Construction, Inc., Santa Ana, CA, to dredge up to 50,000 m^3 of sediment from the Marina del Rey Harbor and to employ a physical separation system to recover sand for placement on the beach in Dockweiler State Beach, which is adjacent to and south of Marina del Rey. The contract allowed for a startup phase to define the operational parameters for the separation processes, followed by a production phase for treatment of the remaining material. The first phase was paid as a lump sum contract; the second phase was paid on a more typical unit cost basis.

Dredge: The dredge selected for this project was an IMS Versi-Dredge, Model 7012, Innovative Material Systems (IMS), Prairie Village, KS. The Versi-Dredge's starwheel drive system allows the dredge to be completely self-propelled. The IMS website (*http://www.imsdredge.com*) indicates that this dredge is transportable on one truck and offers a standard dredging depth of 30 ft (9.1 m). The dredge head is a shrouded, horizontal cutter, 3.4 m wide and equipped with an approximately 8-cm square bar grate over the intake to its 425-hp ladder-mounted submersible pump. Nominal production capacity for this dredge is 350 yd^3 (270 m^3) per hour through a 25-cm discharge line; however the production rate for this project was much less.

Physical separation process: The overall flowchart of the process configuration for the Marina del Rey project is shown in Figure 4. Figure 5 illustrates the overall layout of the physical separation system as it was assembled at Dockweiler State Beach, and Figure 6 shows some of the principal components of the operation. The dredge pumped material through a floating pipeline to the shore where it emptied into a coarse screen consisting of sheet metal with 2.5-cm holes (Figure 6(a)). The screen was fixed to the bottom of a basket attached to a track-mounted crane. This device collected mostly trash, particularly plastic bags and stringy debris, which had proved to be difficult to remove from other screening devices tested in the earliest stages of the project. Once the basket collected a thin layer of debris, the crane lifted the basket out of the flow path and emptied the material into a roll-off dumpster. Underflow from this screen was picked up by a centrifugal pump and transported 2 miles along the beach to the physical separation plant. A booster pump was required about halfway down the stretch.

The heart of the physical separation operation was a package unit consisting of hydrocyclones, vibrating screens, settling tank, and feed/recirculating pumps. Del Tank and Filtration Systems furnished this system, labeled the "Total Clean® TCW-3000," to CJW Construction. As described on the Del Tank web site (*http://www.deltank.com*), the Total Clean® "incorporates a V-shaped tank, a tilted plate baffle system, and a shaftless screw to create a clarifier." A shaftless screw at the bottom of the tank steadily moves settled solids to the suction of the hydrocyclone feed pumps. The hydrocyclones remove the heavy sands and silts, which are subsequently dewatered by vibrating linear screens. The hydrocyclone overflow containing lighter particulates and water is returned to the tank for additional settling and particulate capture prior to overflowing the tank. According to Del Tank literature, capacity of the hydrocyclones is 3 to 4 times the feed rate to the system allowing for multiple passes through the hydrocyclone separators.

The dredge slurry pipeline initially discharged to two linear scalping screens in parallel to remove additional coarse material (Figure 6(b)). These vibrating screens consisted of No. 10 mesh (2 mm) stainless steel screens with a screening surface area of 3.8 m^2 each. For much of

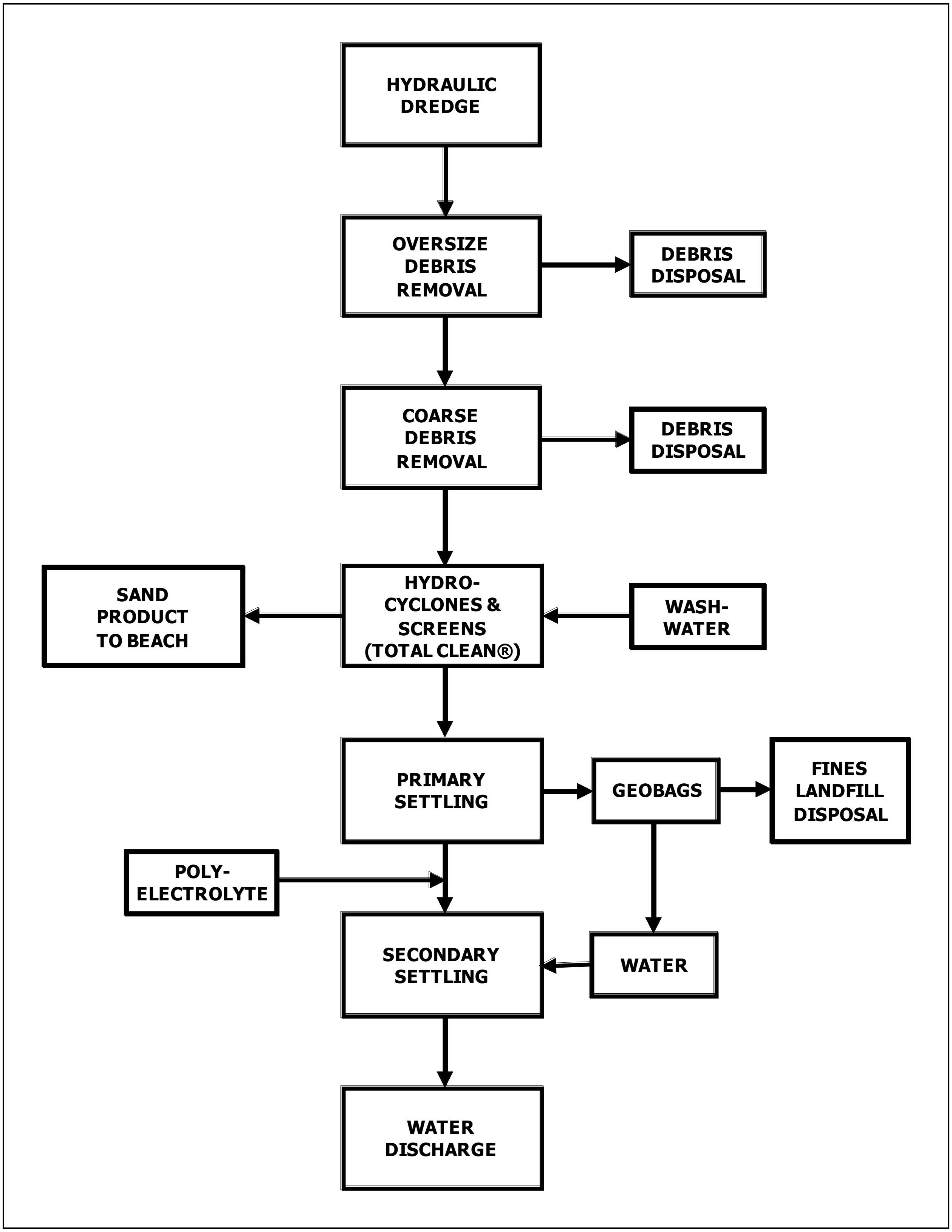

Figure 4. Dredging and physical separation project schematic.

Figure 5. Panoramic view of the physical separation system at Dockweiler State Beach, CA.

the time, only one of these shakers was required. These screens were mounted above the settling tank. The material captured on the screens was primarily vegetative debris (leaves, small twigs, grass, etc.) and bits of paper and other trash. This material was collected in a roll-off container for transport to a disposal site. Underflow from the screen discharged into the first compartment of the tank.

The tank was equipped with four pumps, one for each hydrocyclone-screening unit, and an array of valves to control flow from the bottom of the tank to the hydrocyclones and screens. Three 24-cm Krebs urethane cyclones in parallel were mounted above each of the four linear screens. Sand from the apex of the hydrocyclone cones discharged to the upstream end of the shaking screens (Figures 6(c) and 6(d)).

Each screen was equipped with two nozzles that sprayed fresh water on the screened material to enhance the cleaning of the sand product. For this project, irrigation water (not suitable for drinking) was used. The mesh size for the screens varied with the upstream screens, providing a coarser cut than the downstream screens.

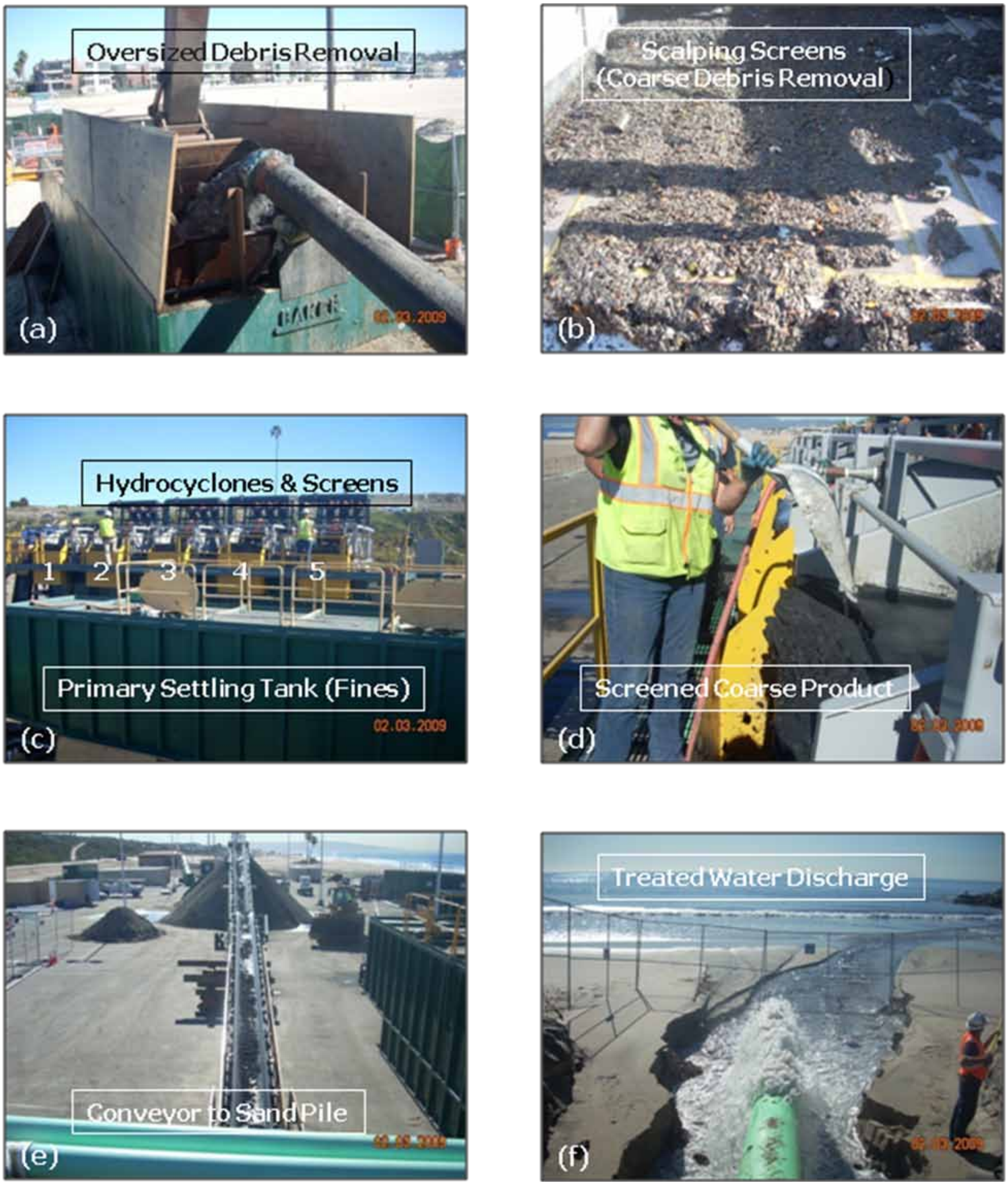

Figure 6. Photographs of principal operations at the Marina del Rey physical separation plant.

These screens were changed out at various stages of the project depending on the cut size favorable for the physical characteristics of the dredged material. In addition to adjusting wash water flow rate and screen mesh size, the inclination angle for each screening unit could be adjusted for optimum operation. Sandy material released from the end of each screening unit fell into a common conveyor belt (Figure 6(e)), which moves the sand to a paved storage area where the sand stacked well with very little free water. After testing for contaminants, this sand was later moved to specified beach areas for final disposition.

Overflow from the hydrocyclones and screening unit discharged to two Baker tanks for primary settling (Figure 6(c)). Overflow from the primary settling tanks flowed into eight 80-m^3 Baker tanks for secondary settling and final clarification before being discharged to the adjacent Pacific Ocean (Figure 6(f)), following confirmation that the effluent met regulatory criteria. Polyelectrolyte addition was used for the early stage of the project, to aid the primary settling step but its benefits were minimal, and the point of injection was relocated to the overflow line from the primary settling tanks to the final settling tanks. Underflow from the primary settling tanks was initially pumped to a belt filter press for dewatering. However, operational problems with the belt filter and difficulties in pumping the material after it accumulated in the settling tanks resulted in switching from the belt filter press to geobags for dewatering and consolidation of the fine-grained material. After dewatering, the fine-grained material was transported by truck to a landfill for disposal.

Except for the oversize debris removal step, all of the processing equipment was set up on a parking lot for Dockweiler State Beach (Figure 5). Sand bags were placed around selected process equipment areas to prevent unintended excursion of water from the site. Because this was a public area, the Los Angeles District continually communicated with the local sponsor and other stakeholders to maintain good community relations and support for the project. A residential area was located near the dredging site and booster pump, so noise was a concern, limiting nighttime operations. Although the timing of the project was off-season (December to March), a number of people were using the beach and walk/bike path for land–based activities during operations, and public safety was of concern. Another consideration was an environmental window for threatened bird species that nest on the beach during the spring. The Los Angeles District contracted with a biologist to observe operations on the beach and to make sure the Snowy Plover was not impacted.

Process operations: Dredged material processing began in late December 2008, and concluded in March 2009. The dredge operated on an intermittent basis due to startup, operational, and regulatory issues. The contractor dredged an estimated 8,000 m^3 of sediment from the channel, and recovered about 70% of the dredged material as sand. While the goal was to operate on a 24-hr/day schedule, the project did not advance beyond 12 hr/day operations. The potential for complaints of noise from the local residents was one reason for restricting operations to daylight hours. Dealing with startup operational issues also contributed to limited operating time.

Dealing with debris was one of the major startup issues. While there were some large objects, stringy materials like plastic bags, wire, and cables tended to initially hang up or get wrapped around the dredge's horizontal cutter and the bar rack over the dredge's pump intake. Removing this material required shutting down the dredge pump and manually removing the material. Some of this material was entrained in the dredged material slurry and pumped to the processing plant. Stationary screens, requiring manual cleaning, were used at first. These were abandoned in favor of the crane-mounted basket discussed in the process description, which proved to be effective in capturing the oversize debris with limited operational difficulty and without interruption of dredging.

Early operations included experimenting with different screen mesh sizes for the sand dewatering screens and modifying the distribution of the flow among the four sand screens. The volume of wash water was also increased in an effort to further reduce the contaminants in the sandy material.

Difficulties in pumping the material after it had consolidated in the primary settling tanks and unsatisfactory operation of the belt filter resulted in changing the process to place the fine-grained material in geobags for passive dewatering and easier handling for disposal. The major difficulty was pumping solids from the settling tank, which did not include any kind of raking mechanism to prevent over-consolidation of the settled solids and to keep material moving to the pump intake. Once material built up in the tank, it became too consolidated to effectively pump to the filter.

Sampling and analysis: Los Angeles District personnel sampled the harbor/channel sediment and collected samples from various points in the treatment process, with the assistance of a consultant, Anchor QEA. Calscience Environmental Laboratories, Inc. performed laboratory analyses under the direction of Anchor QEA. One purpose of this sampling program was compliance with regulatory requirements for placing the recovered sand on the beach near the intertidal zone. Additional analyses were conducted to identify the grain size distribution for adjustment and operation of the physical separation process. During routine sampling, material was collected from either the dredged material slurry or the bottom sediment near the dredge and from the sand product at either the discharge from the screens (Figure 6(d)) or the sand stockpile (Figure 6(e)). Additional samples were collected from individual screens, from the fines removed from the dredged material as collected in the primary settling tank (Figure 6(c)), and from the resulting water discharge (effluent) (Figure 6(f)).

Effectiveness of grain-size separation: The main benefit of physical separation technologies for a dredging project is separation of the dredged material by grain size to produce a product that is less contaminated than the bulk dredged material and that meets the grain size specification for a given beneficial use. There are considerably more opportunities for beneficial use of sand than for fine-grained material; for material to be used as beach nourishment, there is generally an upper limit (10-45%) on the fraction of the material that is fine-grained.

The effectiveness of the Marina del Rey system in separating silt and clay from sand is illustrated in Figure 7, which compares the particle size distribution measured by a Coulter counter for the sediment, material retained on the third and fifth shaking screens (Figure 6(c)), and composite samples from the sand pile (Figure 6(e)) and fines from the belt filter press. As expected, the coarsest material was observed at the most upstream screen, and the finest material was observed coming from the belt filter press. There was a shift in the grain size toward larger particles from the sediment to the sand product (Figure 7).

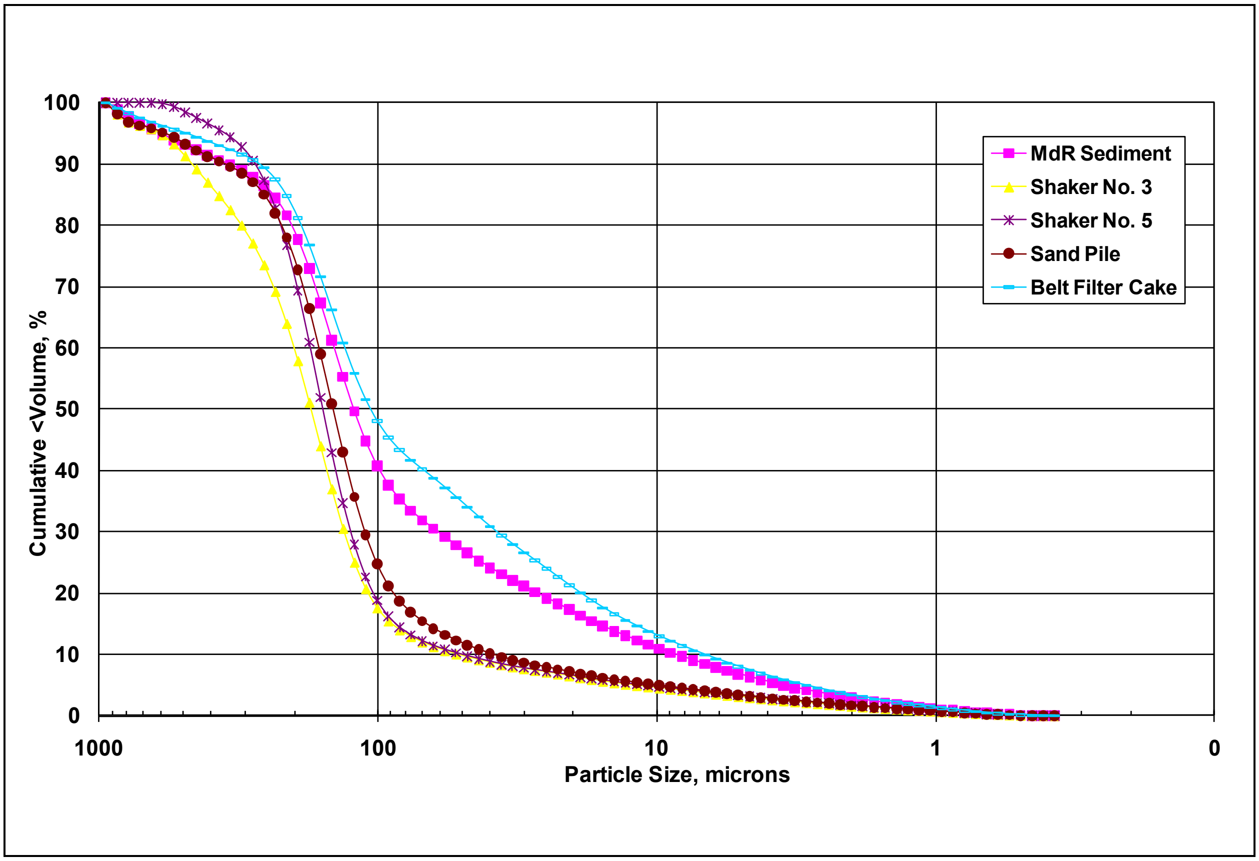

Figure 7. Grain size distribution for samples collected February 3, 2009 at the Marina del Rey physical separation plant.

Effectiveness of contaminant removal: Physical separation has been promoted as a promising technology for treatment of contaminated sediment to remove organic and inorganic contaminants. Contaminants of concern in Marina del Rey include heavy metals, pesticides, polychlorinated biphenyls (PCBs), and polynuclear aromatic hydrocarbons (PAHs). The sampling program for the demonstration project included analyses for heavy metals, pesticides, and PCBs. PCBs were not found above the detection limits for any of the samples collected during the project. Heavy metals and the pesticides chlordane, dieldrin, and DDT metabolites were found in the sediment and in the sand product. The residual contaminant concentrations in the sand product failed to fully meet goals for success.

Figure 8 compares the average concentrations of metals for the sediment (dredged material) versus the sand product. The process slightly reduced heavy metal concentrations with the exception of lead. The differences between average concentrations of sediment and sand product were statistically significant at the 0.05 level for copper, silver, and zinc, but not for the other metals. Average lead concentration increased, but the concentration in the sand was affected by one sample statistical outlier value of 209 mg/kg (based on Dixon's Extreme Value Test). Metals and other contaminant concentrations were compared to the Long and Morgan (1990) Effects Range Low (ERL) and Effects Range Median (ERM) screening criteria for sediment. Average sediment concentrations for copper, lead, and zinc were the only metals exceeding the ERL values; none of the observed sediment or sand product concentrations exceeded the ERM values for any of the metals. Discarding the outlier, mean lead concentrations observed in the sand product were slightly greater than the ERL values (52 mg/kg compared to ERL of 47 mg/kg), but less than the ERM value (218 mg/kg). Average concentrations for other metals in the sand product were less than ERL values.

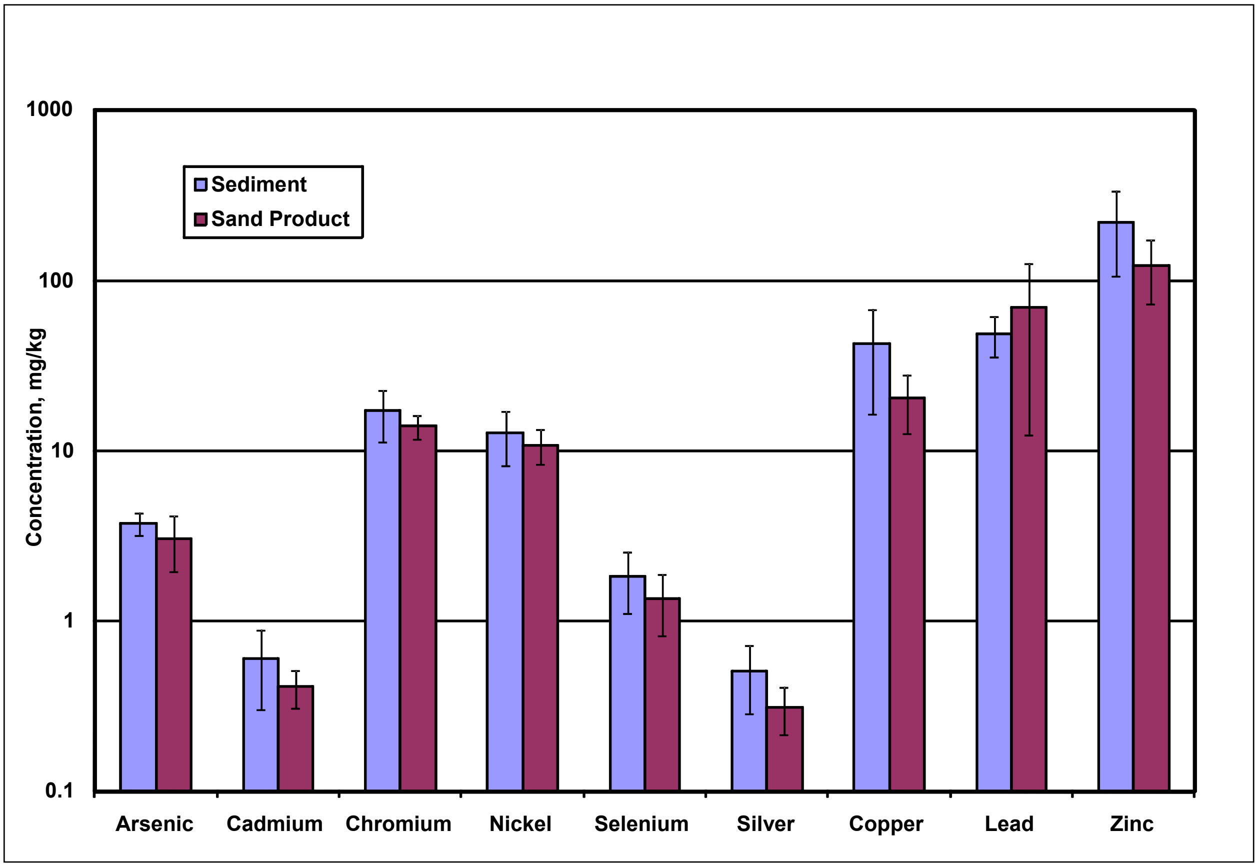

Figure 8. Comparison of heavy metals (mean ± 1 std dev) in sediment feed and sand product.

The differences in pesticide concentrations are illustrated in Figure 9. Concentrations of 4,4'-DDD and 4,4'DDT appear to have been reduced by the sand recovery process, although the statistical variance of the concentrations in the sediment weigh against the strength of this conclusion, i.e., the differences are not statistically significant based on Student t-test. Concentrations of 4,4'DDE, and total chlordane in the sand fraction were not appreciably different from bulk sediment concentrations; concentrations of dieldrin in the sand fraction were higher than bulk sediment concentrations. During the course of the project, chlordane became a cause of concern for placement of the sand on the beach. The concentrations found in the sand were greater than ERM values used by the California Coastal Commission and the Regional Water Board. However, toxicity tests for the sand material showed that the sand product did not exhibit toxicity to the test organisms. Consequently, the sand was placed on the beach, but at an elevation higher than the intertidal zone.

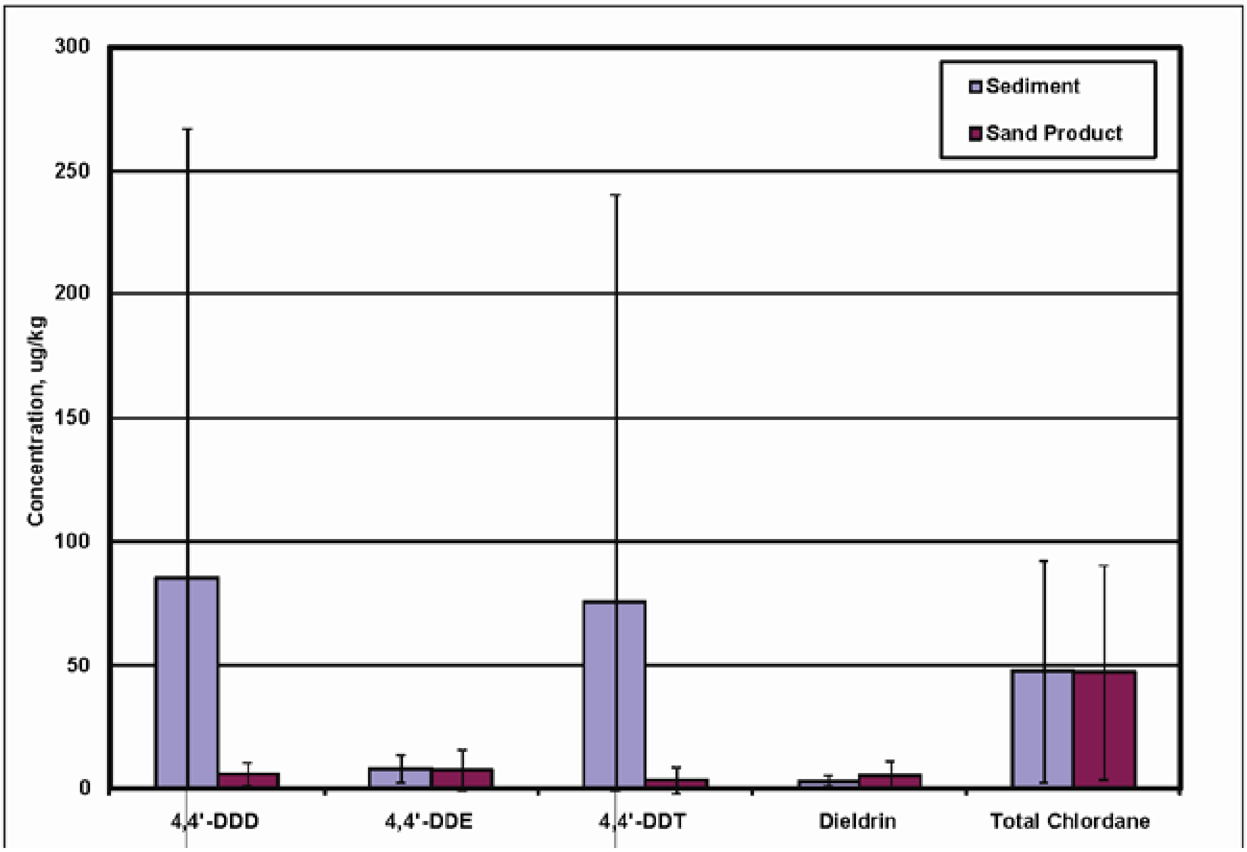

Figure 9. Comparison of pesticides (mean ± 1 std dev) in feed and product.

Contaminants in sediment generally partition to the organic material in the sediment and to the fine-grained clays and silts. These effects are generally illustrated in Table 3. The process reduced the TOC in the sand compared to the sediment, and the fines and debris fractions exhibited greater TOC concentrations compared to the sediment. Similar trends were exhibited for most metals, but not for the pesticides. There are several potential explanations for the pesticides and lead remaining with the sand fraction. Organic particles that strongly adsorbed the pesticides may have separated with the sand fraction, a fraction of the fine particles enriched with contaminants carried over with the sand product, or there may have been an oily organic film coating the sand particles and transporting the pesticides. The monitoring data available do not provide sufficient evidence to fully evaluate these potential mechanisms. Similar phenomena were discussed in preliminary bench scale experiments for Marina del Rey sediment (Estes et al. 2006). If the carbon particles were black carbon (a condensed carbon phase occurring as a product of incomplete combustion, coal, or similar materials), as opposed to naturally occurring amorphous carbon, the contaminants would be expected to be strongly adsorbed to the carbon particles and have limited bioavailability. The absence of toxic effects in bioassays for the sand product lends some credibility to this suggestion.

Table 3. Arithmetic mean contaminant concentrations and sediment characteristics for feed and discharge streams from the Marina del Rey physical separation plant.

Contaminant	Sediment	Treated Sand	Separated Fines	Debris	Dockweiler Beach
Copper, mg/kg	42	20	119	91	2.4
Lead, mg/kg	49	69	125	51	6.1
Zinc, mg/kg	220	120	560	760	11
Dieldrin, µg/kg	3.4	5.5	3.9	6.8	<1.1
Total Chlordane, µg/kg	48	47	45	5500	<11
Total Organic Carbon (TOC), %	2.4	1.1	7.4	30	<.056
Total Solids, %	66	78	52	18	94
Silt + Clay, %	13	7.0	42*	25	0.31
No. Samples	5	9	2 (* 1)	1	2

FOX RIVER NATURAL RESOURCE DAMAGE ASSESSMENT (NRDA) SUPERFUND PROJECT: The Fox River project differs from the Miami River and Marina del Rey projects in several respects. Most importantly for this discussion, it is a cleanup project, not a navigation project. However, part of a USACE navigation project overlaps the cleanup site. The $600 million cost for the project is being funded by the Fox River Cleanup Group. Overseeing the project for the public interest are USEPA Region 5 and the Wisconsin Department of Natural Resources. The prime contractor is Tetra Tech EC, Inc., who teamed up with Boskalis-Dolman and Stuyvesant Dredging Company for design, construction, and operation of the processing plant and with J. F. Brennan Co., Inc., for dredging operations (Larson 2009).

The physical processing system was assembled inside a building constructed to allow continued operations during colder weather in Wisconsin, although the cleanup operations will be suspended during the coldest months. An overview of the facility characteristics and components is provided in the text box that accompanies the photographs in Figure 10. The facility can be considered "fixed," since the cleanup is projected to require nine years to complete. The major purpose of the physical separation system is to reduce the volume of PCB-contaminated material that must be placed in a landfill. About 30% of the dredged material is expected to be sand (Vissers 2009), which can be effectively cleaned and separated from the fine-grained material using screens and hydrocyclones. Eight of the world's largest membrane filter presses squeeze water from the fine-grained fraction to yield a filter cake with more than 50% solids. During the first year of dredging operations, 380,000 m^3 of Fox River sediment was dredged and processed, exceeding the project goal by 50% (USEPA 2010).

CONCLUSIONS: Commercially available physical separation processing equipment was demonstrated in full-scale physical separation and dewatering projects for Miami River, FL, and for Fox River, WI, and in a demonstration-scale sand recovery project at Marina del Rey Harbor, CA. The Miami River project enabled restoration of navigable depths for a dredging project that had been hampered by limited disposal alternatives for contaminated sediments. Material recovered from the Miami project was beneficially used as landfill cover. The ongoing Fox River cleanup project is successfully using physical separation and dewatering processes to reduce landfill requirements for remediating contaminated sediment. Both the Marina del Rey and Fox

Figure 10. Fox River physical separation plant. Top photo shows hydrocyclones; Middle photo shows membrane filters with closeup of plates in bottom left-hand corner, bottom photo shows filter cake being loaded for transport to landfill.

Fox River Natural Resources Damage Assessment (NRDA) Site, Wisconsin (Larson 2009)

- PCB-contaminated sediment
- Remedy includes dredging, treatment and disposal for some areas, capping others
- Dredging began 2009
- Estimated total dredging volume 2.7 million m^3
- Hydraulic dredges operating at 110 m^3/hr pump material as far as 16 km directly to treatment plant
- Computer-controlled processing operations
- Grain size cuts:
  - Scalping screens (>6mm)
  - Cyclones (6mm—0.15 mm)
  - Cyclones (0.15—0.063 mm)
- Coarse dewatering
  - Screens
- Fines dewatering
  - Gravity settling (polymer assisted)
  - Membrane filter presses
- Water treatment
  - Filtration
  - Carbon adsorption
  - Recycle or discharge effluent
- Coarse product disposal/use
  - Concrete sand
  - Fill material
  - Debris to landfill
- Contaminated fines
  - Truck transport
  - Landfill disposal

River projects demonstrated separation systems fed directly by a hydraulic dredge; the Fox River system is operating at a much larger, and sustained, scale. The Fox River process also appears to be more successful in removing low-density materials from the sand, and has produced a sand fraction determined to be acceptable for use as concrete sand and fill material. Sand physically suitable for beach nourishment was produced by the Marina del Rey project; however, residual contaminants in the sand fraction limited placement sites for the sand and suggest that additional process modifications or improved operations are needed to improve contaminant removal, particularly for pesticides. As observed for a number of other investigations, a separated coarse fraction free of contaminants is not a given. Prior to planning and designing a physical separation system for dredged material, bench-scale physical fractionation testing should always be completed for the specific sediment to be dredged, and each size and density fraction should be fully characterized with respect to grain size, density, and concentration of potentially important sorptive phases such as hard carbon, amorphous organic carbon, and oil and grease.

ACKNOWLEDGEMENTS: This technical note was made possible through the cooperation and support of the USACE Los Angeles District and the USACE Jacksonville District.

ADDITIONAL INFORMATION: This technical note was prepared by Daniel E. Averett, Research Environmental Engineer, and Dr. Trudy Estes, Research Civil Engineer, Environmental Laboratory, U.S. Army Engineer Research and Development Center. The study was conducted as an activity of the Dredging Operations and Environmental Research (DOER) Program. For information on DOER, please consult http://el.erdc.usace.army.mil/dots/doer or contact the Program Manager, Dr. Todd S. Bridges, at Todd.S.Bridges@ usace.army.mil. This technical note should be cited as follows:

> Averett, D. E., and T. J. Estes. 2011. *Physical separation process demonstrations--A review of three dredging projects*, DOER Technical Notes Collection. ERDC TN-DOER-T10. Vicksburg, MS: U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://el.erdc.usace.army.mil/elpubs/pdf/doerD##.pdf

REFERENCES

Estes, T. J. 2005. *PAH and PCB distribution in sediment fractions and sorptive phases*. PhD diss., Louisiana State University.

Estes, T., S. Bailey, R. Shafer, J. Fields, and S. Cappellino. 2006. *Sand separation in estuarine sediments and mechanical dewatering for management of fine residuals – Bench scale feasibility testing. Appendix A, Los Angeles Regional DMMP: Upland treatment technologies investigation report*. Los Angeles, CA: U.S. Army Engineer District, Los Angeles.

Estes, T., V. S. Magar, D. E. Averett, N. D. Soler, T. E. Myers, E. J. Glisch, and D. A. Acevedo. 2011. *Mass balance, beneficial use products, and cost comparisons of four sediment treatment technologies near commercialization*. ERDC/EL-TR-11-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Granat, M. A. 1998. Jacksonville District hydrocyclone experience. *Proceedings of the 11th Annual National Conference on Beach Preservation Technology, Tallassee, FL, February 4-6, 1998*.

Kelly, P. J. 2008. Miami River Project. In *USACE/American Association of Port Authorities Quality Partnership Initiative—Emerging Technologies, December 4, 2008*. Alexandria, VA: American Association of Port Authorities.*http://aapa.files.cms-plus.com/SeminarPresentations/2008QualityPartnership/-Dec2008QPI_Kelly_Patrick.pdf*

Landers, J. 2008. Long-delayed dredging of Miami River Channel draws to a close. *Civil Engineering—ASCE*, 78(12):21-23.

Larson, M. 2009. Just-in-time dredging pulls out toxins. *Engineering News Record*, August 3, 2009.

Long, E., and L. Morgan. 1990. *The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program.* National Oceanographic and Atmospheric Administration (NOAA) Technical Memorandum NOS OMA 52. Seattle, Washington: NOAA.

Mallory, C. W., and M. A. Nawrocki. 1974. *Containment area facility concepts for dredged material separation, drying and rehandling*. Contract Report D-74-6. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASAALT). 2007. *Army Source Selection Manual*. Washington, DC: U.S. Army.

Olin, T. J., and D. W. Bowman. 1996. *Soil washing potential at confined disposal facilities,* Environmental Effects of Dredging Bulletin, Vol D-96-3. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Olin-Estes, T. J., S. E. Bailey, D. W. Bowman, and D. L. Brandon. 2002. *Soil separation mobile treatment plant demonstration, Bayport Confined Disposal Facility, Green Bay, Wisconsin.* ERDC/EL TR-02-38. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Taylor, A., J. McWilliams, H. van Dam, and B. Lammers. 2006. Deepening, cleaning and processing sediment from the Miami River. *Terra et Aqua* 103: 23-30.

U.S. Army Corps of Engineers (USACE). 2002. *Final report: Dredged material management plan and environmental impact statement, Miami River, Miami-Dade County, Florida*. Jacksonville, FL: U.S. Army Engineer District.

U.S. Army Corps of Engineers. 2003. *Maintenance dredging, 15-foot project, Miami River, cut-1 thru cut-48, Miami Harbor, Dade County, Florida—Construction solicitation and specifications*. RFP No. DACW17-OZ-R-0016. Jacksonville, FL: U.S. Army Engineer District.

U.S. Environmental Protection Agency (USEPA). 1994. *Pilot-scale demonstration of sediment washing for the treatment of Saginaw River sediments.* EPA 905-R94-019. Assessment and Remediation of Contaminated Sediments Program. Chicago, IL: Great Lakes National Program Office.

U.S. Environmental Protection Agency (USEPA). 2010. *Lower Fox River cleanup*. *http://www.epa.gov/region5-/sites/foxriver/* accessed November 18, 2010.

Van Dam, H. W., B. M. Lammers, A. Taylor, and N. Johnson. 2009. Miami River sediment processing and dewatering—An evaluation. In *Remediation of Contaminated Sediments—2009, Fifth International Conference on Remediation of Contaminated Sediments*. Columbus, OH: Battelle Memorial Institute.

Vissers, R. 2009. Cleanup of the Lower Fox River in Wisconsin, USA: The world's largest sediment remediation project, ed. Harry van Adam. *Pollution Solutions*. June 2009.