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Recovery of dredged material for beneficial use: the future role of physical separation processes

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Abstract

Sediments dredged from navigational waterways have historically been disposed in confined disposal facilities (CDFs) or in open water. When sediments are contaminated, open water disposal is typically not an alternative, and sediments are placed in CDFs. Many CDFs are nearing capacity, and siting and constructing new facilities is both difficult and expensive. In many cases, CDFs contain both clean and contaminated dredged material. Removal of materials suitable for beneficial use (BU) is one alternative under consideration to extend the life of existing CDFs, as is separation of recoverable materials at the time of disposal. Several technologies for recovery of clean materials or treatment of contaminated materials for beneficial use are presently under evaluation. Physical separation technologies have been demonstrated to have potential in reducing the volume of sediment that must be managed with confined disposal, but there are several technical issues that remain to be addressed. Determination of beneficial use specifications, physical and chemical characterization of dredged material, overall site characterization, selection of suitable unit operations, management of liquid and solid residuals, and cost/benefit analysis, are all important aspects to successful implementation of separation processes. Several of these elements are presently being evaluated in research conducted by the US Army Corps of Engineers, at the ERDC Waterways Experiment Station (WES). Published by Elsevier Science B.V.

Keywords: Soil washing; Physical separation; Volume reduction; Beneficial use; Dredged material

1. Introduction

Physical separation processes are generally technically simple methods for separation of particles on the basis of size, density or surface chemistry differences. These processes are well established in the mining industry for selective separation of minerals and, in recent years, have been applied to the problem of volume reduction of contaminated soils and

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sediments. In this context, physical separation is typically referred to as soil washing. The objective is to separate the most contaminated fractions of a sediment from the remainder. The less contaminated, or uncontaminated, fractions require less rigorous treatment or disposal measures, and may be suitable for commercial or beneficial uses without treatment. The most contaminated fractions may require further treatment or restricted disposal. The volume of the fine residuals may be minimized using mechanical dewatering, further reducing storage requirements. Dewatering processes are therefore integral to the physical separation treatment train.

Good examples of beneficial use of dredged material can be found in several of the US Army Corps of Engineers districts. To date, however, clean materials that require little or no additional processing are the principal candidates for beneficial use. Beach restoration and construction fill are probably the most familiar examples; both require predominantly coarse material. There is a much greater volume of sediment that could potentially be tapped, however, if the most contaminated fraction was removed and the fines content restricted to the beneficial use specification. Further research and improvements in processing techniques may demonstrate that some fine materials are potentially recoverable as well. Potentially is the operative word, however. Public, regulatory and environmental acceptability, and quantifiable benefits, are all requisite to implementation.

2. Determining beneficial use specifications

While testing criteria are relatively well defined for dredged material disposal under Section 404 of the Clean Water Act, and Section 103 of the Marine Protection, Research and Sanctuaries Act (MPRSA), beneficial use criteria are generally determined on a case by case basis. Acceptable contaminant levels and testing requirements have not been universally established. Because beneficial use of dredged material is a highly site specific issue, most discussion found in the literature is general in nature. Extensive qualitative discussions can be found in publications of Permanent International Association of Navigation Congresses (PIANC) [1,2], and Beneficial Uses of Dredged Material [3]. Efforts to establish definitive criteria for beneficial uses have been initiated in the states of New York and New Jersey, and the results of those efforts may ultimately serve as a model for other states [4].

Local beneficial use opportunities and material specifications must be identified, and then criteria defining acceptable contaminant levels and testing requirements developed in cooperation with the appropriate regulatory agencies. In a recent study of beneficial use opportunities for Erie Pier materials, for example, the posture taken by the Wisconsin natural resource agency was that re-use of materials is ecologically sound and is encouraged, but must be evaluated and criteria developed on a case by case basis [5]. Where the dredged material is to be incorporated as a raw material, standards established by agencies such as the American Concrete Association, the American Association of State Highway Transportation Officials, or the National Asphalt Pavement Association, among others, may also apply. Evaluation of the disposal effects of the residual materials would be conducted as for any dredged material, consistent with applicable regulations.

Table 1
Characteristics of dredged sediment and washed materials at Erie Pier CDF[a]

Parameter	Dredged material (average)	Washed material (average)	Reduction (%)
Total solids (%)	55.0	86.0	NA
Silts/clays (passing no. 200 sieve) (%)	69.0	14.0	80
Total volatile solids (%)	2.81	0.58	79
PCBs (mg/kg)	0.10	<0.02	>80
Oil and grease (mg/kg)	762	263	65
Total organic carbon (mg/kg)	19300	2206	89
Arsenic (mg/kg)	1.64	0.866	47
Cadmium (mg/kg)	2.98	1.10	63
Chromium (mg/kg)	31.7	10.3	68
Copper (mg/kg)	32.6	22.0	33
Iron (mg/kg)	22200	7220	68
Lead (mg/kg)	65.2	17.4	73
Mercury (mg/kg)	0.108	0.0136	87
Nickel (mg/kg)	20.4	7.62	63
Zinc (mg/kg)	84.8	20.8	76
Cyanide (mg/kg)	0.098	0.06	39
Ammonia nitrogen (mg/kg)	278	164	41

[a] Source: Olin and Bowman (1996).

The Erie Pier CDF is a good example of this process. Located in Duluth, MN, Erie Pier contains materials dredged from the Duluth-Superior harbor. In recent years, coarse material has been recovered from the CDF using a rudimentary sluicing process, and is used as construction fill. Based on previous chemical analysis showing this material to be relatively uncontaminated (Table 1), testing is now primarily required to verify that the material meets the required grain size distribution [6].

Recent testing conducted at the Bayport CDF in Green Bay, WI, confirms that physical separation can be effective in separating a relatively uncontaminated fraction. A sediment containing approximately 30% sand by volume was hydraulically excavated and fed to a 24 in. maximum density separator designed to produce a predominantly coarse underflow. Additional material was processed through a 6 in. maximum density separator for performance comparison. Results of those two tests are summarized in Table 2.

3. Site and material characterization

Site characterization is necessary to estimate relative volumes, types and distribution of materials present in a CDF, to identify contaminants of concern, to determine whether separation and fractionation studies will be needed, and to provide preliminary information for estimating volume recovery potential. Site characterization will precede intensive material characterization. A conceptual approach to characterization of a CDF was developed under the Dredging Operations and Environmental Research (DOER) program at WES. The guidance incorporates a prescriptive approach to estimating volume recovery potential, using

Table 2
Bayport CDF separation demonstration[a]

Constituent	Feed	Overflow	Underflow
Results for 24 in. MDS			
Sand (vol.%)[c]	29.5	18.4	92.1
Silt (vol.%)[c]	53.4	61.4	6.4
Clay (vol.%)[c]	17.2	20.2	1.5
PCB 1242 (ppb)	2714	4038	144
PCB 1260 (ppb)	145	110	12
TOC (mg/kg)	26500	46480	1019
As (mg/kg)	2.8	3.4	0.49
Cr (mg/kg)	38	49	2.9
Pb (mg/kg)	42	60	2.9
Hg (mg/kg)	0.88	1.3	<0.04
Ni (mg/kg)	16	19	2.6
Zn (mg/kg)	81	117	5.4
Results for 6 in. MDS			
Sand (vol.%)[c]	NA[b]	0.3	73
Silt (vol.%)[c]	NA	73	20.5
Clay (vol.%)[c]	NA	26.7	6.5
PCB 1242 (ppb)	NA	8456.5	1645.5
PCB 1260 (ppb)	NA	508	91.1
TOC (mg/kg)	NA	55650	11650
As (mg/kg)	NA	7.0	1.5
Cr (mg/kg)	NA	109	12.8
Pb (mg/kg)	NA	144.5	18.5
Hg (mg/kg)	NA	4.6	0.4
Ni (mg/kg)	NA	30.9	5
Zn (mg/kg)	NA	263.5	32.1

[a] Results are averages for replicates — (five for 24 in. MDS, two for 6 in. MDS).
[b] Not available; the feed material for the 6 in. MDS test was taken from the same location as for the 24 in. MDS test, but was not separately analyzed for physical and chemical parameters.
[c] A determined by Coulter Counter analysis, which measures relative volumes of solid particles exclusive of voids.

available bulk sediment chemistry on channel sediments, operating practices at the CDF, and limited surficial sampling. If this preliminary evaluation is promising, it is followed by development of a more rigorous sampling program based on established methods for interpreting and extrapolating data [7–9].

The strategy is to screen material for beneficial use suitability using physical parameters, which are quickly and inexpensively determined, followed by bulk chemical analysis if the material appears to be suitable [7]. More intensive material characterization, including chemical fractionation studies, are conducted when separation appears to be needed to meet beneficial use criteria.

Initial estimates of material recovery potential can be based on the proportion of material meeting the beneficial use grain size specification. Figs. 1 and 2 illustrate two cases in which materials have a grain size distribution (GSD) finer than the beneficial use grain size specification [7]. The MRP is calculated as follows from the intersection of the GSD curve

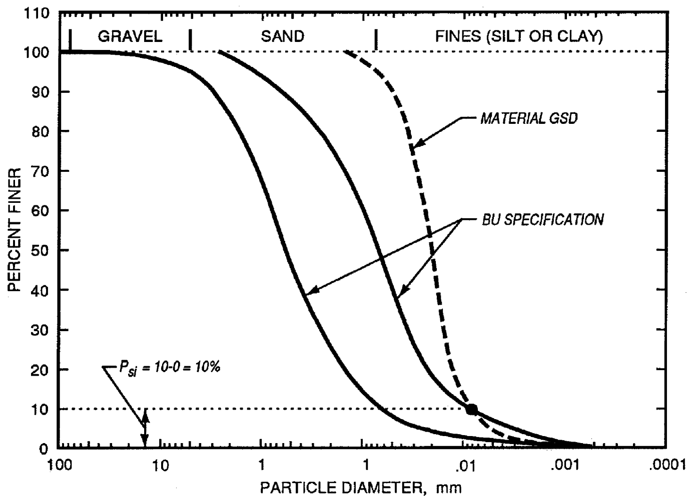

Fig. 1. Material with 10 wt.% meeting the grain size specification.

with the range specified for the BU [7]:

$$\mathrm{MRP} = \sum_{i=0}^{i=n} P_{\mathrm{s}i} W_{\mathrm{s}i}$$

where MRP is the material recovery potential (t), P_{si} the percentage by weight of sample grain size meeting the BU material specification for sample i (as a decimal), $W_{\mathrm{s}i}$

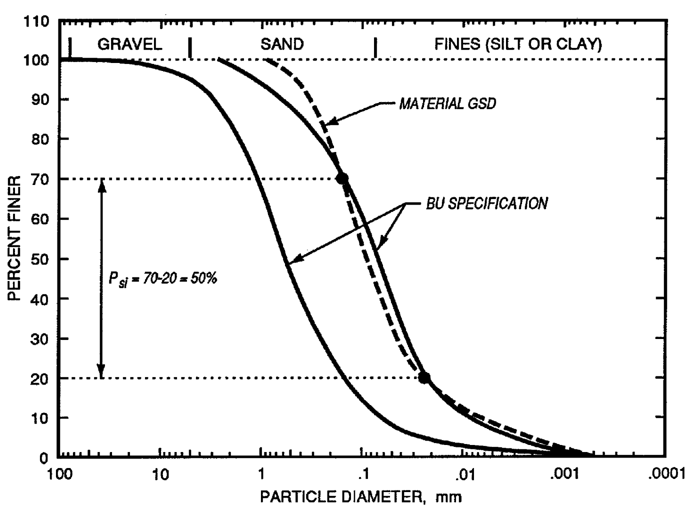

Fig. 2. Material with 50 wt.% meeting the grain size specification.

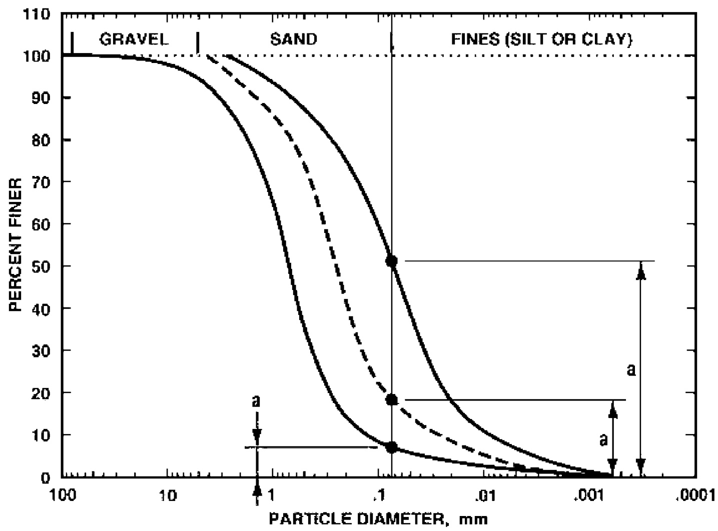

Fig. 3. Determining percentage of material meeting percent fines restriction.

the dry weight of material represented by sample i (t) and n is the number of samples considered.

Alternatively, a beneficial use specification will limit the percentage of fines (10–15% is a typical value for beach nourishment or construction fill, for example). Fig. 3 illustrates this for three grain size distribution curves. Based on the percentage of material meeting the percent fines restriction, P_{si} is calculated as follows:

$$P_{si} = \frac{(100 - a) + b}{100}$$

where a is the percentage of material passing the defined size threshold and b is the allowable percentage of fines by weight.

In cases where the BU specification is given as a single D_{50} grain size, P_{si} can be expressed as

$$\text{For } D_{50} < D_{50\,\mathrm{spec}}: \quad P_{si} = \frac{(100 - \%\,\text{passing } D_{50\,\mathrm{spec}}) \times 2}{100}$$

$$\text{For } D_{50} > D_{50\,\mathrm{spec}}: \quad P_{si} = \frac{\%\,\text{passing } D_{50\,\mathrm{spec}} \times 2}{100}$$

$$\text{For } a \geq b: P_{si} = \frac{(100 - a) + b}{100}$$

$$\text{For } a < b: P_{si} = 100\%$$

This is illustrated graphically in Figs. 4 and 5 [7]. The dry weight represented by a sample, W_{si}, can be estimated as follows:

$$W_{si} = 0.0135 V_i \gamma_i$$

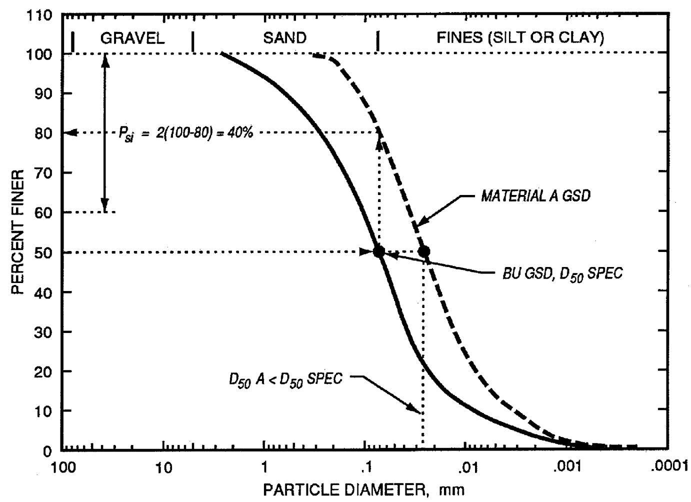

Fig. 4. Material with $D_{50} < D_{50\,\mathrm{spec}}$.

where W_{si} is the dry weight of solids represented by sample i (t), V_i the volume represented by sample i (cubic yards) (determined by survey data), γ_i the unit weight of the dry material for sample i (lb/ft^3) (determined based on water content or dry density measurement) and 0.0135 is the conversion factor.

Extrapolating MRP by weight to MRP by volume requires consideration of initial and final material conditions. Percent sand by volume is a function of percent sand by weight, specific gravity of mineral and organic fractions and their relative proportions, and void

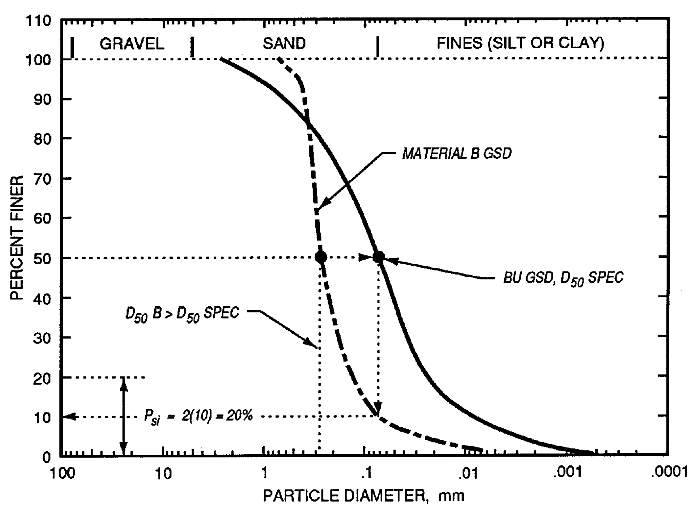

Fig. 5. Material with $D_{50} > D_{50\,\mathrm{spec}}$.

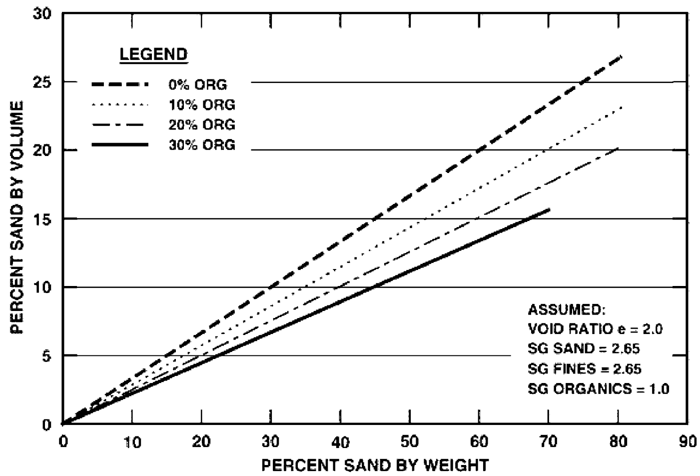

Fig. 6. Percent sand by volume for sediment with organic fraction specific gravity of 1.0 and void ratio of 2.0.

ratio. Figs. 6–8 were developed using the mathematical relationship between the sediment fractions. In these figures, the volume occupied by the sand particles in an in situ sediment sample is given as a function of organic material content, for a selected void ratio and organic material specific gravity. The specific gravity of the coarse and fine mineral fractions were assumed to be equal for these examples. Note that percent by mass as determined by sieving and weighing the different size fractions of a sample includes the mass of organic material in each size fraction. In Figs. 6–8, percent sand by mass is exclusive of the organic mass. Additionally, once the sample is disturbed and a fraction removed, recovered volume is a

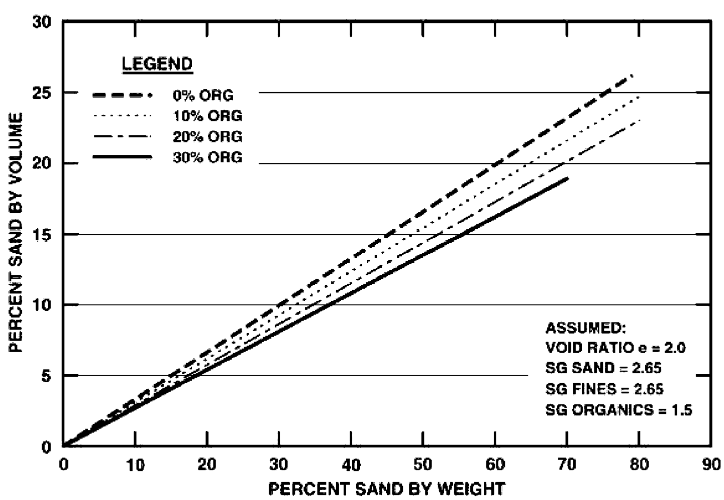

Fig. 7. Percent sand by volume for sediment with organic fraction specific gravity of 1.5 and void ratio of 2.0.

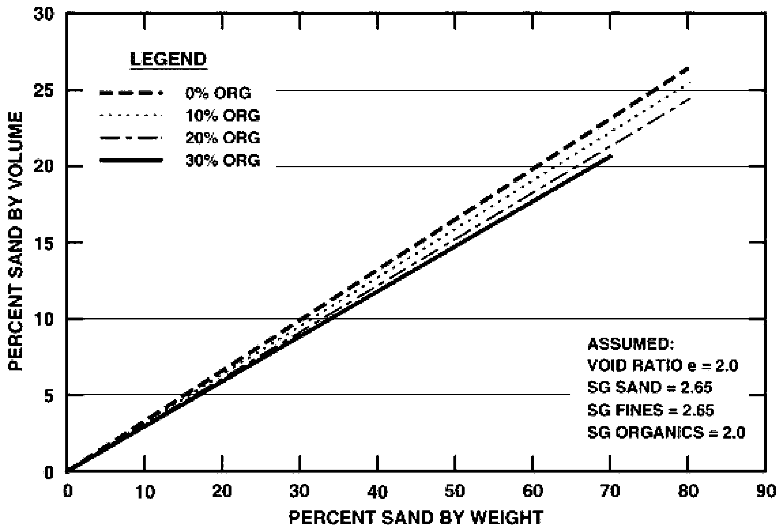

Fig. 8. Percent sand by volume for sediment with organic fraction specific gravity of 2.0 and void ratio of 2.0.

function of the volume represented by the solid fraction removed, and the new void ratio of the remaining fractions.

Total volume is a time-dependent function for materials undergoing consolidation, such as those placed hydraulically after separation. Materials that are mechanically dewatered following separation will undergo much smaller volume changes with time. Material properties obtained from field sampling, and bench or pilot process testing, can be used to obtain an estimate of the volume reduction potential for selected processes. Because recovery of storage capacity is one of the key objectives of processing, however, it is also important to compare the estimated final volume of processed material requiring disposal to design volumes for conventional placement and dewatering. Where hydraulic placement is the usual placement method, volume required to provide freeboard and ponding depth can potentially be recovered in addition to any reduction in volume of the solids (Fig. 9).

Compatibility of the material with other BU specifications, such as contaminant concentration or percent organic material, must also be evaluated if material recovery potential based on grain size appears to justify the necessary processing. When separation appears to be necessary to meet grain size or contaminant level criteria, more extensive characterization is required to identify unit operations required and to evaluate the chemical character of the process streams. Contaminant fractionation studies examine the distribution of contaminants with respect to particle size and density. The size and density cut points at which the sample will be separated for analysis may be influenced by the end use, by the mineralogically significant cut points, or both. Although there is some variation between the different classification systems, the sand fraction ranges from approximately 75 μm to 4.75 mm, the silt fraction from approximately 3–75 μm, and the clay fraction 3 μm and below. Organic materials may be distributed over all particle sizes. The density of organic materials and

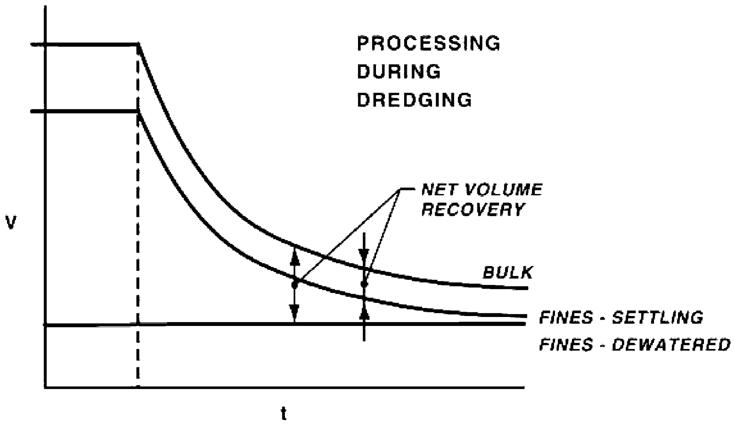

Fig. 9. Storage volume requirements for hydraulically placed materials vs. dewatered materials.

minerals varies, but separation at a specific gravity of approximately 2.0 gives a reasonable separation of organics and minerals for characterization purposes. The relative distribution of organic and inorganic contaminants in these size and density fractions is presently being studied at WES, as well as the correlation to various parameters such as oil and grease and total organic carbon. Procedures for bench scale density separations using heavy media are also under development.

4. Selection of unit operations

The processes making up the physical separation plant vary, and are usually determined on a site specific basis. A physical separation plant can be thought of as consisting of three primary processes, however, each of which may incorporate one or more unit operations. These processes are (1) preprocessing, (2) separation and (3) dewatering.

The preprocessing step involves excavation and prescreening necessary to prepare the material for the treatment train. Prescreening involves the removal of materials from the bulk sediment that would interfere with downstream processing operations. Oversize will be defined by the equipment in the treatment train, but typically includes materials approximately 50 mm in size or larger. These materials may require further washing to remove fine sediments adhering to them, but are typically then disposed of separately from the sand and silt fractions. Oversize materials may consist of stones, tree limbs, and large clumps of soil, but may also include rubbish ranging from aerosol cans to large slabs of concrete. Grizzlies and trommels are very commonly a component of the prescreening process, and may be used in conjunction with log washers, comminutors, attritioners or hand picking to remove oversize materials [10].

Size separation is typically the core of the soil washing process, with a sand/silt separation (at approximately 75 μm) a common objective because of the higher contaminant concentrations often associated with the finer fractions. Screens and hydrocyclones are among the most common size separation equipment encountered in the field, although large sand screws with integral hoppers are also being used to separate sand from fines.

Density separations may be employed if there are sufficient density differences between contaminated and uncontaminated fractions to achieve effective separation on this basis. This is typically going to be of advantage principally when separating low specific gravity fractions or when metal fragments are present, although density effects play a role in most size separation. Spiral concentrators and mineral jigs are the common examples of equipment found in density separation circuits [10].

Mechanical dewatering can significantly reduce the volume of the process streams, and improve handling characteristics. Solids concentrations of 45–80% are possible, depending upon the size and character of the material and the dewatering processes used. Because coarse materials dewater quite readily, most attention is focused on dewatering the fine residuals. Chemical additives to promote flocculation and facilitate dewatering may be a significant associated cost. Belt filter presses and plate and frame filter presses are most commonly encountered for fine materials dewatering processing. Centrifuges are sometimes used, but are a higher cost alternative with little or no advantage over presses for simple dewatering. Screw classifiers are sometimes used to further dewater coarse materials. Screens and rotary vacuum filters represent two additional equipment options [10].

5. Management of liquid and solid residuals

One of the disadvantages of physical separation processes is that material must be slurried for processing. Large volumes of process water are introduced and dewatering of process streams is therefore necessary. The availability of storage capacity for settling and dewatering can be a significant advantage to operation at a CDF. Alternatively, more aggressive chemical and mechanical dewatering can be employed. The additional cost of progressively more expensive dewatering alternatives must be evaluated in light of the increase in both short-term and long-term volume recovered, and the potential for recycle of process water.

The expected level of contamination in the process streams must be evaluated in the material characterization step, and monitored during processing. Fine or organic residuals may have order of magnitude higher concentrations than the coarse fractions. The potential regulatory classification of the residuals, and the possible need for additional treatment or disposal in a permitted facility, must be anticipated and factored into the cost/benefit analysis.

6. Cost/benefit analysis

A favorable cost/benefit ratio is requisite to implementation for any project; federal projects must comply with the Federal Standard, which specifies that the lowest cost alternative consistent with good practice be selected. Because mechanical separation and dewatering represent an additional processing cost over conventional sediment disposal practices, an overall operating cost savings attributable to volume reduction must be demonstrable. The relative volumes of clean to contaminated fractions, the waste streams produced in separation, the subsequent treatment or disposal requirements of the respective fractions, the value of volume recovered, and income generated by production of a marketable material, are all quantifiable variables in evaluating the economic justification for additional processing. In the best case scenario, a commercially viable product results, with potential for revenues to offset processing costs. Additional benefits may include greater control over contaminant release pathways, shorter time to re-use of the site, and better structural characteristics of the material placed in the CDF.

Because treatment costs are highly site specific, there is little general guidance available for conducting a cost/benefit analysis for physical separation. Within the WES research programs, efforts are being directed toward development of guidance to provide the framework for estimating volume recovery for cost evaluation purposes. The general approach will be to establish the value of storage capacity recovered and income, if any, generated by the production of material for a specified beneficial use. This will set the upper threshold for justifiable processing costs.

Unit processing costs can be found in the literature, but it is difficult, if not impossible, to discern the incremental cost of separation and dewatering from overall project costs. Reported costs range from roughly US$ 15 per cubic yard for dredging, separating and placing uncontaminated materials near the dredging site, to several hundred dollars per cubic yard, including water treatment, disposal of hazardous residuals and substantial public relations efforts [11,12].

7. Summary

Physical separation processes may provide a useful tool for maintaining and recovering capacity of CDFs. Suitability must be evaluated on a site specific basis. Beneficial use alternatives must be identified and criteria established for each locale, in cooperation with industry and state and federal regulators, and in compliance with accepted material standards. Processing costs are also site specific and tailored cost estimating guidance not yet well developed. Efforts are presently being directed at addressing these impediments. Although physical separation will not be applicable to every site, growing interest in the technology at the operations level suggests that the technology is maturing as a sediment management tool. Expertise specific to this application is developing in both the public and private sectors. As the number of successful and proposed projects continues to grow, it is expected that the technology will find increasing acceptance.

References

[1] PIANC, Beneficial Uses of Dredged Material: A Practical Guide, PIANC Working Group 19, PIANC, Brussels, Belgium, 1992.
[2] PIANC, Dredged Material Management Guide, PEC Special Report, Supplement to Bulletin No. 96, 1997.
[3] USACE, Beneficial Uses of Dredged Material, EM 1110-2-5026, US Army Corps of Engineers, Washington, DC, 30 June 1987.
[4] NYSDEC, Upland Management of Navigational Dredge Material Regulation, Summary of Proposed Amendments to 6 NYCRR, Part 360, Solid Waste Management Facilities, New York, March 1997.

[5] B. Fitzpatrick, 1998. Personal communication, Wisconsin Department of Natural Resources.
[6] T.J. Olin, D.W. Bowman, Soil Washing Potential at Confined Disposal Facilities, Environmental Effects of Dredging, Vol. D-96-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS, 1996.
[7] T.J. Olin-Estes, M.R. Palermo, Determining Recovery Potential of Dredged Material for Beneficial Use — Soil Separation Concepts, DOER Technical Notes Collection (TN DOER-CZ), US Army Engineer Research and Development Center, Vicksburg, MS, 1999, www.wes.army.mil/el/dots/doer.
[8] T.J. Olin-Estes, M.R. Palermo, Determining Dredged Material Recovery Potential for Beneficial Use — Site Characterization: Prescriptive Approach (TN DOER-CX), US Army Engineer Research and Development Center, Vicksburg, MS, 1999, www.wes.army.mil/el/dots/doer.
[9] T.J. Olin-Estes, Determining Dredged Material Recovery Potential — Site Characterization: Statistical Approach, DOER Technical Notes Collection (TN DOER-CY), US Army Engineer Research and Development Center, Vicksburg, MS, 1999, www.wes.army.mil/el/dots/doer.
[10] USEPA, Physical Separation (Soil Washing) Equipment for Volume Reduction of Contaminated Soils and Sediments, EPA-905-R-99-006, Assessment and Remediation of Contaminated Sediments Program, Great Lakes National Program Office, Chicago, IL, 1999.
[11] S. Tapp, S. Baylor, Personal communication, USAE District, St. Paul, 2000.
[12] B. Fitzpatrick, Personal communication, Wisconsin Department of Natural Resources, 2001.