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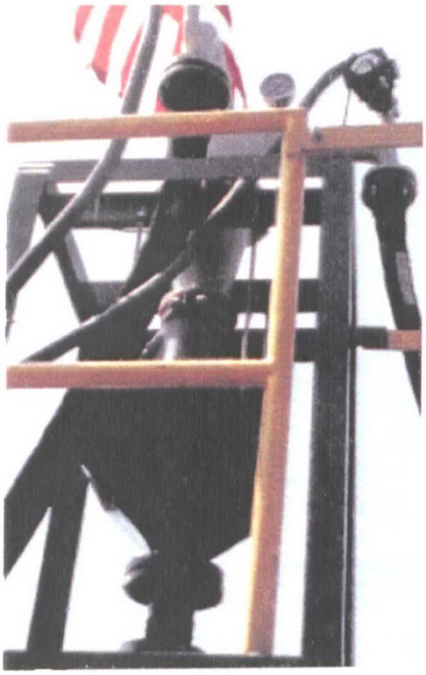
Reduction of Contaminated Soils and Sediments Processes and Equipment



Trudy J. Olin and Susan E. Bailey
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, Mississippi 39180

Michael A. Mann, Christopher C. Lutes, Carl A. Seward and Carl F. Singer
ARCADIS Geraghty & Miller, Inc.
14497 North Dale Mabry Highway
Suite 240
Tampa, Florida 33624

ARCADIS Geraghty & Miller, Inc.
4915 Prospectus Drive
Durham, North Carolina 27713

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Olin, Trudy J.; Bailey, Susan E. of USAE WES and
Mann, Michael A.; Lutes, Christopher C.; Seward, Carl A.; Singer, Carl F. of ARCADIS Geraghty-Miller

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USAE Waterways Experiment Station, Environmental Lab
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

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Physical separation processes have long been used in the mining industry for selective separation of minerals from gangue. In recent years, these technologies have been adapted for volume reduction of contaminated soils and sediments. Physical separation processes are generally technically simple techniques by which the most contaminated fraction of a soil and sediment can be separated from the uncontaminated volume. Volume reduction is a viable consideration where a portion of the contaminated material is not readily treatable, where significant savings could be realized in reducing the volume requiring treatment or disposal, or where some benefit can be obtained by recovering reusable material. This document is intended as a consolidated reference for planning-level process feasibility evaluations. An overview of the standard unit processes, general equipment selection and operating considerations, and equipment and technology sources are provided. Summaries from the literature and field experiences and sample treatment trains are also included.

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Abstract

Physical separation processes have long been used in the mining industry for selective separation of minerals from gangue. In recent years, these technologies have been adapted for volume reduction of contaminated soils and sediments. Physical separation processes are generally technically simple techniques by which the most contaminated fraction of a soil and sediment can be separated from the uncontaminated volume. Volume reduction is a viable consideration where a portion of the contaminated material is not readily treatable, where significant savings could be realized in reducing the volume requiring treatment or disposal, or where some benefit can be obtained by recovering reusable material. This document is intended as a consolidated reference for planning-level process feasibility evaluations. An overview of the standard unit processes, general equipment selection and operating considerations, and equipment and technology sources are provided. Summaries from the literature and field experiences and sample treatment trains are also included.

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Contents

List of Figures

List of Tables

Page

1 Overview of Unit Processes

Introduction

Physical separation processes have long been used in the mining industry for selective separation of minerals from gangue. In recent years, these technologies have been adapted for volume reduction of contaminated soils and sediments, and collectively referred to as soil washing. (This is distinct from soil flushing, an in-situ process.) Physical separation processes are generally technically simple techniques by which the most contaminated fraction of a soil and sediment can be separated from the uncontaminated volume. Depending on its characteristics, the "clean" fraction may require less rigorous treatment or disposal measures or may be suitable for commercial uses without treatment. The most contaminated fraction typically requires further treatment or restricted disposal.

Volume reduction is a viable consideration where a portion of the contaminated material is not readily treatable, where significant savings could be realized in reducing the volume requiring treatment or disposal, or where some benefit can be obtained by recovering reusable material. The relative volumes of "clean" to "contaminated" fractions, the waste streams produced in separation, and the subsequent treatment or disposal requirements of the respective fractions are all critical considerations in determining the viability of physical separation as a management alternative. In cases where a commercially viable product results, potential revenue production or cost avoidance should also be factored into the economic evaluation.

This document is not a comprehensive design guide but, rather, a consolidated reference for planning-level process feasibility evaluations. It is intended for both technical and nontechnical staff responsible for decision making in the management or treatment of contaminated soils and sediments. Feasibility evaluations and development of an effective physical separation treatment train require consideration of many site-specific conditions including, but not necessarily limited to, the following:

- project budget and objectives,
- applicable state and Federal regulations,
- soil and sediment types and volumes,
- contaminant type and distribution,
- potential end use or disposal options, and associated criteria, of process streams,
- equipment cost, availability and operating limitations, and
- location and climatic considerations.

Comprehensive treatment of these design considerations is beyond the scope of this document. An overview of the standard unit processes, information requirements, general equipment selection and operating considerations, and equipment and technology sources is provided. Summaries from the literature and field experiences and sample treatment trains are also included. An extensive search was conducted to identify vendors and locate case histories. Sources within the consulting industry contributed from their expertise and field experiences. Equipment cost ranges, where available, were compiled from the literature, vendor information and a commercial estimating guide (Western Mine Engineering 1996). Unit costs and cost breakdowns were estimated for three treatment scenarios by ARCADIS Geraghty & Miller Inc., of Tampa, FL.

Chapter 1 provides an overview of physical separation, the basic unit processes utilized in typical physical separation treatment trains, and a systematic methodology for conducting feasibility evaluations. Chapter 2 contains a more detailed discussion of the unit processes, and selection and operating factors of individual pieces of equipment within these categories. Chapter 3 contains sample treatment trains and cost estimation advice. Chapter 4 contains case studies from the literature, US Army Corps of Engineers project records, and the consulting industry. From these case studies, the reader should be able to develop a technical and economic sense of scale, and where potential problems may be encountered in the field when applying physical separation processes to contaminated soils and sediments. Appendix A contains examples of detailed cost estimates. Appendix B is an equipment and technology source listing. While every effort was made to ensure that this would be a comprehensive listing, all potential sources could not be identified within the constraints of the project.

Overview of Soil Washing Processes

Definition of Terms

Some working terminology is needed to describe the range of materials that will be encountered in a soil or sediment remediation project. The following are working definitions that can be modified locally as necessary.

Field Oversize

Field oversize refers to material generally larger than 50 mm effective diameter. This material can include, but is not limited to, boulders, concrete rubble, tree cuttings, debris, scrap metal, reinforcing bar, structural steel scrap, appliances and parts, automotive debris, and industrial scrap. Every site will be different in terms of the characteristics of this fraction. The field oversize can be difficult to handle because of irregular shapes and comingling with soils; it can block feed hoppers and process equipment. Oversize must be removed from the feed stream before the soil is introduced into the process plant. Field oversize is staged and segregated. In most cases, unless this fraction is highly organic, it will test as uncontaminated and can be disposed locally.

Process Oversize

The process oversize is the fraction < 50 mm and generally larger than 2 mm. This fraction generally consists of gravel and broken or downsized debris, including plastic, metal chips, and so on. This component of the feed is also found to meet site treatment standards in most cases. As such, it can be used as backfill when mixed with other clean products, or it can be disposed locally.

Coarse Products

The coarse products are that portion of the feed stream < 2 mm and greater than the "cut-point" between sands and silts. By definition, the cut point between sand and silt is approximately 75 μm (U.S.C.S.). Clays are approximately 3 μm and smaller. For practical purposes, the cut-point ranges from 38 to 75 μm (0.038 to 0.075 mm). The coarse product is a sandy material often comingled with particles lighter and/or heavier than sand. These non-sand materials can consist of shredded natural organics like grass, leaves, and roots (a light fraction) or particulate materials such as lead, comprising a heavier component. The coarse fraction may be either clean or contaminated. If clean, no further treatment is required, of course, but if contaminated, further treatment may be required, and that will be discussed later in this chapter.

Fine Products

Fine products are those materials less than the selected cut-point and consist of clays and silts. In many cases contaminants exhibit a propensity to be concentrated in the fines (clays and silts), primarily because of the very large surface area presented by this fraction. The fines are also difficult to handle, treat and dewater. The dewatered fines are normally contaminated and, due to the concentrating effect of separating them from the bulk matrix, may be reclassified as hazardous waste, requiring disposal at a Resource, Conservation, and Recovery Act (RCRA) facility.

Contaminated Residuals

Any fraction that does not meet the site-specific treatment standard is referred to as a contaminated residual. This may include liquid process streams as well as contaminated soil or sediment fractions.

Introduction to Unit Processes

The purpose of this section is to provide the reader with an understanding of some of the tools available to achieve the desired volume reduction. Much of the philosophy of volume reduction comes from hundreds of years of mining experience worldwide. Miners are faced with problems similar to those encountered in remediation. Miners must handle a very diverse range of feed materials to recover small amounts of valuable minerals. The remediation engineer has the same challenge; to remove small amounts of contaminants from complicated and diverse feeds. Central to all mining operations is sizing. Sizing is central to processing since oversize interferences must be removed prior to further treatment. The development of a process flowsheet for the miner or remediator progresses first from simple operations to more complicated. The most complicated (and costly) steps are reserved for the smallest (and most prepared) fraction. Volume reduction uses a fundamental understanding of the physical and chemical characteristics of the feed soil or sediment and a simple, inexpensive treatment train to remove clean material. This results in a smaller mass of contaminated material to be either further treated or disposed. When properly employed, this process results in significant cost savings. The major flowsheet divisions can be referred to as physical separation, physical and chemical separation, and chemical extraction. These major divisions represent increasing complexity and cost. The focus for this document is on physical separation, but physical/chemical and extraction processes may be referred to peripherally.

Physical separation in the strictest sense is separation on the basis of differences in physical characteristics of materials, particularly size, density and magnetic properties. Inherent surface chemistry differences are also sometimes utilized, as in froth flotation. Flotation and chemical extraction processes may be used in conjunction with physical separation. Particle-size and density separations are overwhelmingly the most useful types of separations. This document will concentrate predominantly on equipment supporting these two types of separation. Soil washing treatment trains are generally composed of sequential treatment processes as dictated by the nature of material being handled, the type and distribution of contamination, the end objectives of the treatment process (regulatory requirements and material specifications), and the ultimate disposition of processed material and residuals. There are five principal components: pre-screening, size separation, density separation, solid/liquid separation and solids dewatering. Additional components, such as chemical extraction, may be required in some cases. The five components are introduced here, and further discussed, along with candidate equipment and equipment selection criteria, in Chapter 2.

Pre-Screening

Pre-screening refers to the removal, or reduction in size, of oversize materials from the bulk soil or sediment that would interfere with downstream processing operations. Oversize materials are roughly 50 mm in size or larger and require separate handling or disposal. Depending upon the history of the site, oversize materials may consist chiefly of stones, tree limbs and large clumps of soil, but may also include rubbish such as tires, concrete, plastics and even refrigerators. Dredged material and landfill soils are typically replete with a variety of non-natural objects. Firing ranges may harbor large unexploded ordnance.

The pre-screening stage of the treatment train may involve one or more of the following elements: feed hoppers, fixed bar screens (grizzlies), rotating trommel screens, comminutors, attritioners, log washers and hand picking. Fixed bar screens, trommels and hand picking are processes for achieving gross size separation. Comminutors and log rollers are size reduction processors. Attritioners are somewhat analogous to grinding mills, but their function is to free the particles from within agglomerated materials rather than reduce the size of the mineral particles. Handpicking is the utilization of manual labor to visually observe incoming materials and to remove, by hand, designated components. Handpicking of field oversize is the most unsophisticated, yet often the most efficient, method of removing troublesome debris. The laborers may be assigned to work at the point of excavation or along a particular run of conveyor belt. Handpicking should be considered when equipment design is very difficult, unavailable, or costly.

Primary Physical Size Separation

Size separation is the core of the soil washing process. Because many contaminants associate chiefly with the finer soil fractions, separation of sand size particles (> 75 μm) from silts and clays (75 μm and smaller) is typically the foundation on which the remainder of the soil washing treatment train is established and refined. (Pre-screening is, in part, a preliminary size separation step.) Sands, silts and clays also differ mineralogically, and therefore chemically. Separation of these soil fractions permits tailoring of subsequent treatment processes to the fraction being treated. In some cases, a portion of the soil will be relatively uncontaminated. Size separation then reduces the volume which must undergo further treatment or controlled disposal, resulting in significant cost savings. In other cases, size separation might be utilized to remove a contaminated fraction which cannot be successfully treated from uncontaminated fractions, or fractions which are amenable to treatment.

Size separation equipment may include one or more of the following processes: screens (fixed or vibrating, wet or dry), hydrocyclones and sieve bends. Screens separate particles predominantly on the basis of size and shape, as distinct from classifiers, which separate on the basis of size, shape and density. Certain screen configurations may be influenced by material density as well, however.

Density Separation

Density separations are useful in cases where there are significant density differences between contaminated and uncontaminated soil or sediment fractions, or between the soil/sediment matrix and the contaminants (as with fractions contaminated with heavy metals, or containing residual munitions fragments). Minimum specific gravity differences between the materials to be separated are required for density separation to be effective. This minimum value is a function of the equipment utilized to effect the separation. A density separation circuit might include: spiral concentrators, mineral jigs, multi-gravity separators, dense media, shaking tables, or a pinched sluice. Spiral concentrators and jigs are the most commonly utilized in soil/sediment remediation processes. Shaking tables are useful for diagnostic work, but would typically not be included in a full scale treatment train. Dense media is used at full scale in mining processes, but media is expensive and the residuals likely to be problematic in most soil/sediment processing operations.

Solid/Liquid Separation

Soil washing, as the name suggests, requires processing the soil or sediment in an aqueous slurry. The volumes of water introduced to the process to achieve effective separations can be considerable. Gross separation of the solids and liquids is necessary to prepare solid residuals for more extensive dewatering treatments and to permit treatment or recycle of the process water. The distinction between solid/liquid separation and solids dewatering is not entirely clear cut, but is largely a function of the efficiency of the process. Processes resulting in a thickened sludge (perhaps 25% to 35% solids) are classified here as solid/liquid separation processes. More efficient processes, resulting in dryer product, are treated under dewatering. A solid/liquid separation stage might include one or more of the following: clarifiers, sedimentation basins, lamella clarifiers and flotation cells.

Solids Dewatering

Dewatering of solid residuals is necessary to produce a final product with good handling characteristics. Solids concentrations of 45% to 80% are possible, depending upon the size of the material and the dewatering processes used. Fine materials are most difficult to dewater and typically represent a significant portion of overall processing costs. A dewatering circuit might utilize one or more of the following: screens, belt filter presses, plate and frame filter presses, centrifuges, screw classifiers and rotary vacuum filters.

Treatment Trains

The principal soil washing processes would be assembled in a treatment train according the decision process outlined in Figure 1-1. A schematic representation of a typical treatment train is illustrated in Figure 1-2. A more complete discussion of treatment trains and the factors influencing the addition of various unit processes is contained in Chapter 3 Treatment Trains and Cost Estimation.

Planning for Field Operations: Material Handling and Processing Interfaces

In addition to selecting suitable unit processes for the material to be treated, consideration must be given to field operations. Materials management for a soil washing plant is particularly important if field operations are to progress smoothly and treatment is to be effective. Operational interfaces, containment, residuals management and process validation are all important elements of the planning/feasibility evaluation process.

Interface between Excavation/Dredging, Staging, Blending and Processing

Recognizing that material handling activities are directly related to processing is important. Excavation should not proceed independently of planning for effective pre-treatment, staging, plant feeding and treatment. If the interdependence of excavation and treatment is not considered and anticipated, soils could become piled in a huge staging area, where potential "hot-spots" (highly contaminated areas) are lost, problem soils are masked, and the pre-treatment/treatment manager has lost flexibility to control plant feeds.

The excavation plan will define locations for the placement of soils awaiting treatment. Staging areas for the feed material should be identified and should be located near the plant to optimize loading/hauling/feeding. Several staging areas may be required depending upon the source material, distances to the treatment facility, and the amount of pre-treatment required prior to introduction of the soils into the plant. Any treatment plant, irrespective of the unit operations used, will be designed for a certain range of feed characteristics. For soil treatment plants described herein, the most important feed control parameters are soil type and contaminant concentration. Thus, the remediator should do everything practical to arrange the feed piles to match the design feed characteristics of the treatment plant. This is done by managing the feed pile in discrete volumes, using field analytical tools to measure important parameters, and blending discrete piles to match, as well as possible, the design feed requirements. This blending should not be confused with dilution. Feed soils are blended to balance the contaminant load to the plant and optimize performance.

A common scenario is as follows: soils are excavated and placed on a raw soil pad; raw soils are prescreened to remove gross oversize material; the oversize is moved to a designated staging area; the undersize is moved to a feed soil staging pad to await introduction into the plant. On upland sites, soils may have already been excavated and staged, while others may be in urban industrial areas with large amounts of backfilled debris. Also, hydraulically and mechanically dredged feeds will differ substantially. Knowledge of the excavation/dredging plan can suggest methods and requirements of material handling and transfer that will simplify the pre-treatment and make the processing interfaces more efficient.

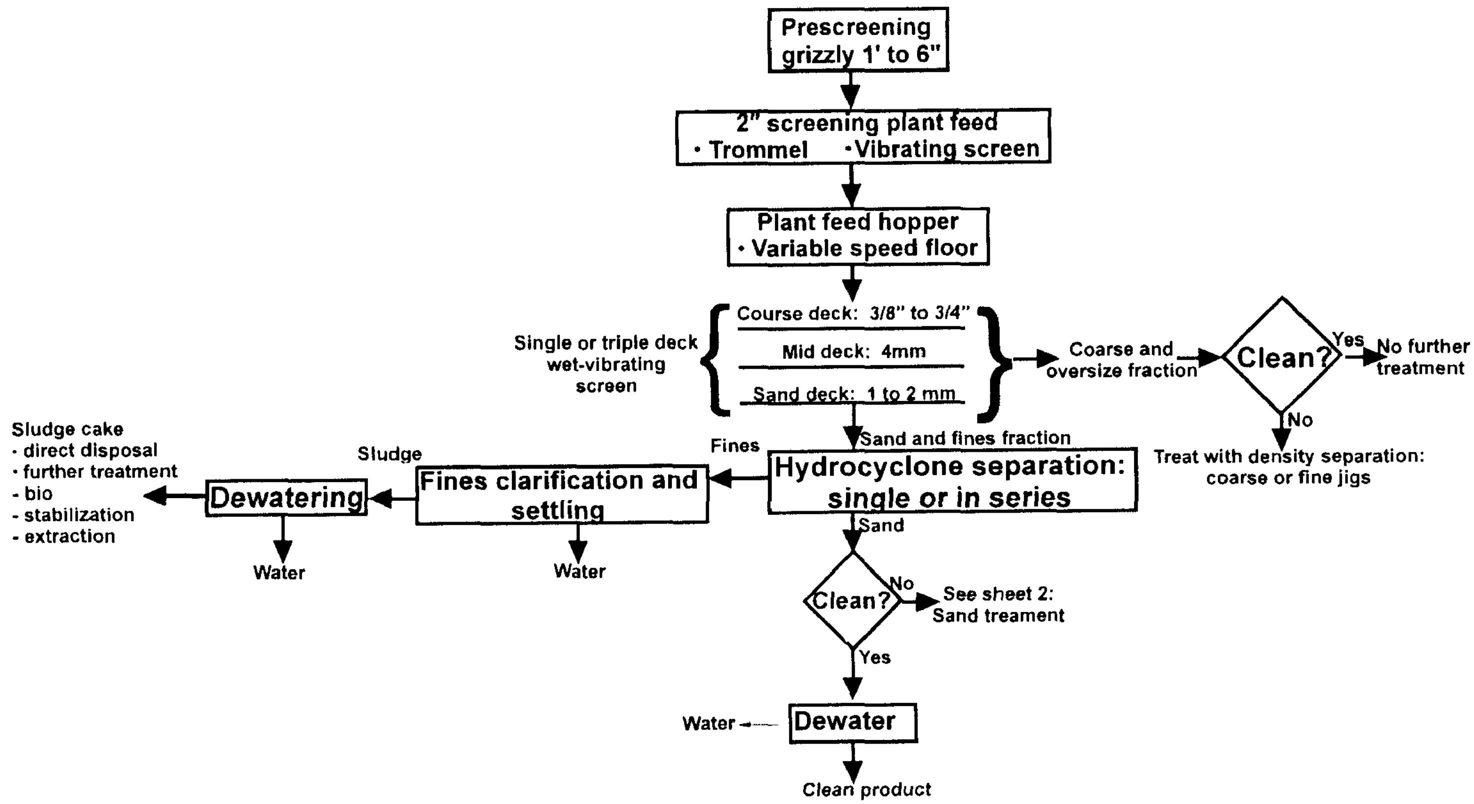


Figure 1-1a. General aspects of a physical separation treatment train (continued on the following page).

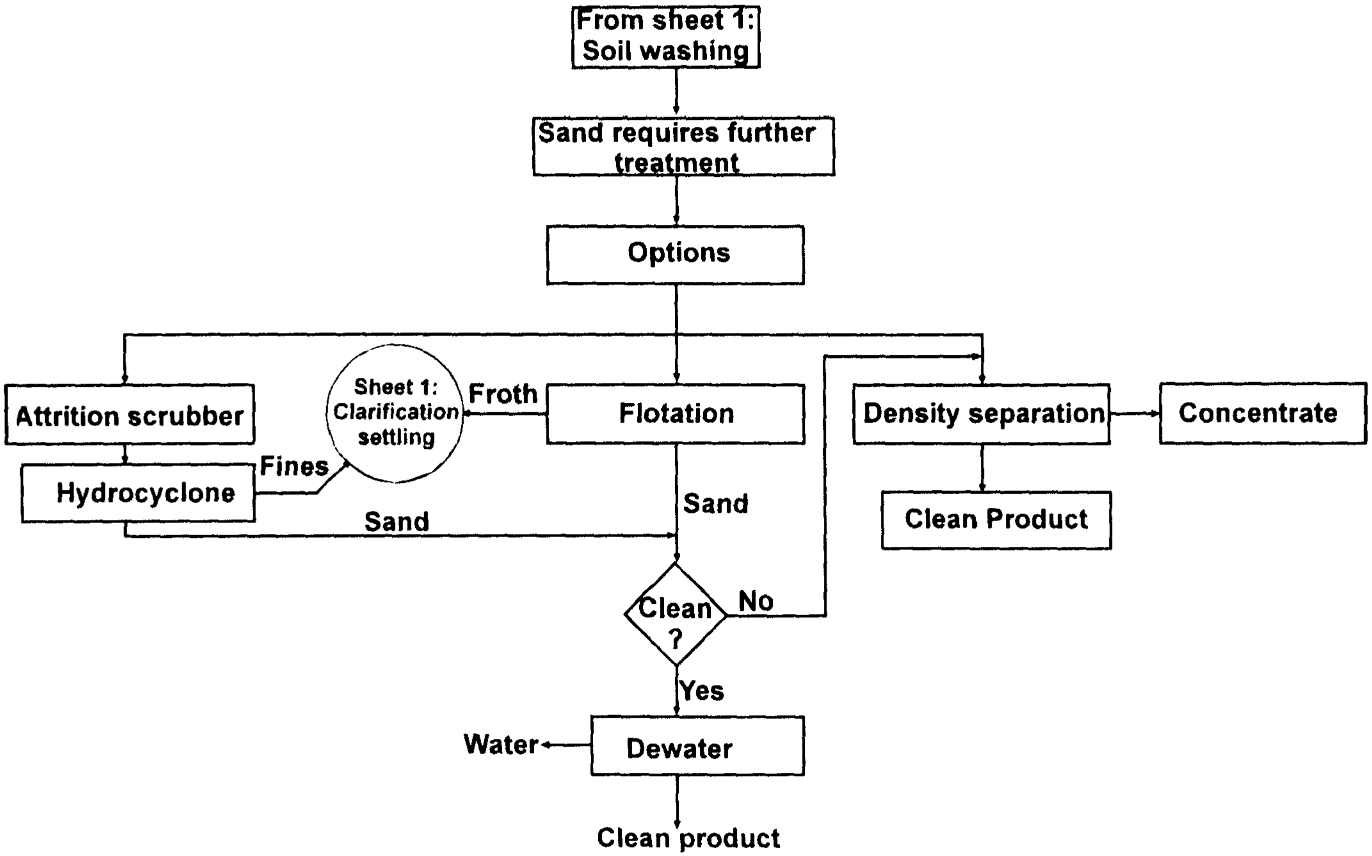


Figure 1-1b. General aspects of a physical separation treatment train (continued from previous page).

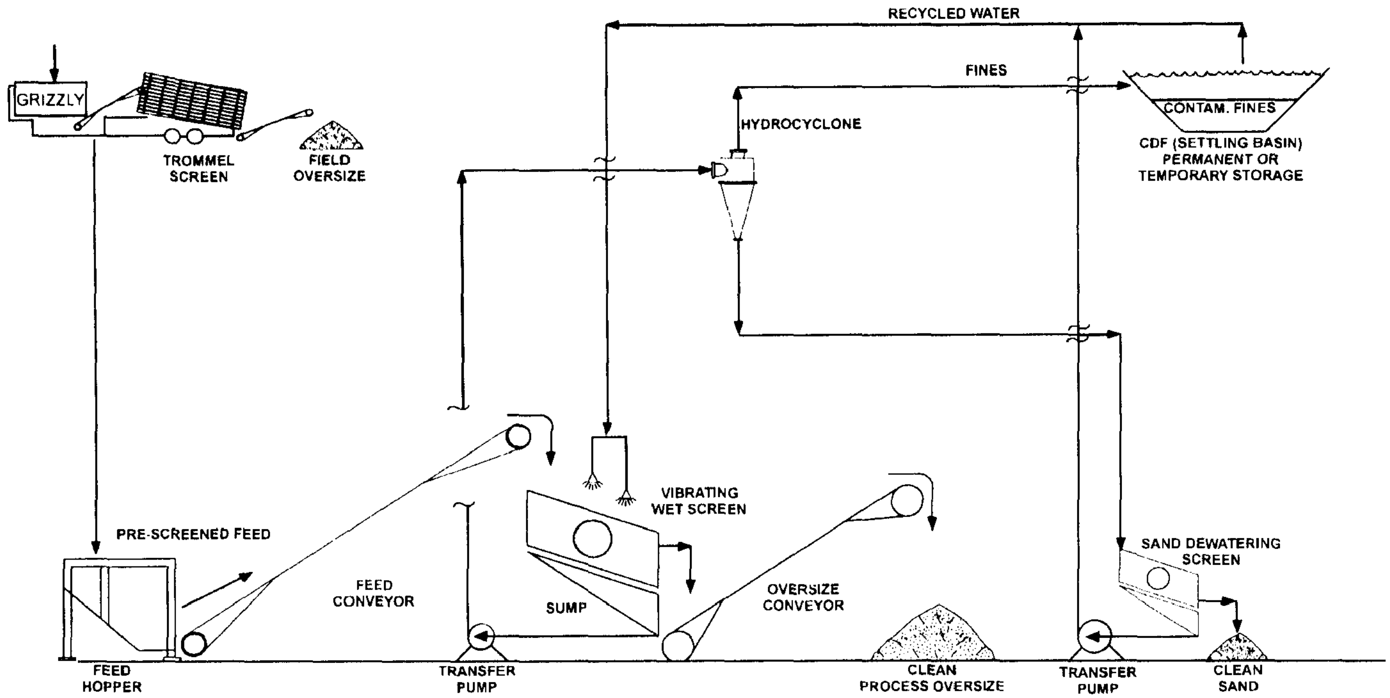


Figure 1-2. Treatment Train 1, simple physical separation.

Containment of Feed, Products, and Residuals

Staging areas may require a liner/concrete pad arrangement to protect groundwaters or surface waters from run-off or infiltration. In cases where the contaminants can be demonstrated as immobile, the pad/liner arrangement may be avoided. Consideration must also be given to weather conditions and periods of operation to protect feeds from heavy rains or freezing conditions. Feed piles are usually managed with front-end loaders; consideration must be given to bucket scraping on the underlayment such that liners or subbase are not damaged in the process. Staging areas can be easily segregated by the use of precast concrete dividers to maintain the integrity of the produced volumes.

Residuals

Both solid and liquid residuals produced by soil washing processes should be given serious consideration prior to implementation of soil washing as a remediation process. Considerable volumes of water are introduced during the soil washing process. While process water is frequently recycled through the treatment train to minimize water usage, treatment to remove solubilized and particulate contaminants is typically required both prior to recycle and prior to ultimate release. Processing costs associated with this treatment can be significant. Further separation of the most contaminated soil or sediment fraction results in a concentration effect. Contaminant concentrations per unit mass will be higher in the contaminated fraction after separation than they were in the bulk soil or sediment matrix. As a result, the regulatory classification of the material may be affected, requiring additional treatment or controlled disposal. Again, significant costs can be incurred as a result.

Bench-Scale Process Validation

All soil remediation projects require bench-scale validation work before implementation. It is essential to work with the soil matrix, to perform particle-size distribution tests, to analyze the chemical constituents, to determine the form of the contamination, and to run each unit operation in the proposed flowsheet. It is important that each contractor bidding on a project be allowed to perform individual testing. If one set of data is to be used, common agreement on such data is essential. More information on process validation is found under the headings "Step 2" and "Step 5" in the feasibility evaluation process section of this chapter.

Field Analytical Support

While a voluminous amount of analytical data has been generated on most sites, the characterization data often does not fully represent soils delivered to a treatment plant. Thus, simple, quick-turnaround analytical capability must be provided to the plant to quantify actual key contaminant feed concentrations. The principal analytical tools available include x-ray fluorescence (XRF) for metals, field gas chromatography (GC) for organics, soil gas detectors, portable radiological survey meters, colorimetric devices, and immunoassay for organics. All of these tools can be correlated with full laboratory protocol methods to provide a reasonable level of confidence in the results. These tools are not intended to replace standard analytical protocols for regulatory compliance. They are used to control and manage the feed in a balanced manner.

Overview of Feasibility Evaluation Process for Physical Separation

A systematic conceptual procedure for evaluating the suitability of physical separation for a given soil or sediment is requisite to successful implementation. Figure 1-3 provides a conceptual overview of this procedure, which begins with preliminary information gathering and materials characterization followed by preliminary evaluation of the feasibility of physical separation. If this evaluation is favorable, then more in depth information is gathered to support a more detailed feasibility evaluation whose results can be assigned a greater degree of confidence.

Step 1

Preliminary information needs, including the problem for which physical separation is being considered, the volume of material and its sources, and the anticipated time line for handling the material, must be clearly defined. The budgetary constraints, typically expressed either in cost per unit volume, costs for the entire project, or as a cost/benefit analysis, must also be assessed.

A review of existing site documents and discussions with personnel experienced in working on the site should be used to define the contaminants or other undesirable characteristics of the material that motivate the use of physical separation. The primary contaminants and pathways for any ecological or human health risks that are important with regard to the material must be kept in mind during the feasibility evaluation process. The site's history (as well as published information about similar sites) should be reviewed for clues to the distribution and disposition of contaminants. All available information on how evenly the contaminants are likely to be distributed should be gathered. For example, with regard to metals contamination, the determination made must include if they were introduced to the environment in dissolved or particulate form, what compounds/valence state they were in at that time and how long the material has had to transform or "weather" in the environment. Data on the characteristics of the bulk matrix, such as solids/moisture content, particle-size distribution (sand, silt, clay), redox potential, concentrations of total organic carbon, acid volatile sulfide, and dissolved oxygen should be collected. Even qualitative observations of the nature of the bulk matrix (e.g., "tarry"), if available, are better than a total absence of information.

The nature of the bulk matrix is important in drawing preliminary conclusions about the forms in which the contaminants exist in the environment, how they may contribute to any observed toxicity, and thus how they can best be separated or immobilized. Also, as part of the first preliminary information gathering step, the potential beneficial-use applications for clean/treated material should be assessed. Potential applications including shoreline stabilization, fill for infrastructure projects (e.g., roads), wetlands creation, landfill cover and soil improvement for agriculture should be considered in the context of the local/regional economy, geography (Landin 1997) and regulatory climate. The requirements in terms of volume, scheduling, cost, physical materials characteristics, toxicity, and contaminant concentration/mobility for each application that appears feasible should be assessed. Similar information should be gathered about non-beneficial disposal options that can serve as a basis for comparison of the beneficial-use options or could be used for disposal of the contaminated fraction of the material following a physical separation process. Disposal options may include open water disposal (EPA/USACE 1991 and 1998), confined disposal facilities either upland, near-shore or in-water,

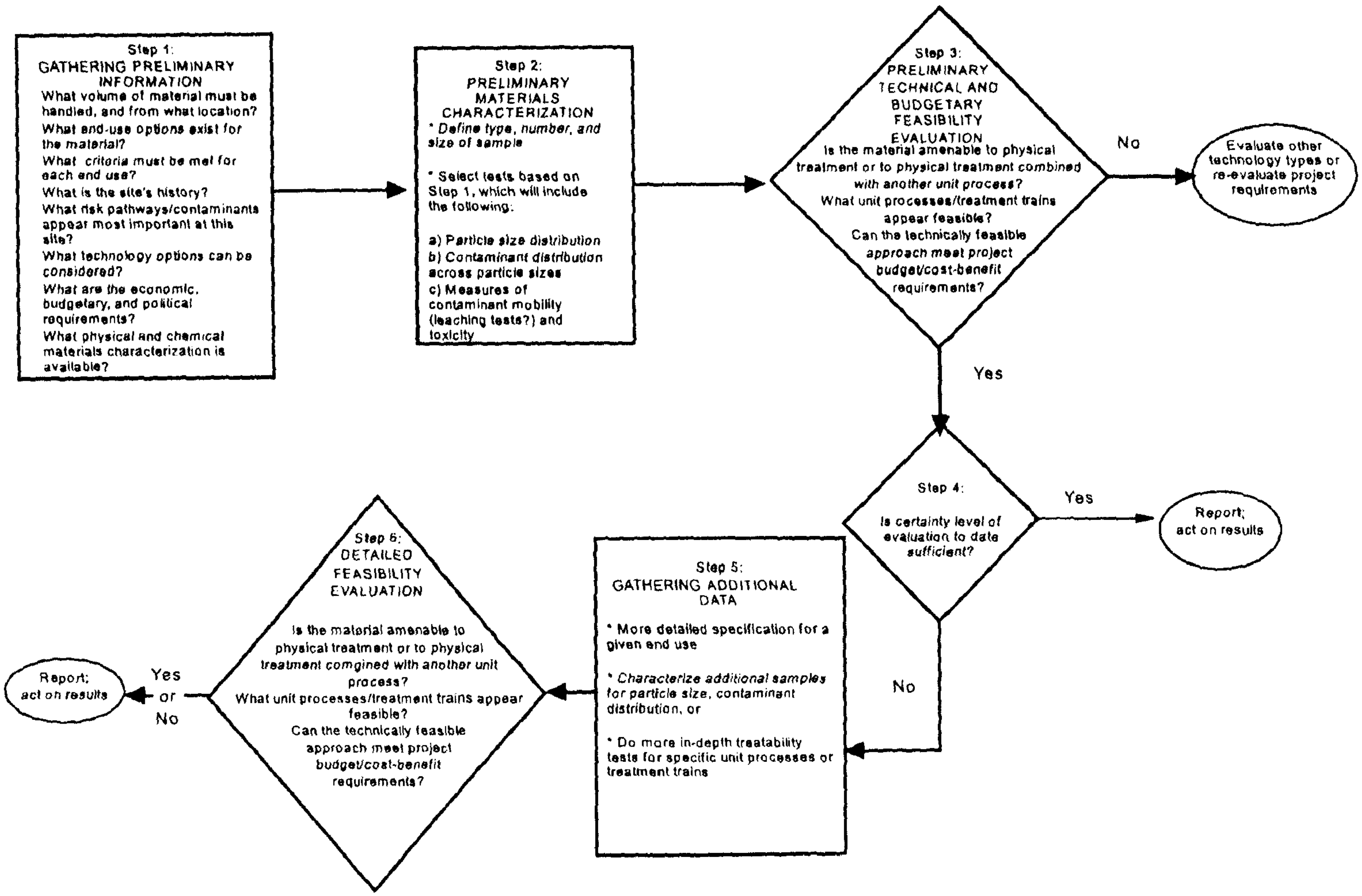


Figure 1-3. Feasibility evaluation process.

and upland disposal in municipal or hazardous waste landfills. As a rule of thumb, upland disposal and beneficial reuse options have traditionally been regulated based on a comparison between measured concentrations of contaminants of concern in the bulk material (or eluted concentrations) and "look-up" tables of values developed based on risk considerations. On the other hand, aqueous disposal options for sediments are generally regulated based on the toxicity of the whole material (EPA/USACE 1991 and 1998). In either case, determination of available disposal alternatives is a regulatory issue which may significantly impact process economics.

In addition, the range of technologies available to address the handling of the material in question needs to be defined. While this document will provide a good overview of the available physical technologies and their stage of development, chemical, biological and thermal processes should also be considered both as alternatives to and complements to the physical technologies.

Step 2

The second step as shown on Figure 1-3 is a preliminary materials characterization. This step is analogous to the "Physical Prescreening" described in EPA's "Guide for Conducting Treatability Studies Under CERCLA: Soil Washing, Interim Guidance" (USEPA 1991b). The data needs that this step will address will be defined in large part by the information gathered in Step 1. In most cases, the volume of the material requiring treatment and the level of contamination it contains will have been defined well enough to support a preliminary feasibility evaluation. However, in many cases vital information for the evaluation of physical separation processes such as particle-size distribution and the distribution of contaminants among particle-size classes is not available from site documents. At this stage, characterizing the mobility (leaching) of the contaminants of interest or their toxicity (depending on applicable regulatory scheme) for each particle-size class may be beneficial. An evaluation of the handling characteristics of the bulk material may also be desirable, either based on the qualitative observations of laboratory personnel or on geotechnical testing. Other parameters such as clay content, liquid limit (LL) and plastic limit (PL) may be of qualitative interest but may not be of practical use if they cannot be directly correlated to equipment selection.

Soils will always be characterized by type (gravels, sands, clays, silts, and so on) and quantified by the soil particle-size distribution (ASTM 422D). The particle-size distribution curve will typically be generated by sieving the material through each of ten successively smaller sieves. The material retained on each sieve is dried and weighed. The masses are then plotted on semilog paper, and the particle-size curve results. A particle-size curve always reports masses with 0% moisture or 100% dry matter. When mass balances are created, moisture must be factored back in. Contaminant distribution with respect to particle size and/or density will be a determining factor in the feasibility of achieving product specifications using only physical separation. Soils and sediments with contamination distributed over all particle sizes may require additional treatment to produce a clean product. Materials with contamination chiefly confined to a limited size fraction can typically be treated with physical separation alone. The relative volume of contaminated to clean material, however, is a key determinant to the economic viability of the process. Disposal costs of contaminated materials and process streams must be factored into the economic analysis.

Characterizing the material to be processed is also a critical intermediate step between determining product specifications and developing a treatment train. Guidance has been developed and is being further refined for addressing this step but at a minimum will require particle-size distribution and contaminant distribution analysis. Demonstrated approaches to this intermediate step were developed in the Netherlands (where some of the earliest application of soil washing to soils and sediments took place). Two such procedures are the Fingerprint Method (developed by Heidemij Realisatie, now ARCADIS Realisatie) and the TDG test (developed by ARCADIS Realisatie and TNO Institute of Environmental and Energy Technology). The Fingerprint Method is a pilot-scale method that uses sequential hydrocyclone separations to fractionate a sample into various (typically six) particle-size classes. These classes may then be further subdivided according to density by gravity separation. The distribution of contaminants across all the various size and density fractions (11 in one case) is then determined. The results of this procedure are then used to design a full-scale treatment system that is optimized to isolate the most contaminated material from the bulk of the material, which can often be beneficially reused. This procedure has been applied more than twenty times by ARCADIS in the Netherlands (Bovendeur et al. 1991, Bovendeur and Mozley 1993, Bovendeur and Visser 1993).

The TDG test is a more simplified, small-scale procedure in which a wet screening step is used to produce three size fractions. The intermediate fraction (63 to 500 microns) is then gravity separated into three subfractions. The contaminant distribution over the resulting five fractions is then determined, and the results are used similarly to determine the optimum remedial approach (Feenstra et al. 1995).

The Waterways Experiment Station (WES) is working to develop a method to streamline the analysis and reduce costs. The method involves limiting the size and density of the cuts to only the critical fractions (i.e., cuts that separate the mineralogically different size and density fractions). For example the transition from silt to sand occurs at 63 or 75 microns, depending upon the standard used, and from clay to silt at roughly 2 to 3 microns. These fractions behave differently in their ability to hold contaminants. Significant density separations would be made to separate organic material (SG < 1.8) and metal particulates (SG > 3.0) from the mineral fraction.

No list of tests applicable to every site can be formulated. Rather, the list of required tests should be formulated using the professional judgment of persons familiar with physical separation technologies and the background of the sites. Once a set of tests to be performed is selected, the right number, volume, and type of soil or sediment samples should be collected to be tested so that they will be representative. In this sampling stage the most major problems with physical separation projects occur. The sampling and compositing must be guided by a well-thought-out plan prepared by an engineer with experience in full-scale physical separation and by an environmental chemist or geologist. The sampling plan must be executed by well-trained, motivated personnel who understand the objectives of the project. In formulating a sampling plan, careful consideration should be given to representing the type and range of material that a hypothetical full-scale physical separation plant would receive as an input. Serious errors can be made either by compositing portions of the site that would not be composited during the excavation or dredging process, and thus potentially underestimating the peak concentrations of contaminants, or by failing to composite areas of the site that would be composited during the excavation or dredging process and thus potentially overestimating the peak concentrations of contaminants that the plant would be required to treat. Sample quantities, holding times, preservation methods, etc., must be coordinated with the analytical and treatability laboratories involved during the writing of a sampling plan. Historic practices at the site and its geographic and geologic nature are important considerations in formulating a sampling plan that will adequately represent the diversity of materials found at the site. Statistical and practical considerations involved in representative sampling are beyond the scope of this document. However, guidance can be found for sediments in the work of Mudroch and Azcue (1995) and for surface soil in manuals prepared by USEPA (1996), USEPA (1986), ASTM (1995), and the Soil Science Society of America (Petersen and Calvin 1996).

Step 3

Step 3 as shown in Figure 1-3 is the preliminary technical and budgetary feasibility evaluation. Most of the material in this document is designed to help answer the questions that must be posed in this step: "Is the soil or sediment amenable to physical treatment or to physical treatment combined with another unit process? If so, which processes or treatment trains appear feasible? Can any of the technically feasible processes which have been identified meet budgetary or cost/benefit requirements?" Further guidance in addressing these questions can be found in USEPA (1991a) and Anderson and Mann (1993).

If the answers to the questions posed in Step 3 indicate that no feasible physical process exists, then other types of technologies (e.g., biological, chemical or thermal) must be considered or the budgetary and technical goals for the project must be reexamined in light of practicality. If the answers to the questions posed in Step 3 suggest that physical separation is a feasible alternative for the site, then the certainty of that determination should be assessed.

Step 4

In this step, the confidence or certainty surrounding the preliminary positive feasibility evaluation made in Step 3 should be assessed. Both the personnel involved in the work of Steps 1 through 3 and independent technical reviewers should attempt to address the question, "Is the basis for the positive evaluation sufficiently certain, given the stage of the project/purpose of the evaluation?" If the answer to this question is positive, then the feasibility evaluation has been successfully completed. If the confidence in the evaluation is not high, most likely due to gaps in the information available on which to base the evaluation, the process should continue to the next step.

Step 5

In Step 5 additional data is gathered to support a more detailed feasibility evaluation. Again no "one size fits all" set of data gathering activities can be described. However, the preliminary feasibility analysis by this point has probably narrowed the range of beneficial reuse and disposal options, allowing a more detailed study to be made of the specifications and requirements for a treated product to be put to a given end use, and the amount of material that a given end use can handle at a given time.

Cost considerations may have forced compromises in the number of samples or types of tests performed in Step 2. After a preliminary positive feasibility determination has been made, the costs for a thorough program of sampling and analysis may be more easily justified.

The most important information gathering activity in Step 5, however, is likely to be more extensive treatability testing in which the capabilities of individual unit processes and entire treatment trains to handle the material of interest is assessed either at the lab pilot or field pilot scales. For example, where in Step 2 a bench-scale sieve and hydrometer based particle-size separation was used, here in Step 5 a pilot scale separation involving sieves, hydrocyclones, and spiral density separators may be carried out. Further information on this process can be found in later sections of this document as well as in USEPA (1991b), Feenstra et al. (1995), and Bovendeur et al. (1991). This step can be considered to roughly parallel the remedy selection treatability studies described by USEPA.

Step 6

Based on the further information obtained in Step 5, the technical and budgetary feasibility evaluation would be revised. The questions addressed here are the same as in Step 3: "Is the soil or sediment amenable to physical treatment or to physical treatment combined with another unit process? If so, which processes or treatment trains appear feasible? And can any of the technically feasible processes which have been identified meet budgetary or cost and benefit requirements?" Step 6 will result in a more detailed determination of the feasibility of the process which, after an evaluation of the confidence level of that determination, can lead to appropriate action (i.e., proceed to engineering design of a treatment system).

2 Equipment Selection and Operating Factors

General Selection Criteria

Equipment selection for physical separation of contaminated soils and sediments requires that a number of interdependent parameters be reconciled. As discussed in chapter 1, selection should begin with the desired product specifications (e.g., percent fines, maximum acceptable contaminant levels for a given beneficial use) and maximum allowable capital and operating costs. Then work backwards to identify equipment options suitable to the characteristics of the material being processed, capable of providing the necessary capacity and efficiencies, and with capital and operating costs falling within the proposed project budget.

None of the unit processes available is capable of producing a perfect "cut." All are subject to varying levels of efficiency which are a function of the type of equipment, material characteristics, and the loading. Series installations may be necessary to refine the separation to satisfactory levels, or parallel installations may be required for sufficient capacity. These determinations are best made by testing the material to be treated in equipment of the same size selected for the treatment train and optimizing the operating parameters. Since these determinations are not always possible without first purchasing equipment, the planner must rely heavily on the expertise of the equipment and technology vendors in making reasonable initial equipment choices and the results of bench or pilot scale testing. The system so assembled will probably require some additional modifications once set up and running in the field.

The purpose of this chapter is to provide more detailed information about key unit processes in a standardized format. This information was mostly derived from vendor literature and handbooks. Each unit process for which there is adequate information is treated in a common format that provides information such as:

1) a brief restatement of the nature of the unit process,
2) a photo (if available),
3) feed material specifications,
4) capacity,
5) description of the various types of equipment available for each unit process,
6) waste/product streams produced,
7) operating variables,
8) physical size of the equipment,
9) cost (if available),
10) general comments,

11) position in flow sheet, and

12) vendor names. (Address and phone information are given in Appendix B, Equipment and Technology Sources.)

Costs were converted to January 1998 US dollars, using Chemical Engineering Plant Cost Index (CE Index). In many cases, vendors are reluctant to provide generalized cost estimates. Therefore, cost estimates are based on best available information and must be confirmed and refined for specific applications. One limitation of the Western Mine Engineering (1996) cost reference is that some of the equipment is of a type and scale relevant chiefly to large mining operations. This limitation does not present a problem for much of the milling equipment such as screens, screw classifiers and filters, but conveyor size and costs contained in this reference are clearly beyond the scale required for most soil or sediment treatment plants. In addition, there are a wide variety of pumps, hydrocyclones, and other pieces of equipment available in the marketplace, all of which could not be represented in a consolidated reference such as this. Ultimately, the only way to assess the breadth of equipment available is to contact vendors individually about equipment tailored to specific project needs. Generic cost references, however, do a reasonable job of defining the broad ranges of capacities available and associated cost as a function of capacity.

The reader should be aware that while physical separation is applicable to sediments as well as soils, much of the information discussed here is taken from mineral processing technology, which is more closely related to soils than to sediments. Sediments tend to present additional handling concerns and possible increased expense. For example, sediments often have a "sticky" nature that could be problematic in equipment such as a grizzly or trommel where the material is not yet in slurry form. Clay balls are commonly encountered in hydraulically dredged sediments and could pose processing problems. Transport and storage of wet sediment may also require different handling and containment procedures. As would also be true for some uncompacted soils, confined disposal facilities (CDFs) may not provide a stable staging area, and off site operations may be necessary.

Pre-Processing

Feed Hoppers

Feed hoppers are the logical starting point of moving raw, "as-excavated" soils into the treatment train. Feed hoppers are one of the most overlooked aspects of most plants because they are believed to be simple boxes that start soils to the more complicated downstream steps. Nothing could be further from the truth. More projects have failed because of poorly designed feed hoppers than any other aspect of the process. Feed hoppers must be selected with an awareness of the type of soil to be introduced.

The predominant feed hopper design for soil washing is the walking floor or conveyor. A sloped bottom hopper is mounted above a variable speed chevron conveyor belt. The hopper should have an adjustable feed discharge door. This adjustable door and the variable speed belt allow control of the feed rate by controlling the cross-sectional area of the feed on the belt as well as the belt speed. Feed characteristics will determine the preferred control method.

Grizzlies (Fixed-Bar Screens)

One of the first unit operations in the typical pre-screening treatment train is the fixed-bar screen or grizzly. Grizzlies are large screens (grates) consisting of fixed parallel bars, usually 100 to 200 mm apart (Osborne 1990). In mineral processing operations, grizzlies appear before the primary crushing operations to minimize the material passing through the crusher by removing the oversize material. In soil/sediment treatment operations, grizzlies primarily serve to screen out large cobbles and debris often present in feed materials. A grizzly may be incorporated as part of the first feed hopper or may be a stand alone piece of equipment, fed by front end loader and evacuated by loader or conveyor as shown in Figure 2-1.

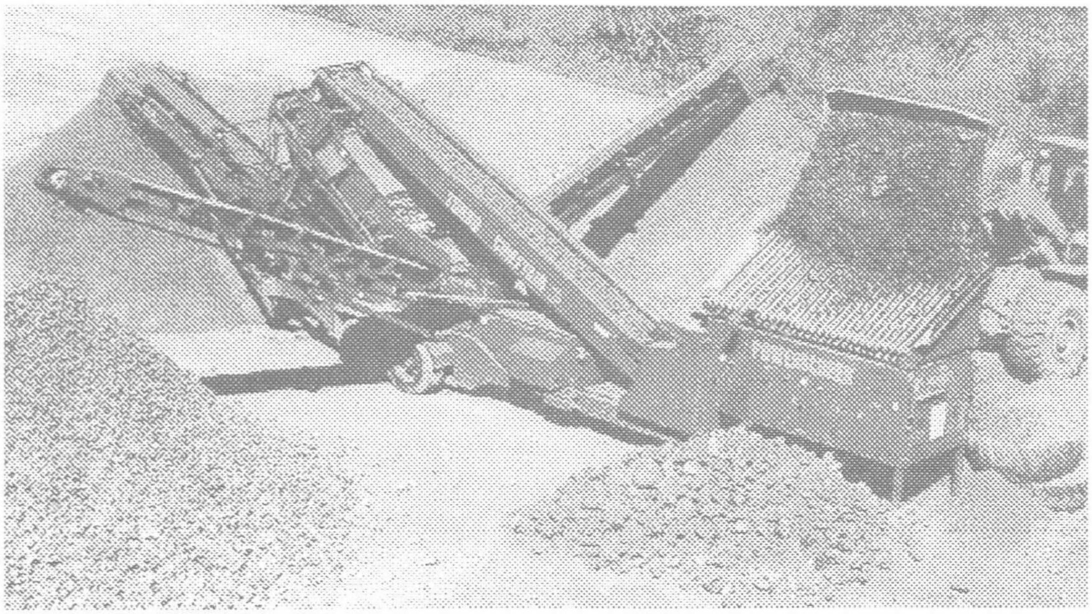


Figure 2-1. Grizzly in series with a screen (provided courtesy of Powerscreen of Florida, Inc.).

Feed material specifications -

Specific gravity - n/a

Solids content - Usually fed dry or at prevalent site water content.

Washwater - Not typically applied to grizzlies.

Particle-size ranges - Grizzly bars are usually spaced 1" to 2" (2.54 to 5.08 cm) apart.

Capacity - Limited primarily by loading equipment.

Type - Site built grizzlies are usually stationary bars. Vibrating grizzly bars promote product and oversize movement.

Waste/product streams - Oversize material is either retained on the grizzly for hand picking or slides from the inclined face of the grizzly bars.

Operating variables/parameters - Parameters for vibrating grizzlies include amplitude and frequency of vibration. The dimensions of oversize material will be determined by the spacing of the bars.

Size - Not limited with respect to size but may typically be approximately 12' x 12' (3.66 m by 3.66 m).

Cost, capital and operating - Western Mine Engineering (1996) gives capital costs for vibrating grizzlies with deck sizes ranging from 3' x 5' to 6' x 20' (1 m x 1.5 m to 1.8 m by 6 m) as $19,230 to $86,920 with operating and maintenance costs ranging from $1.38 to $6.25/hr.

General comments - Grizzly bars may be installed on vibrating assemblies; undersize product flowing between the bars. Minimum spacing nominally 1.5" (3.81 cm). Stationary bars are often installed over bins and hoppers. They are typically fed with a front end loader.

Flowsheets - Grizzlies are normally the first stage in the treatment train as shown in the generalized process flow diagram, Figure 1-1.

Vendors - Triple/S Dynamics Inc.

Trommels

Trommels (Figure 2-2) are rotating screens consisting of cylindrical, slotted drums. Oversize material passes through the central axis of the drum, while undersize material passes through the slots of the drum. Trommel screens can be removed and modified to provide a removal range of 25 to 75 mm. Trommels can be arranged in series to achieve successively larger or smaller separations by feeding either the oversize or the undersize to the next trommel. The angle of the drum and the rotating speed can be adjusted to improve performance. Moderately sized trommels have a throughput rate of approximately 100 tons per hour. While trommels are relatively inefficient, they are ideal for preparing feed soils for further treatment. Clay can be problematic, and attention must be given to application of enough energy to force feeds to their natural particle size to overcome agglomeration.

Feed material specifications -

Specific gravity - Not limited.

Solids content - Feed to trommel is normally dry or at prevailing site conditions.

Washwater - Not typically used in soil/sediment separations.

Particle-size ranges - EPA's ARCS guidance document (1994b) indicates a maximum feed size of 4 cm and a target separation range of 0.006 to 0.055 cm.

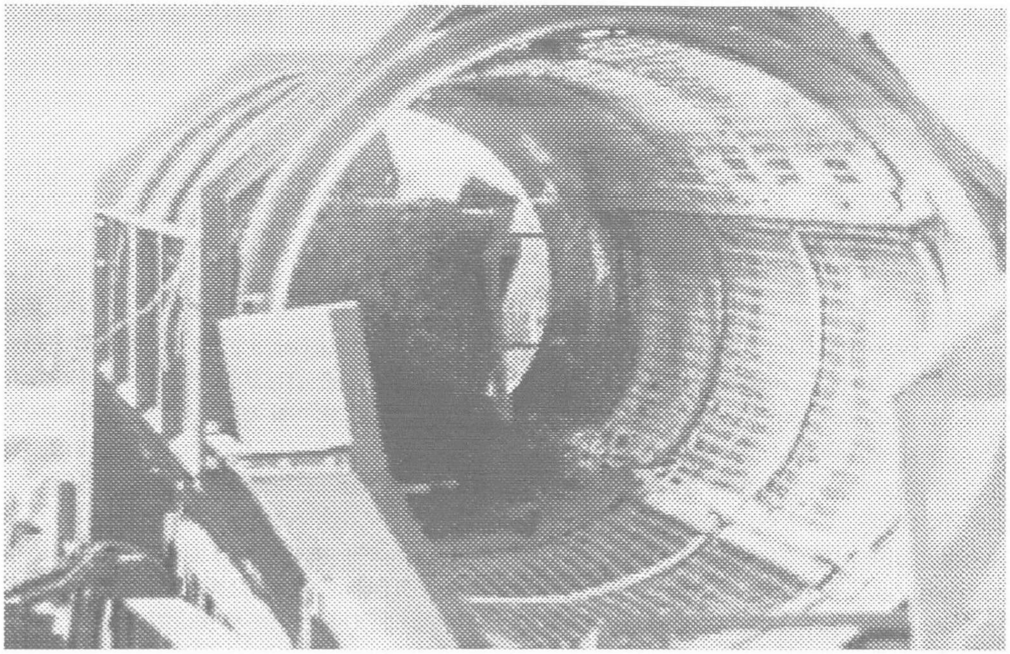


Figure 2-2. Trommel (provided by ARCADIS Geraghty-Miller).

Capacity - Western Mine Engineering (1996) gives capacities for fixed trommels at 40 to 720 cy/hr and for mobile trommels at 25 to 500 cy/hr.

Type - Trommels may be equipped with spikes or knives to aid in de-agglomeration or size reduction.

Waste/product streams - Oversize material travels down the inside of the rotating trommel and is discharged through a hopper at the end of the drum. Large agglomerates will discharge with the oversize if they have not been reduced. Undersize material passes through the grate of the trommel and is discharged through a separate hopper.

Size - Fixed trommels described range in size from 36-inch (91.44-cm) diameter and 12 feet (3.66 m) in length to 96-inch (243.84-cm) diameter and 44 feet (13.41 m) in length. (Western Mine Engineering 1996)

Cost - capital and operating - Cost information is provided for both fixed and mobile trommels (Western Mine Engineering 1996). Capital costs for fixed trommels range from $20,330 to $203,300 and operating costs from about $1.00 to almost $13.20/hr. Unit capacity costs range from approximately $300 to $500/cy/hr, with unit cost decreasing with increasing capacity. Motors are additional.

Capital costs for mobile trommels range from approximately $81,000 to $1,321,000, and operating costs from approximately $4.00 to $63.00/hr. Unit capacity costs range from approximately $2,540 to $3,250/cy/hr. Additional capital cost is attributed to skid mounting and auxiliary equipment included for the trommel operation. The reason for the higher operating costs is not given. Other assumptions on which these cost ranges were based are contained in Western Mine Engineering (1996).

Flowsheets - Trommels are typically used following a grizzly and, in soil and sediment separations, in front of a screen.

Vendors - Triple/S Dynamics Inc.
Powerscreen of Florida, Inc.

Comminution

Comminution is a general term for size reduction that may be applied without defining the actual mechanisms involved. The equipment that could be used in this area includes a wide array of crushers, grinders, and mills. Even explosive shattering is, in fact, a comminution technique. In soil treatment, these methods are rather infrequently employed. In remedial applications, the field or process oversize may be contaminated, requiring crushing or grinding to process for the removal of target contaminants.

A reasonable rule of thumb for the lower size limit resulting from various size reduction techniques is as follows: 1 m for explosives, 100 mm for primary crushing, 10 mm for secondary crushing, 1 mm for coarse grinding, and 100 µm for fine grinding. Fine grinding will create a small enough particle size such that treatment can be affected in most soil treatment facilities. These processes are used on large volumes and are expensive on both capital and operating cost levels. Power consumption is high. Common machines in this category include jaw crushers, gyratory crushers, cone crushers, hammer mills, ball mills, rod mills, and autogenous mills.

Autogenous grinding is the grinding of feeds by natural contact, rather than by using special metallic or non-metallic grinding bodies distinct from the feed. Tumbling mills are autogenous mills used where the ore (in remediation, feed soils) is used as the grinding media to produce a feed of the desired size range. The mining industry learned that when autogenous grinding was not effective, performance could be improved by adding a quantity of steel balls to the mill in an amount of 2% to 10% of the mill volume. The use of the steel balls reduced the retention time and energy requirement in the mill while producing an improved discharge.

Dispersion of agglomerates can often be performed effectively in comminution equipment. For soil remediation applications, clay soils and agglomerated soils may require additional input energy to produce acceptable treatment plant feed. Hard rock oversize can work nicely instead of steel balls. Trommel screens, modified to increase retention time, with the addition of field oversize rock, are referred to in this document as SAG (semi-autogenous grinder) mills.

A log washer is another device used to break up clumps of agglomerated soil. It consists of two rotating parallel logs with steel projections (spikes). This action results in coarse attritioning of the material.

Attritioners or attrition mills are machines that are used in remediation applications to grind materials in the coarse fraction to insure that agglomerated materials are driven to their natural particle size. Often, clays and silts can be bound together from waste formation pressures or in-place stress making the agglomerated mass appear to a screen or hydrocyclone as sand particles. Through the use of the attritioner, grinding forces are placed upon the input soils, reducing the materials to inherent particle sizes. Attritioning is synonymous with abrading, that is using the soils as the media affecting the grinding. Attritioners can be classified as rotating-disk, fluid, and abrading sand machines. The most commonly used in remediation applications are of the rotating-disk type.

Particle-Size Separators/Classifiers

Screens

In a volume reduction operation, screens will be used for grading (sizing) material, though they may also have dewatering applications. When slurry is fed onto a screen, particles larger than the screen apertures (oversize material) pass across the screen. Particles smaller than the aperture (undersize) pass through. Because contaminants very often (but not always) associate predominantly with fine materials, which have high surface area and activity, coarse/fine separations are typical of the majority of volume reduction operations. Desirable "cuts" will be determined by the contaminant distribution with respect to particle-size and the required fines content in the finished material.

Screens will usually appear at more than one point in the treatment train, beginning with very large screens to remove field oversize materials, followed by finer screens to make the desired coarse and fine cut(s). The smallest practical size for screening is approximately 1 mm (1000 µm). While vibrating screens are available down to 500 µm, they are very large and difficult to operate. It is not feasible to use mechanical screens for separations smaller than 500 microns.

Screens may be stationary, reciprocating, or vibrating, and either wet or dry operation. High pressure spray bars on the screens are advantageous to break up agglomerated materials. (See Figure 2-3.) Deck material and configuration vary. Primary selection factors are required aperture and percentage of open area, which varies in practice from 30 to 80% of the total screen area (Osborne 1990). However, aperture shape, weave and hole pattern must also be considered. Screen manufacturers are the best resource for these determinations. Ultimately, a pilot test of the material to be processed is advisable if performance is to be adequately evaluated prior to selection.

The most widely applicable deck is the wedge wire cross-flow deck (Osborne 1990). Other mediums are rubber, polyurethane, woven wire (square or slotted holes), and perforated plates (round, square or slotted holes). While demonstrating good wear characteristics, the non-metallic surfaces all share the disadvantage of reduced open area with decreasing aperture. Screens are very durable, with long useful lives, and are generally designed so that the perforated decks can be replaced for process changes or when worn.

Feed rate and separation efficiency are the two primary design criteria for screens (Osborne 1990). There are a number of empirical relations for sizing screens. Because screen capacity is somewhat affected by the characteristics of the feed, however, capacity calculations should be based on a pilot run of representative feed materials (Osborne 1990). In general, capacity is a function of the open area. Open area is, in turn, related to wire bar profile, in the case of wire screens, and inclination. For feasibility level evaluations, only familiarity with the aperture ranges of the different types of screens, typical separation and operational efficiencies, and relative advantages and disadvantages of each type is necessary. Manufacturers are typically in the best position to size equipment for final selection.

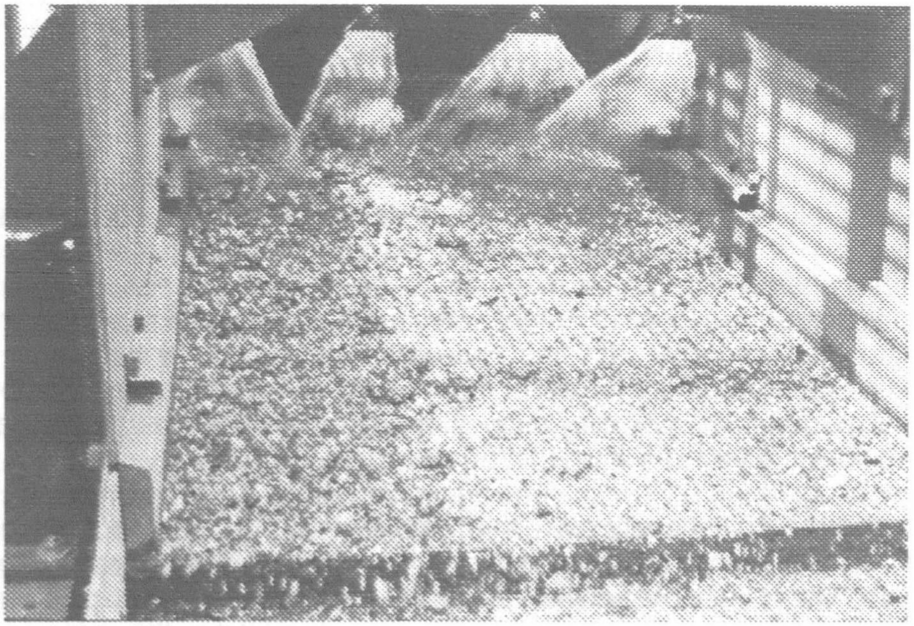


Figure 2-3. Vibrating screen with wash water (provided courtesy of ARCADIS Geraghty-Miller).

Feed material specifications -

Specific gravity - No restrictions were found in the vendor literature.

Solids content - Virtually any solids content may be fed to a screen. Moist solids tend to cause blinding on the screen restricting throughput. Accessories such as heaters or ball decks are often available to reduce blinding.

Washwater - A well-designed water spray system can increase screening capacity. Water spray systems can generally be installed on any deck.

Particle-size ranges - Particle-size separation will be dependent on the cloth chosen for the screen. Feed material should be free of particles greater than about 300 mm, or smaller depending on screen size, to avoid damaging the screen. Screens may be considered when the desired cut size is greater than about 25 μm.

Characteristics - Though not discussed extensively in vendor information, screens generally remove top sizes from fines. Some nearsize fines entrainment can generally be expected with the oversize because nearsize particulate will rarely strike the cloth at the center of an opening. Physical damage to the screens may allow oversize particles to discharge on lower screens or with the undersize product. Agglomerates will tend to behave as a large particle unless broken up by washwater or other mechanical action.

Capacity - Screen capacity is a function of the feed particle-size distribution, density, moisture, end product specifications, and other factors. Operational factors affecting capacity may include screen selection, vibration frequency and amplitude, wash water distribution, and flowrate. Pilot tests are often necessary to properly size equipment. Capacity may be up to approximately 4.5 short tons per hour per sq. ft. for metallic ores and will vary for different materials (Deurbrouck and Agey 1985).

Type -

Fixed Mechanical Screens - Fixed screens are mounted directly to the supporting structure and rely on the input energy to the loading process to stratify the bed and to perform the separation. Fixed screens are generally used for field screening to remove field oversize. The screens in this category are relatively inefficient, but the low capital and operating costs support their use.

Vibrating Screens - Vibrating screens, both inclined and horizontal, produce motion perpendicular to the plane of the screen surface. Vibrating screens are shaken by low-frequency motors mounted to the supporting frame. As the screening surface is vibrated, the bed of the material tends to develop fluid-like characteristics. Smaller particles sift through the void spaces and find their way to the bottom of the bed while larger particles remain on the screen. This effect, called stratification, improves screening efficiency and reduces on-deck retention time. Vibrating screens are enhanced by high pressure spray bars that add an additional dimension to the stratification while also forming a slurry in the bottom tank or "trough" of the screen. The wet, vibrating screen is particularly useful in diverse soils with reasonable mass fractions of process oversize and coarse grained materials.

Multiple-Decked Screens - Screening systems can be combined with multiple decks with different slot sizes. Double-decked and triple-decked screens are commercially available. These multiple-decked screens are particularly useful when a range of process oversize products is desired.

Waste/product streams - Undersize material passes through the screens and discharges from a chute or hopper with the bulk of slurry or washwater. Oversize material travels over the screen discharging from the end of the screen which is usually fitted with a chute. Oversize material is substantially dewatered when discharged from the screen.

Operating variables/parameters - The amount of water spray can be adjusted to affect the screening capacity. The amplitude of vibration may generally be adjusted with weights designed by the vendor. Some models are available with frequency adjustment as well. On vibrating gyratory screens, the flow pattern may be adjusted with eccentric weights.

Size - Width 20" to 8' (50.8 cm to 2.44 m). Length 4' to 25' (1.22 to 7.62 m). Inclined and horizontal vibratory screens are available in discrete elements by vendor. Larger sizes can be provided by some vendors when necessary. Vibrating gyratory screens are available from 24" to 72" diameter (60.96 to 182.88 cm).

Cost - capital and operating - Cost information is available for horizontal and inclined screens and polyurethane and woven wire decks (Western Mine Engineering 1996). Capacity is given in tons/hr sq.ft for screen openings ranging from 0.838 mm to approximately 100 mm, different screen levels, and both wet and dry feed. Wet screening is typically necessary in soil/sediment processing because of the need to break up agglomerated materials, and those costs are referenced here. Horizontal screens with single or multiple decks ranging in size from 4 ft by 12 ft to 6 ft by 20 ft (1.22 m by 3.66 m to 1.83 m by 6.10 m) have capital costs ranging from approximately $20,330 to $60,990 and operating costs of $1.52 to $4.57/hr. Inclined screens with polyurethane decks ranging in size from 4 ft by 8 ft to 8 ft by 20 ft (1.22 m by 2.44 m to 2.44 m by 6.10 m) have capital costs ranging from approximately $17,300 to $97,600 and operating costs ranging from approximately $1.00 to $6.60/hr. Capital costs for inclined deck with woven wire screens range from approximately $14,700 to $81,300; operating costs range from approximately $1.00 to $6.10/hr. Motors are included in these costs.

Unit capacity costs are difficult to estimate because capacity is a function of deck material as well as operating conditions, and given capacities are not referenced to a specific deck. However, if a double deck is assumed with a screen opening of 0.838 mm and a capacity of 0.21 tons/hr sq.ft. average, 1) cost for a horizontal screen will range from approximately $1,010 to $1,220/ton/hr capacity, 2) cost for an inclined screen, polyurethane deck, will range from approximately $1,220 to $1,420/ton/hr capacity, and 3) cost for an inclined screen, woven wire deck, will range from approximately $690 to $710/ton/hr capacity. Generally, the larger screens have slightly lower unit capacity costs, but this is not true in every case. Unit capacity cost spread is relatively small, however, when compared to other equipment. Other assumptions on which these cost ranges were based are contained in Western Mine Engineering (1996).

General comments - Accessories to effect feed distribution such as chutes or spreaders are generally available. Additional accessories include ball trays to reduce blinding with damp and nearsize material, screen heaters to prevent blinding with damp material, and dust enclosures. Units may generally be suspended or platform mounted. Models are available with one to five decks.

Flowsheets - Vibrating screens are typically placed after a grizzly and before processes which classify contaminated sands and fines.

Vendors - Triple/S Dynamics Inc.
Midwestern Industries, Inc.
Dorr-Oliver Inc.
W. S. Tyler, Inc.
SWECO Products
Macon Wire/DEWCO

Hydrocyclones

A hydrocyclone is a simple cone shaped device with no internal moving parts used primarily to classify but also to clarify or dewater solids from a slurry feedstream. Slurry is fed into the cone of the hydrocyclone (Figure 2-4), entering tangentially at the side. The heavy material is forced to the interior wall of the cone and moves downward in a spiral path, exiting at the bottom through the apex or spigot (underflow). As a result of the strong centrifugal forces, a central

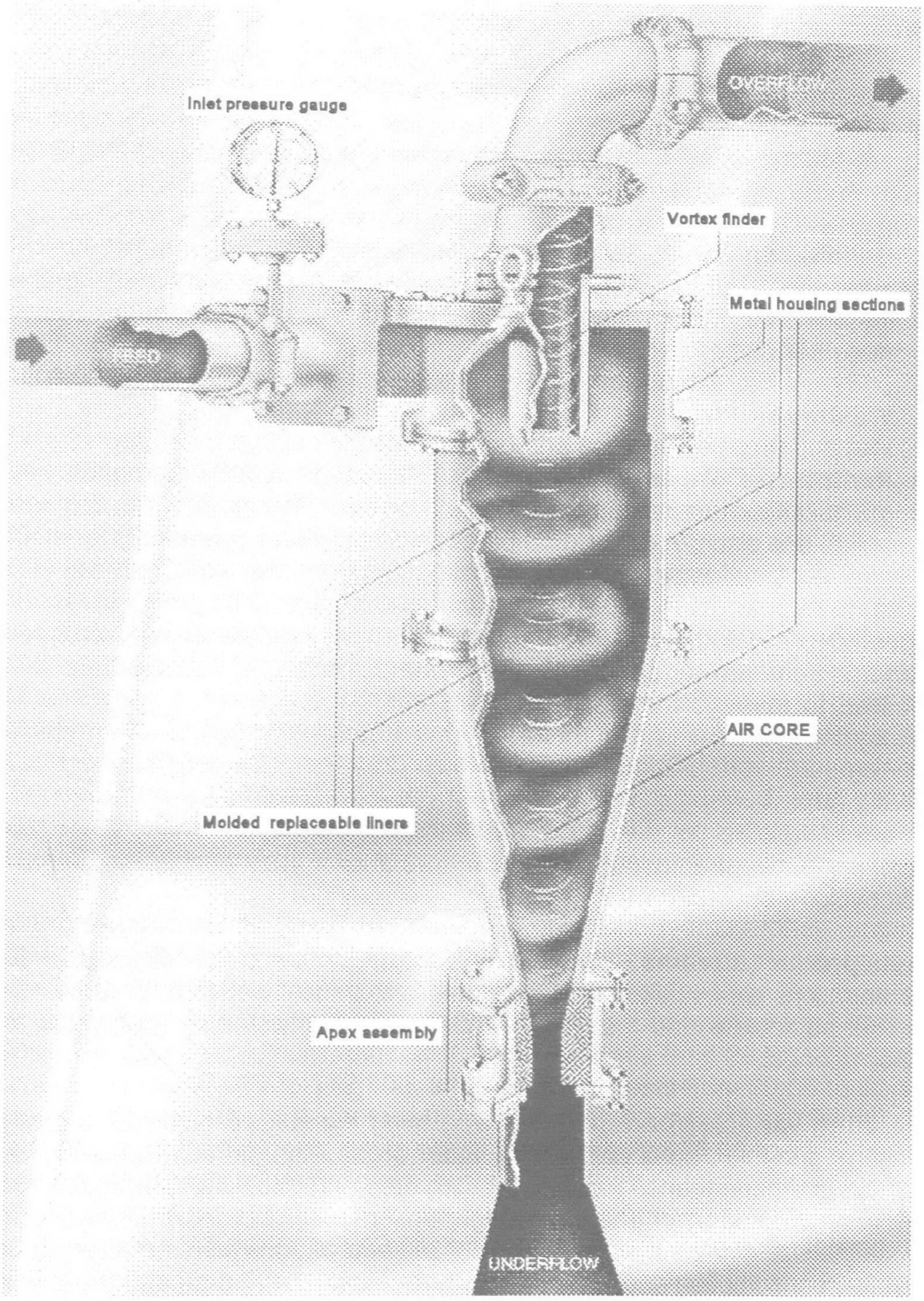


Figure 2-4. Section view of a hydrocyclone (provided courtesy of Krebs Engineers).

vortex is formed into which smaller materials are carried by the fluid out the top of the cone through the vortex finder (overflow).

Feed material specifications -

Specific gravity - Separation requires a difference in specific gravity of the fluid and the particulate. All else being equal, greater differences in specific gravity result in easier separations. Most nomographs are generated assuming a specific gravity of 2.7 for solids in water.

Solids content - Hydrocyclone feed slurry solids content typically ranges from approximately 15 to 30% solids by weight. Operation is most efficient with a dilute, low-viscosity feed which results in a finer particle size cut. General recommendations are to maintain slurry below 35% solids by volume.

Washwater - n/a

Particle-size ranges - Approximately 2 - 250 µm cut. No information was identified in the product literature regarding top size; however, the diameter of the apex, where coarse solids are discharged, should be considered when evaluating feed suitability. Largest particles entering hydrocyclone should generally be no more than half the size of the apex.

Capacity - 0.2 - 2500 m^3/hr (0.9 - 1100 gpm). Throughput is roughly correlated to size; smaller diameter units are required to achieve fine cut sizes. Pressure drop (head) can also be adjusted to manage throughput but this alters the cut size. Capacities for Mozley brand hydrocyclones are 0.1 - 1.2 m^3/hr for C155-one inch (2.54 cm), 8 - 28 m^3/hr for C516-five inch (12.7 cm), 20 - 110 m^3/hr for C630-ten inch (25.4 cm) (Carpco, Inc.).

Type - Available in poly and metal bodies, lined or unlined. Some models have interchangeable or adjustable vortex finders and/or apex orifices and other interchangeable hydrocyclone body parts.

Waste/product streams - Underflow discharge contains the "oversize" fraction. Underflow concentrations are usually limited to not more than 60% solids by volume. Overflow contains the fine particulate and the bulk of the water. Nomographs give liquid and solid split for hydrocyclones.

Operating variables/parameters - Operating variables include feed slurry solids content, pressure, and inlet, apex and vortex finder areas. The primary operating variables affecting hydrocyclone performance include pressure drop and viscosity. Changes in pressure drop are generally affected by changing throughput. Pressure increase will increase throughput and reduce the size of the cut point. Efficiency of separation is also increased, but at the expense of energy consumption and component wear. Flow rate and pressure are also related to inlet area. It is also important to maintain a constant feed rate. Constant volume pumps are recommended for this application.

Viscosity is affected by the solids content of the slurry. Temperature can also have a large impact on viscosity. In addition, some models have an adjustable apex which helps control the solids content of the underflow.

Size - Hydrocyclones are typically sized using the D_{50} cut point. At this particle size, 50% of the material will report to the underflow and 50% to the overflow. The result is a distribution, rather than an absolute cut point. A smaller size cut can also be achieved by reducing the vortex finder size. However, the cut is less sharp (a wider distribution) and the underflow density also decreases because more water is then diverted to the apex. Underflow density is also an important parameter. For a dilute underflow, the discharge from the spigot will form a spray pattern. Higher underflow density will result in a "ropey" discharge, which has the effect of minimizing the fines entrained in the underflow, but will force coarser material into the overflow (lower efficiency of separation). It can be seen that these variations are opposite sides of the same coin. The operating conditions will therefore be determined by whether the characteristics of the overflow or the underflow are most important.

The nominal size (as listed by the manufacturer) of the cyclone selected is a function of the particle-size cut desired. Within limits, the operating variables can be adjusted to achieve different cut sizes and efficiencies. As a rule, the larger the diameter the coarser the cut: roughly, 500 mm for 150 μm cut, 250 mm for 75 μm, 100 mm for 40 μm, and 25 mm for down to 5μm (Elliot 1991). This will vary, however, depending upon the arrangement of the interdependent operating variables. Efficiency curves (percentage of a given particle size reporting to underflow), capacity curves (throughput as a function of pressure and vortex finder diameter) and volume split curves (volume of feed liquid to underflow at a given pressure, as a function of vortex finder and spigot diameter) are performance indicators. These should be used, at least initially, in hydrocyclone selection followed by pilot testing with a volume of material large enough to be representative. (Selection is largely a judgement call, but will be based on documented heterogeneity of the materials to be separated, total volume to be treated, and budget). System verification is required because efficiency curves are established for a given set of conditions. Actual performance may vary significantly.

Cost – capital and operating - Cost information is given for hydrocyclones ranging in size from 4 to 28 inches (10.2 to 71.1 cm) in diameter. A 12-inch (30.5-cm) diameter is probably the maximum encountered in soil/sediment processing) (Western Mine Engineering 1996). Costs differ depending on housing construction, including rubber lined cast iron/steel and fiberglass/polyester, and unlined polyurethane. Capacity ranges from 20 to 2200 gpm, capital costs from approximately $4,070 to $12,200, and operating costs from $0.05 to $0.15/hr. As for centrifuges, unit capacity cost decreases with increasing size. For 10-inch (25.4 cm) diameter and smaller hydrocyclones, costs range from roughly $23.40 to $230.00/gpm. For 12 inch (30.48 cm) and larger hydrocyclones, costs range from roughly $5.00 to $66.00/gpm. The overlap in unit cost ranges is a reflection of the effect of capacity ranges for individual hydrocyclones, which may vary from 40 to over 1500 gpm from low to high end per unit, depending upon operating conditions. Other assumptions on which these cost ranges were based are contained in Western Mine Engineering (1996). Typical costs for hydrocyclones for soil and sediment remediation are estimated by EPA in 1998 dollars to be between $4,050 and $8,100 for a throughput of 18 to 55 dry tonnes per hour. Operating costs are estimated at $0.13 to $0.38 per dry tonne.

General comments - Cut size and sharpness of the cut in hydrocyclones are related to feed composition and hydrocyclone geometry and size. Hydrocyclones with small-cut sizes are generally smaller and have lower throughput than units for large cut sizes. Manufacturers often have interchangeable components that affect throughput, cut size, and the sharpness of the cut. Hydrocyclones are typically manifolded in parallel to obtain the desired throughput, as in Figure 2-5. Hydrocyclones made with special materials or with liners are available to resist wear from abrasion.

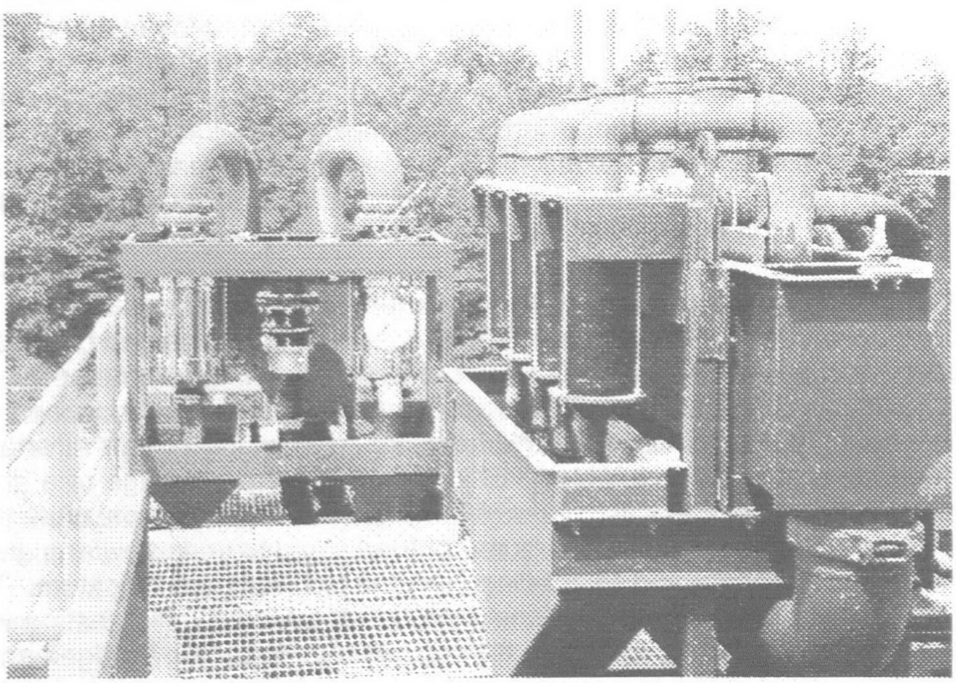


Figure 2-5. Bank of four fines separation hydrocyclones in foreground with bank of two sand dewatering hydrocyclones in background (provided courtesy of ARCADIS Geraghty-Miller).

Flowsheets - Hydrocyclones are used to separate the contaminated sand or fines size fraction. They are typically located after an oversize removal on a screen but before other classification equipment. They are also used after attrition scrubbing to separate fine contaminated material from the clean sand.

Vendors - Bailey-Parks Urethane
Encyclon Inc.
Dorr-Oliver Inc.
Krebs Engineers
Technequip Limited
Richard Mozley Limited (distributor: CARPCO, INC.)
METPRO Supply, Inc.
Yardney Water Management Systems, Inc.

Hydraulic Classifiers

Hydraulic classifiers (Figure 2-6) are countercurrent settling chambers, which may be used to classify solids based on settling velocity. Typically, slurry is fed in from the top, and a column of water rises from the bottom. Solids with a settling velocity less than the velocity of the rising water are carried out in the overflow. Solids with a greater settling velocity are carried out in the underflow.

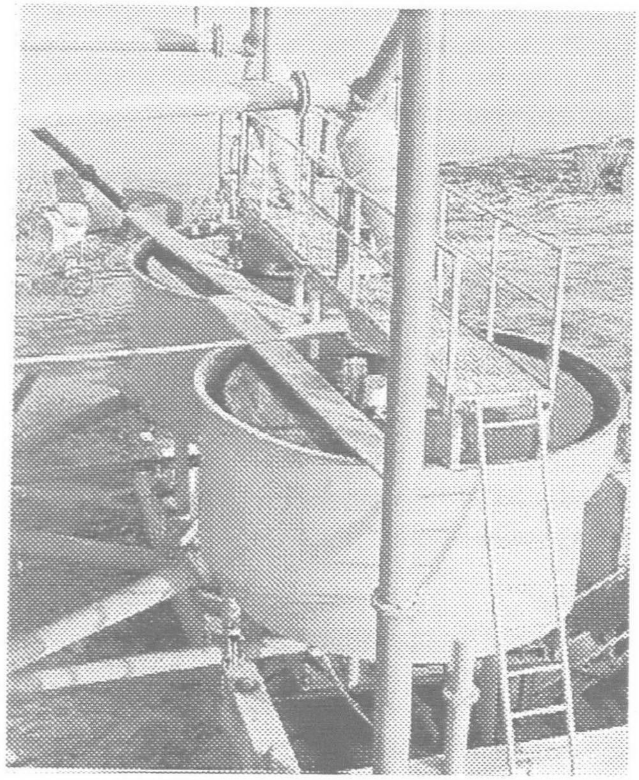


Figure 2-6. Two monosizer hydraulic classifiers fed by hydrocyclones (provided courtesy of Dorr-Oliver).

Feed material specifications -

Specific gravity - Separation requires there be a difference in specific gravity of the fluid and the particulate. All else being equal, greater differences in specific gravity result in easier separations.

Solids content - 800 to 1000 g/l

Washwater - Clean or clarified water must be provided to entrain underflow product at a minimum, or fines will contaminate the underflow.

Particle-size ranges - Nominal top size should not exceed 4 mm. Cut sizes down to 75 µm are achievable.

Characteristics - In hydraulic separators, particles with a lower settling velocity than the fluid flow will report to the overflow while particles with higher settling velocity will report to underflow. Settling velocity is determined by particle size, shape and density and by fluid density and viscosity.

Capacity - Units are available with nominal capacities up to 50 tons/hr. Capacity will vary with feed concentration and the desired cut size.

Type - Single-cell and multiple-cell units are available.

Waste/product streams - Fine particulate reports to the overflow while oversize or fast settling particulate reports to the underflow. Both streams are generally discharged as slurry.

Operating variables/parameters - Upflow velocity can be adjusted to vary cut size, within limits.

Size - Single-cell vertical flow settling basins are available from 0.2 to 24 m^2 cross sectional area.

General comments - Hydraulic classifiers are available as a single cell or "pocket" or in an eight pocket in series classifier unit.

Flowsheets - Hydraulic classifiers may be considered in a flowsheet after oversize removal and before other classification processes in the same locations considered for hydrocyclones.

Vendors - Dorr-Oliver Inc.
Floatex Separations Ltd.

Sieve Bends

Sieve bends are types of screens in which separation is affected not only by size and shape but also by density. A sieve bend is typically composed of a curved wedge wire deck. Feed is directed against the upper portion of the screen, which passes particles of a diameter approximately one half the distance between the wires. This separation is achieved in part by centrifugal effects, hence the dependence upon density. As the screen becomes worn, the edges of the wires become rounded, with an attendant decrease in the size of material passing through the screen. Regular turning of the screen can usually address this problem. The included angle of the bend varies. For mineral separations, the included angle is typically 45 to 60 degrees, with a capacity of 5 to 100 l/hr per meter of screen width for particle size separations in the range of 200 to 2000 μm. Variables in the use of sieve bends include opening size, slurry density, inclination and open area (Osborne 1990). The sieve bend is frequently useful in soil remediation work for the removal of natural organic materials (grasses and roots) from the sand fraction of the feed.

Density Separation

Spiral Concentrators

A spiral concentrator is a multi-turn helical trough. Spiral concentrators are flowing film-concentrating devices. Figure 2-7 is an example from coal processing but is applicable to soil washing. Slurry is fed into the top of the spiral. Depending upon the channel configuration of the spiral, separation of dense from light material occurs across the channel as slurry flows down the spiral. The spiral itself has no moving parts except for the flow splitters inside the channel. Test rigs are usually equipped with a hopper and centrifugal pump. Spirals incorporated as part of a larger treatment train will typically be fed by the previous unit operation and discharge to holding or settling basins for dewatering or subsequent processing. Because of their low capacity, spirals are often operated in parallel. Their use in processing of soil for remediation purposes is well established.

Efficiency may be improved by restricting the feed to a narrow size range and may be preceded in the treatment train by a hydrocyclone for that purpose. Spirals require a consistent feed rate at roughly 30% solids by weight. Spirals are adjusted with a knife-point separation tool that directs the separated fraction at the discharge end of the spiral. Spirals are equipped with two such devices that, when considering the inside and outside walls, can create three products: a heavy, a middling, and a light product. As the slurry comes down the spiral, particles heavier than sand tend to come to the inside of the spiral, while light material tends to move to the outside of the spiral. The knife-blade cutter devices can be adjusted visually to make the heavy, middling, and light separations. These three products can be directed to three segregate sumps for disposal, recycling, or further treatment. Spirals have two configurations intended for the primary removal of light or heavy materials optimized to emphasize heavy or light removals. Spirals are particularly effective for the removal of lead particles from sand, for example, or the removal of light, small-particle organic debris from the sand fraction.

Figure 2-7. Bank of spiral concentrators (provided courtesy of ARCADIS Geraghty-Miller).

Feed material specifications -

Specific gravity - 1.0 to 1.5 differential sp. gr.

Solids content - Carpco, Inc. (1993) indicates that their spiral operates with the greatest efficiency when the slurry density is between 15 and 45% solids.

Washwater - Not required for all models.
< 0.1 m^3/hr (0.5 gpm) Humphreys Mini-Spiral

Particle-size ranges - 0.075 to 3.0 mm (for coal) (Mishra and Klimpel 1987)
20 X 200 mesh (Humphreys Mini-Spiral)
Approximately 50 to 1000 µm (Carpco, Inc. 1992)

Capacity - Spirals are available in laboratory and full size. The Humphreys mini-spiral operates with as little as 20 lbs of sample for execution of feasibility studies. Spirals require a consistent feed rate and, like concentrating tables, may be more efficient for a limited size range feed. Spirals are sometimes preceded by a hydrocyclone for this reason. Capacity is increased with additional spirals (starts) operating in parallel.

1 to 1.5 tph/start (Mishra and Klimpel 1987)
2.3 m^3/hr (10 gpm) (Humphreys Mini Spiral)
(Not given for Humphreys full size spiral)

Type - Spiral concentrators vary in pitch depending on the density of the desired product. Steeper spirals are typically used for dense material, such as particulate lead, while less steep spirals are used for separation of less dense materials such as organics. Spirals are also available with multiple starts, usually two helical troughs around the same axis.

Waste/product streams - Like the concentrating tables, material coming off the spiral is generally separated into three product streams. The division of the material occurs as the material leaves the spiral through a flow splitter. Any of the process streams can be reprocessed through spirals in series for cleaner separation. Each stream must ultimately undergo dewatering. Coarser materials can be separated by simple primary settling or filtration. Fine material may require coagulation followed by lamellar settlers and filtration.

Operating variables/parameters – Flow splitters are manually adjusted.

Size - Full scale spirals typically have a footprint of nominally 3' x 3' (1 m x 1 m). They are typically purchased with multiple spirals to achieve desired capacity.

Cost - capital and operating - USEPA (1994b) estimates a typical 91 tonne/day circuit employing spirals for density separation to have a capital cost of $292,000. Operating costs are estimated at $6.54 per tonne.

Capital cost for a 5 ft to 8 ft (1.52 m to 2.44 m) single helix unit, with distributor, framing, etc. is approximately $3,050. (Western Mine Engineering 1996). Operating costs (other than labor) are limited to parts replacement, and range from $0.01 to $0.05/hour. Other assumptions on which these cost ranges were based are contained in Western Mine Engineering (1996).

Flowsheets - As spirals are generally most effective for dense particulate of the sand fraction, they are typically used after removal of fines and clean sand fractions. Therefore, they are generally considered for use after hydrocyclones.

Vendors - Carpco, Inc.

Jigs

Jigs provide density-based separation of particulate larger than 1 mm. Essentially, a jig is an open tank filled with water with a horizontal jig screen at the top and with a spigot in the bottom for concentrate removal. The jig bed consists of a layer of coarse, heavy particles, or ragging placed on the jig screen onto which the slurry is fed. The feed flows across the ragging, and the separation takes place in the jig bed so that grains with a high specific gravity penetrate through the ragging and screen to be drawn off as a concentrate, while the light grains are carried away by the cross-flow. Separation is accomplished in the bed which is rendered fluid by a pulsating current of water so as to produce stratification. The motion can be obtained either by using a fixed sieve jig and pulsating the water or employing a moving sieve.

Feed material specifications -

> **Specific gravity** - Jigs classify largely on the basis of density. Separations are more effective when there is a large difference in density between contaminants and clean material (i.e. gravel).
>
> **Solids content** - Solids in the jig are generally quite high, 30 to 50%.
>
> **Particle-size ranges** - Generally applied to particulate larger than 1 mm but can provide concentration down to about 200 mesh for some dense materials such as gold.
>
> **Characteristics** - Pulses of water expand a solid bed. Classification is a function of differences in settling rates.

Capacity - Capacity is dependent upon the degree of separation required. For high concentrations, rates are between 0.5 to 1 cubic yards per square foot of jig area per hour.

Waste/product streams - The waste will be a slurry concentrated with the dense contaminant. The product stream will be cleaned gravel or sand slurry. Classification will not be 100 percent efficient, and some gravel/sand should be expected with the waste stream and some dense material in the product stream.

Operating variables/parameters - Classification is dependent upon the feed rate and upon the intensity and frequency of the water pulsation. Higher pressures to the jig result in greater concentration (grade) of the waste stream. Lower pressures result in lower grade.

Size - Circular jigs are available with 3 to 9 square feet (0.279 to 0.836 sq m) of bed area.

Cost - capital and operating - Western Mine Engineering (1996) gives the following costs.

Table 2-1. Cost Ranges of Several Jig Types.

Type	Size Range	Capital Cost (1998 dollars)	Hourly O&M Cost (1998 dollars)
Baum	72 - 220 sq.ft.	$337,100 -$674,100	$14.23 - $29.74
Bendelari*	6"x8" (1 cell) - 42"x42" (3 cell)	$3,810 - $28,500	$0.14 - $1.35
Circular	1.4 sq.ft. (1 cell) - 448 sq.ft. (12 cells)	$1,875 - $296,800	$0.07 - $10.27
Duplex	12" cell - 42" cell	$3,314 - $13,300	$0.11 - $0.56
Fine Coal	178 - 267 sq.ft.	$832,100 - $990,200	$32.54 - $41.92
Shot Separator		$4,190	$0.13

*Price does not include mounting platforms. Add 30% to 50% for mounting platform, maintenance catwalk and discharge launders.

General comments - There appear to be several types and manufacturers of jigs not found in the vendor literature reviewed for this document.

Flowsheets - Jigs perform density separations on oversize material. They should be considered for location after removal of sands and fines, which is generally after a screen.

Vendors - RMS-Ross Corporation

Shaking Tables

Shaking tables, like the one in Figure 2-8, also known as wet concentrating tables, consist of rectangular or semi-rectangular grooved decks which may be mounted either horizontally or on a slight incline and which operate with a reciprocating motion. Slurry is fed onto the table where it separates according to size and specific gravity of the particles. The operative mechanisms of separation are fluid flow and asymmetrical acceleration. The idealized distribution of the particles across the table is as pictured in Figure 2-9. This distribution can be affected by the height and placement of the riffles (grooves) and any irregularities of operation. The coarse low-density particles are entrained in the upper flowing fluid film where velocities are highest. The fine high-density particles report to the bottom of the fluid layer where velocities are lowest. Coarse, high-density and fine, low-density particles move through the middle fluid layer at an intermediate velocity (Deurbrouck and Agey 1985).

Tables are available in laboratory and full size. Based on the lack of references in the literature, concentrator tables are not considered to be field proven in applications involving soils or sediments. Some work has been done at lab scale with firing range soils at WES indicating potential for treatment of heavy metals contaminated soils. However, based on the literature and lab experience, it appears that concentrator tables may require more monitoring and adjustment during processing than other classifiers and may be more sensitive to changes in feed. However, if a pretest indicates suitability to a specific material, tables could provide a cost effective component of the treatment train.

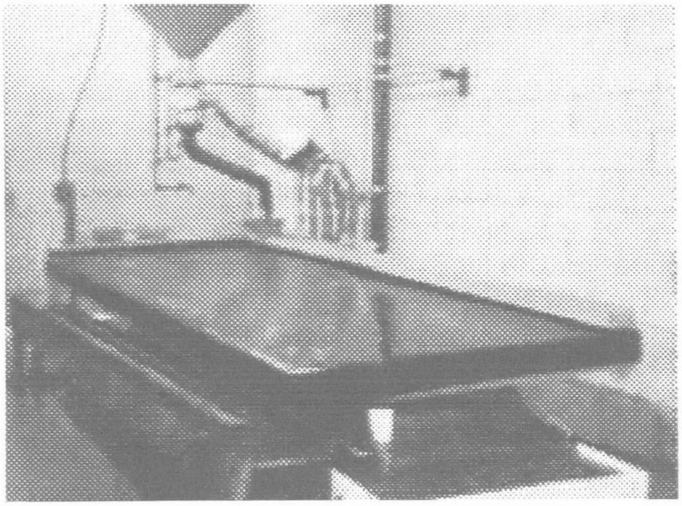


Figure 2-8. Typical final tabling in a gold application (provided courtesy of Humphreys Division of Carpco Inc.).

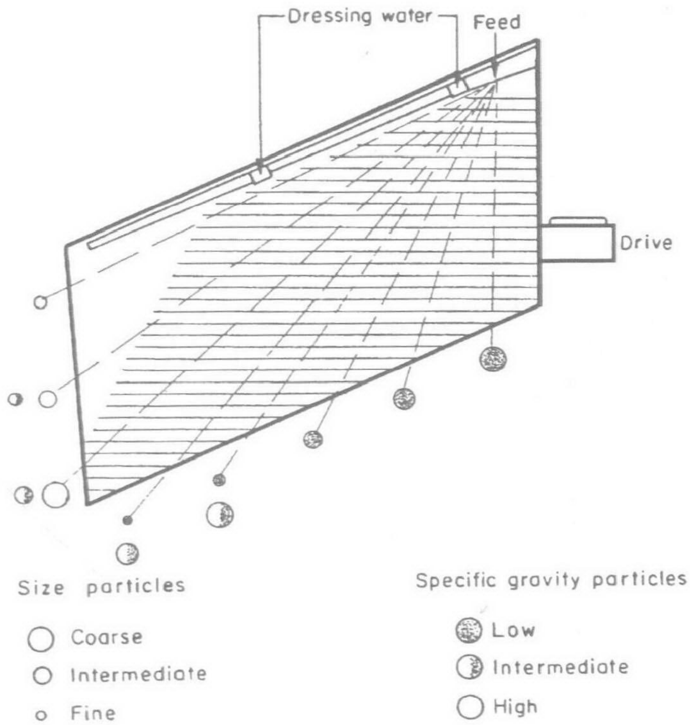


Figure 2-9. Distribution of table products by particle size and density (provided courtesy of Society for Mining, Metallurgy, and Exploration).

Feed material specifications -

Specific gravity - Specific gravity differences of at least 1.0 are typically required for efficient separation, if size and shape differences are not so significant as to govern. For soils, specific gravity differences are typically less than 1.0 (2.65 for sand, 2.65 to 2.80 for clay and silt), unless heavy metals (sp. gr. > 3.0$\pm$) or organic materials (sp. gr. 1.8) are associated with the particles. This specific gravity difference of less than 1.0 may account for the lack of references in the literature to the use of tabling in soil separation, as well as the monitoring required to maintain the desired cut. Tables may be more useful for treatability evaluation than in a continuous flow treatment train.

Solids content - Required feed solids content varies; however, the range given for slime ore is 800 to 1000 gal per ton (Deurbrouck and Agey 1985). For materials with a specific gravity of 2.65, this corresponds roughly to 25 to 30% solids by weight (W_{solids}/W_{water}). Soil processing would be expected to require this much, and possibly more, given the cohesiveness of clay materials, but this parameter does not appear to have been established for soils. Carpo, Inc. (Humphreys) recommends a 20% solids mixture for their 13A sand deck. Large top sizes (19 mm or ¾ inch) or a high proportion of fines in the feed typically impose the higher water requirements.

Particle-size ranges - Feeding a limited particle size range will improve tabling efficiency. For a given feed, the finest material is least efficiently washed (Deurbrouck and Agey 1985). Maximum top size for coal is approximately 19 mm (¾ inch) down to 10 mesh (2 mm, 0.08 inch) for heavier minerals . For materials with the density of coal (1.15 to 1.5 g/cc), ⅜ inch (0.9525 cm) to 100 mesh, or in some cases 200 mesh, is acceptable. For higher density materials, the range may be larger, ⅜ inch (0.9525 cm) to finer than 325 mesh, for example (Deurbrouck and Agey 1985). The presence of fine materials (slimes) increases the viscosity of the bed on the table and slows the stratification. Most soil components will probably fall between these two ranges. Optimum feed particle-size range must be determined on a case by case basis. Carpco, Inc. (1992) suggests a range of approximately 40 to 1000 μm. Jigs or heavy separators are more efficient for coarser materials.

Characteristics - Tabling was originally developed for mineral processing, where fine materials (referred to as slimes) are normally removed prior to tabling to improve efficiencies. For remediation processing of soils and sediments, however, removal of the fine fraction on the table may be one of the objectives and the feed will therefore be non-ideal from a mineral processing perspective. Operating parameters may need to be adjusted to compensate for this.

Capacity - Capacity is a function of table size, slurry solids concentration, and material particle size and characteristics. Capacities are highest for low density materials such as coal and larger particle sizes. Capacity of mineral processing tables for soils has not been established, but will probably be similar to that for minerals, which ranges from as little as 0.1 tons per hour to 1.2 tons per hour for a 6.5 by 14 foot deck (1.98 by 4.27 m). Capacity for a given efficiency level must be determined by pilot testing. Tables 2-2 and 2-3 give some examples for mineral processing, which range from less than 1 ton per hr per deck to over 15 ton/hr/deck. Capacities are also given by individual manufacturers/distributors.

Waste/product streams - In mineral processing applications, material coming off the table is typically separated into three product streams: cons, mids and tails. Cons are the highest density materials; mids are the mid range; and tails are the lightest particles (see Figure 2-9 for distribution of product on the table). To increase efficiency, any of these process streams may be reprocessed on tables in series. Ultimately, these streams must undergo dewatering. Coarser materials can be separated by simple primary settling or filtration. Fine material may require coagulation followed by lamella settlers and filtration.

Operating variables/parameters - Operating parameters for concentrating tables include riffle design, capacity, speed and stroke, tilt, and feed solids content. Sand tables are characterized by deep and extensive riffles, and slime tables by shallow riffles. Slime tables would most likely be suitable to soil separation, but the selection will be dictated by the desired material cut and the expected particle-size range of the feed.

Table type - Sand table, deep riffles: coarse material
Slime table, shallow riffles: fine material

Speed and Stroke - Variable. Length and frequency of stroke are interdependent variables (Deurbrouk and Agey 1985).
230 to 285 rpm and 1-¼ to ¾ inch (3.175 to 1.905 cm) stroke for coarse sands
285 to 325 rpm and ¾ to ⅜ inch (1.905 to 0.9525 cm) stroke for fine material

Table tilt - Set at the minimum inclination necessary to achieve good distribution of material across the table.

Table 2-2. Table Operating Parameters Suggested by Manufacturers (Deurbrouck and Agey 1985).

		Feed							Horsepower	
		Fine size		Coarse size						
Table Model	Type	Top size	Capacity, ton per hr per deck	Top size	Capacity, ton per hr per deck	Speed, rpm	Stroke, in.	Deck size	Installed	Operating
Super duty and Concenco Tables, Deister Concentrator Co.										
No. 6	Ore	100 mesh	0.25	6 mesh	2.0	285-300	½-¾	6 ft 5 in. X 14 ft 1 in.	2	½
No. 666 (3 decks)	Ore	100 mesh	0.25	6 mesh	2.0	285-295	½-¾	6 ft 5 in. X 14 ft 1 in.	3	3
No. 7	Coal	28 mesh	5.0	3/4 in.	15.0	280-290	½-1½	8 ft ¼ in. X 16 ft 9¼ in.	3	1
No. 77 (2 decks)	Coal	28 mesh	5.0	3/4 in.	15.0	280-290	¾	8 ft ¼ in. X 16 ft 9¼ in.	3	3
Wilfley and Holman Tables, Wilfley Mining Machinery Co., Ltd.										
Wilfley No. 20	Ore	100 mesh	0.25	6 mesh	2.0	300-325	⅜-⅞	6 ft 0 in. X 15 ft 6 in.	3	1
Wilfley No. 21	Ore	100 mesh	0.125	6 mesh	1.0	300-325	⅜-⅞	4 ft 0 in. X 0 ft 0 in.	2	1
Holman	Ore	100 mesh	0.25	6 mesh	2.0	270-280	⅜-⅞	5 ft 6 in. X 18 ft 0 in.	2	¾-1
Wilfley No. 20C (3 decks)	Coal	28 mesh	5.0	3/4 in.	13.0	230-270	1-1¼	7 ft 0 in. X 15 ft 6 in.	3*	1
Wilfley Tables (MSI Industries, Inc.)										
No. 6A and 11D (standard)	Ore	(†)	0.5	(†)	6.25	240-300	¾-1¼	6 ft 0 in. X 15 ft 0 in.	1½	½-¾
(oversize)	Ore	(†)	0.75	(†)	7.25	240-300	¾-1¼	7 ft 0 in. X 15 ft 0 in.	2	¾-1
No. 12	Ore	(†)	0.25	(†)	0.75	260-300	¾-1¼	3 ft 6 in. X 7 ft 0 in.	1	¼-½

* Per deck
† Not available

Table 2-3. Wilfley Concentrating Table Operating Parameters (Carpco, Inc. 1992).

Model	Particle Size Range	Water Requirements L/min (gpm)	Deck Size mm (in)	Coarse Feed Stroke mm (in)	Coarse Feed Freq RPM	Coarse Feed Max Capacity kg/hr (lbs/hr)	Fine Feed Stroke mm (in)	Fine Feed Freq RPM	Fine Feed Max Capacity kg/hr (lbs/hr)
6A Standard		19-76 (5-20)	1829 X 4496 (72 X 177)	19-25 (3/4-1)	260-280	1800 (4000)	13-19 (1/2-3/4)	300	750 (1600)
6A Oversize		19-76 (5-20)	2134 X 4496 (84 X 177)	19-25 (3/4-1)	260-280	1900 (4200)	13-19 (1/2-3/4)	300	800 (1800)
12		11-57 (3-15)	1168 X 2337 (46 X 92)	10-16 (3/8-5/8)	260-300	450 (1000)	10-16 (3/8-5/8)	260-300	180 (400)
13A Sand Deck	-20+200 Mesh	4-15 (1-4)	457 X 1016 (18 X 40)	6-13 (1/4-1/2)	250-350	70 (150)	-	-	-
13A Slimes Deck	-200+235 Mesh			-	-	-	6-13	250-350	45 (100)
13B Sand Deck	-20+200 Mesh	4-23 (1-6)	610 X 1270 (24 X 50) Sand Deck	6-13 (1/4-1/2)	250-350	115 (250)	-	-	-
13B Slimes Deck	-200+325 Mesh			-	-	-	6-13 (1/4-1/2)	250-350	90 (200)

Size - Sizes range from 5 to 90 sq.ft./deck (0.465 sq.m to 8.36 sq.m/deck) with single, double, and triple deck units available (Western Mine Engineering 1996).

Cost - capital and operating - Operating costs for concentrating tables are low relative to other methods of concentration and include supervision, utilities and maintenance. Supervision costs will be a function of uniformity of feed. Significant changes in table feed require changes in table settings. Single-deck tables typically use 1- to 3-hp motors. Double- and triple-deck tables typically use 3-hp motors. Actual power consumption is somewhat less than installed horsepower (Deurbrouck and Agey 1985). Maintenance costs are reasonably low.

Complete, single deck concentrating tables range in capacity from 0.4 to 1.0 tons per hour for fine sand and 0.6 to 3.0 tons per hour for coarse sand for a table area of 32 sq ft (2.97 sq. m) and 0.8 to 2.1 and 1.25 to 6.25 tons per hour respectively for fine and coarse sand for an 80 sq ft table (Western Mine Engineering 1996). Capital cost for the 32 sq ft (2.97 sq. m) unit is given as $11,000, and $14,400 for the 80 sq ft (7.43 sq. m) unit. Unit capacity costs range from $3700 to $27,400/ton/hr for the smaller unit, and from approximately $2300 to $18,300/ton/hr for the larger unit. Operating costs range from approximately $0.85 to $1.13/hour. Other assumptions on which these cost ranges were based are contained in Western Mine Engineering (1996).

Table 2-4. Concentrating Table Cost Ranges (Western Mine Engineering 1996).

Concentrating Tables	Area (ft^2)	1998 Capital Costs	1998 Operating Costs (hourly)
Single Deck	5-90	$4570-17,100	$0.35-1.46[2]
Triple Deck	240 (80/deck)	$34,500[1]	$2.69

1) Including deck, base, frame, launders (some sizes), drive mechanism and motor.
2) Including parts, labor for maintenance, power (electric), lubrication. Operator costs are not included and will vary with the type and amount of material being processed and the number of units on-line.

General comments - Primarily useful as a diagnostic tool.

Flowsheets - Shaking tables may be considered for density separation after removal of fines (de-sliming). This typically would place shaking tables immediately after hydrocyclones in a generalized flowsheet.

Vendors - Carpco, Inc.

Multi-Gravity Separators

The Mozley Multi-Gravity separator is an enhanced gravity device for the separation of fine (dense) particles down to one micron in size. The principle of the Multi-Gravity Separator may be explained by considering the shaking action of a shaking-table in cylindrical form. The rotating action of the drum provides a high "g" force which pins the heavy particles to the drum surface to be removed by the drum scrapers. The basic variables in operation of Multi-G Separator are stroke frequency, rotational speed, surface profile on the inside of the drum and addition of wash water. The Multi-Gravity Separator may be used for removal of fine dense contaminated particles from the silt or fines fraction (< 75 microns) where other more common gravity separation techniques are ineffective.

Dense Media Separation

The most common means of making a dense media separation is to use a suspension of fine, heavy particles in water or dense salt solution as a pseudo fluid. The use of this heavy medium at a selected density (specific gravity up to 3.0) will allow the separation of different density materials. Typically, a heavy medium suspension is prepared using very fine ferrous media (< 65 mesh) suspended in water. The fine magnetic media can be recycled from the heavy media suspension by magnetic separators. The basic features of this technology are (1) ability to make sharp separations in the specific gravity range 1.25 to 3.8, (2) ability to make rapid changes in the suspension specific gravity to meet changing feed characteristics, (3) ability to remove the sink product continuously, (4) ability to treat a wide range of sizes, (5) ability to start-up and shutdown the operation quickly with minimum loss of separation efficiency, (6) ease of recovery of medium from the separated products with relatively low media losses, (7) modest medium cost, (8) low operating and maintenance cost, and (9) large capacity units occupying relatively small floor space. Dense media separation may be used for separation of contaminant material from coarse soil fraction (> 2 mm). The contaminant material must have a higher density as compared to native gravel. Significant quantities (in excess of a couple thousand tons) of coarse soil material to be separated are required in order for this technique to be considered for implementation on a project.

Pinched Sluice

The pinched sluice, or sluice box, is essentially an inclined trough through which feed is washed after large stones have been removed by means of a grizzly or trommel. Riffles are placed in the bottom to create bed turbulence, establish a hindered settling zone, and retain heavy minerals and particulate metals (e.g. lead shot, metallurgical slag) or metals associated with heavy minerals. Variables in the use of sluice boxes are width, length, and slope, selected principally by the character of the material to be concentrated. Coarse and very high specific density particles (e.g., lead) settle quickly and require a short length. Slope must be adequate to transport the pebbles and also prevent sand packing within the riffles. Common slope is about ½ inch per ft (1.27 cm per 0.3048 m) of length. The total width may be 4 to 6 feet (1.22 to 1.83 m) and total length up to 120 feet (36.58 m). Removal of dense material (concentrate) takes place every 7 to 10 days. The sluice box may be used to remove metals occurring in particulate form or metals associated with heavy minerals. The sluice box may be considered for remedial projects with a large volume of materials to be processed in which coarse predominates (70% of the particles to be removed are coarser than 30 mesh).

Liquid/Solid Separations

Settling Basins/Clarifiers/Lamella Separators

Solids clarification is a process that separates fine solids from a slurry stream producing a thickened sludge and a clarified liquid. There are many types of process equipment to accomplish the separation including circular tank clarifiers, rectangular tank clarifiers and lamella clarifiers. Some system variables that are related to solids clarification are solids concentration and particle size, liquid specific gravity and viscosity, density of the solids, flow rates and the desired clarity of the liquid. Solids clarification is used in soil remediation to separate fine solids, typically from a sand screw or hydrocyclone overflow. The solids from clarification can be dewatered as a sludge product or further processed by bioremediation or other techniques to remove a contaminant.

Sedimentation basins, a type of clarifier, are tanks installed either in or above ground for the purpose of making separations of solids and liquids. Sedimentation basins are commonly used in wastewater treatment applications for municipal and commercial customers. Sedimentation basins must be designed to introduce feed slurries in a uniform manner, achieving a quiescent period for durations adequate to allow solids to settle and thicken while removing the relatively solids-free water as an overflow. In remediation applications, sedimentation basins can be constructed from construction materials (concrete and steel) or from excavating and lining designated areas. Field expedient "swimming pool" tankage has been constructed for use in the sedimentation step for relatively low flows. For higher flows, such as those that might be encountered in a dredging operation, sedimentation basins have been contoured or excavated into existing site profiles to provide this solids-liquid separation facility.

The lamella clarifier (Figure 2-10) is a tilted stacked plate clarifier used primarily to remove solids from a clay slurry. The tilted plate design provides a large effective settling area with a small footprint. A lamella with a 20 ft by 12 ft (6.10 m by 3.66 m) footprint can have an equivalent effective settling area of a 35-ft (10.67 m) diameter circular clarifier. Typically, a flocculator and flash mixer are provided with the lamella clarifier. The design parameters include input flowrate and solids content, settling rate of the solids, and desired clarity of the overflow. The lamella clarifier is used to concentrate the fine solids slurry from less than 5% solids to a thickened sludge of 25% solids. The sludge is then further dewatered.

Figure 2-10. Two lamella clarifiers operating in parallel (provided courtesy of ARCADIS Geraghty-Miller).

Feed material specifications -

Specific gravity - Generally applicable.

Particle-size ranges - Particles reporting to the clarifier must be large enough to settle. For fine particulate this may require a flocculation step before the clarifier. Some clarifiers incorporate flocculation equipment prior to the settling chamber.

Capacity - Prefabricated lamella clarifier units are available with between 5 and 1500 gpm nominal capacity. Larger units and conventional clarifiers are site built.

Type - Conventional clarifiers are essentially large circular or rectangular settling basins with mechanical rakes to move sludge to a central discharge point. Lamella clarifiers collect sludge on vertically angled plates, resulting in dramatically reduced footprints.

Waste/product streams - Clarified liquid exits the top of the clarifier through an overflow launder. Sludge is discharged from the bottom of the clarifier. A sludge pump or an auger are sometimes used to transport the sludge. Sludge concentration is a function of the sludge properties and clarifier features, such as sludge residence time, geometry, and mechanical action.

Operating variables/parameters - Performance of the clarifier is generally dependent upon the flow rate and the settling velocity of the particulate. The settling velocity is greatly influenced by flocculation, by the amount and type of flocculant, and by the hydraulic forces during flocculation. In lamella clarifiers, the plates can often be removed to increase spacing between remaining plates to control re-entrainment, though this results in decreased collection area. Increased sludge residence times generally result in denser sludges. Sludge level may be controlled with a level controller to maintain appropriate residence times.

Size - Size is a function of expected flowrate and the settling velocity of the smallest particles. Sedimentation tank sizes for wastewater treatment typically range from 3- to 5-m (10- to 16-ft) depths with 3- to 60-m (10- to 200- ft) diameters for circular tanks and 15- to 90-m (50- to 300-ft) lengths by 3- to 24-m (10- to 80-ft) widths for rectangular tanks (Metcalf and Eddy 1979). Prefabricated lamella clarifiers are available as small as 7' high, 7' long and 3' wide (2 m x 2 m x 1 m) .

General comments - Performance of a clarifier is dependent on both the settling characteristics of the solids and on the flow patterns within the clarifier. Settling characteristics of the slurry must generally be evaluated by lab tests to establish settling time and sludge consolidation. In lamella clarifiers, the settled solids must be able to flow down the incline of the plates. Bypassing and re-entrainment must generally be minimized in clarifier design. In addition, clarifiers are generally designed to minimize floc dispersion. It is important to consider that flocculation may cause bulking in which the volume of the solids is increased.

Flowsheets - Clarifiers produce a clarified liquid and a thickened sludge, typically from a fine feed slurry. Clarifiers would generally be encountered after hydrocyclones and immediately prior to final dewatering.

Vendors - Filtration/Treatment Systems, LTD
Carpco, Inc.
Graver Water Systems, Inc.
Westech Engineering, Inc.

Flotation

Soil remediation flotation is a process that separates a contaminated residual from the sand-sized soil fraction. Flotation may be used to classify solids having similar settling and density characteristics based on differing surface properties. The floated material can be contaminated organic mass or an undesired mineral. A froth flotation tank (Figure 2-11) is equipped with air diffusers and mixers. The sand is chemically and/or mechanically treated to cause the contaminant to become hydrophobic. The diffused air bubble can then "attach" itself to the particle and allow it to float. The soil feed rate, contamination concentration/particle size, chemical selection/dosing, air flow rate, and retention time are design and process variables that can affect flotation.

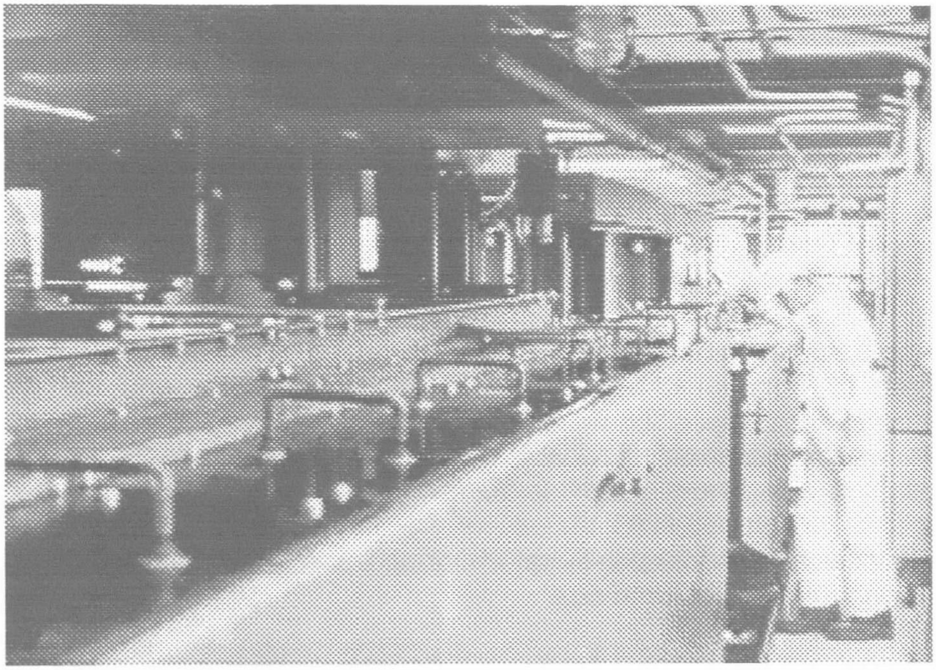


Figure 2-11. Froth flotation (mechanical) cells (provided courtesy of ARCADIS Geraghty-Miller).

Feed material specifications -

Specific gravity - Specific gravity of flotation is related to particle size of flotable fraction. Increasing specific gravity decreases the particle size that can be floated.

Solids content - Variable, typically dilute slurries about 20% solids.

Washwater - Flotation equipment may be equipped with washwater which generally sprays over the foam enhancing the separation.

Particle-size ranges - Flotation is not generally effective on fines (slimes) as fine particulate will tend to concentrate at the air water interface irrespective of the composition. Ores are often deslimed before beneficiation by flotation. Averett et al., as cited in Olin and Preston (1995), indicate maximum size separated is roughly 50 to 65 mesh.

Characteristics - Flotation equipment exploits differences in wetting properties of different solids. These differences are usually enhanced with chemicals. When a hydrophobic particle encounters a rising air bubble, it is caught on the surface of the bubble and entrained to the top of the tank. The rising bubbles form a froth above the water surface which contains the hydrophobic material. Since not every contaminated particle will be impacted and entrained by air, the cleaned product will typically have some residual contamination. In addition, the air will entrain to the froth some particles which would not be considered contaminants.

Type - There are two general types of froth flotation machines: mechanical cells and columns. Froth is swept off the mechanical cells with sweeping arms. Columns produce a variable depth froth that is allowed to overflow the vessel.

Waste/product streams - Hydrophobic particles tend to concentrate at the air water interface of rising bubbles and discharge in a froth. Hydrophilic particles tend to remain in the slurry and are discharged as the cleaned product. Reagent residuals may be found in both fractions, and toxicity of reagents is a consideration in selection.

Operating variables/parameters - Primary operating variables include selection and dose of chemicals, the amount of air introduced, mixing intensity, and the throughput. Slurry concentration and composition will also affect flotation effectiveness. In addition, some units allow for varying degrees of washwater for additional concentration of the hydrophobic particles. Columns generally provide more washing capability than mechanical cells.

Size - Mechanical cells found in literature range between 1 and 5300 ft^3 (0.28 and 1501 m^3). No data was found on column size.

Cost - capital and operating - As described in Western Mine Engineering (1996), individual self aerating flotation cell volumes range from 11 to 3000 cubic feet (0.31 to 85 m^3), requiring a corresponding floor space of 9 to 185 sq ft. (1 to 17 m^2). Flotation cells utilized in mineral circuits are normally installed in multiple banks, and this is assumed in the cost information given. Capital costs range from approximately $7,100 to $165,000 per cell, and operating costs from $0.30 to $13.20/hr. Motor and launders are additional. Unit costs range from approximately $50 to $660/cu ft, with unit cost decreasing with increasing size. Capital costs of standard flotation cells are marginally less than for self aerating, but require blowers in addition to motors and launders for operation. Operating costs are comparable. Other assumptions on which these cost ranges were based are contained in Western Mine Engineering (1996).

EPA estimates capital cost in 1998 dollars of a 91-tonnes/day froth flotation plant at $810,100 based on mineral industry experience. Operating costs are estimated at about $13/tonne.

General comments - Flotation is a complex process and should be considered in consultation with a vendor. It will only be applicable when the contaminant is not distributed over all particle-size ranges but rather, a discreet fraction of particles. In addition, the contaminant must be rendered more hydrophobic than the rest of the matrix, usually through the use of chemical additives since the contaminant is to be removed with the froth. Design and operation of the flotation cycle must proceed with due consideration to the acceptable amount of contaminant in the clean product. Pilot tests are required to evaluate the feasibility of flotation and for process design.

Flowsheets - Flotation is typically considered for use after the removal of fines in hydrocyclones for removal of organics from sand. The contaminated fraction would then typically be sent to clarification or dewatering.

Vendors - Dorr-Oliver Inc.
Osna Equipment
MIM Technologies GPO
EIMCO Process Equipment
Cominco Engineering Services Ltd
JETFLOTE Pty Limited

Solids Dewatering

Centrifuges

Centrifuges (Figure 2-12) are used to dewater or clarify slurries by enhancing sedimentation in rapidly rotating equipment. Operation of a centrifuge is not labor intensive; however, it does require a consistent feed source. Centrifuges are used for fines dewatering in soil remediation. They may be used to classify solids, analogous to hydroseparators, by adjusting operating parameters.

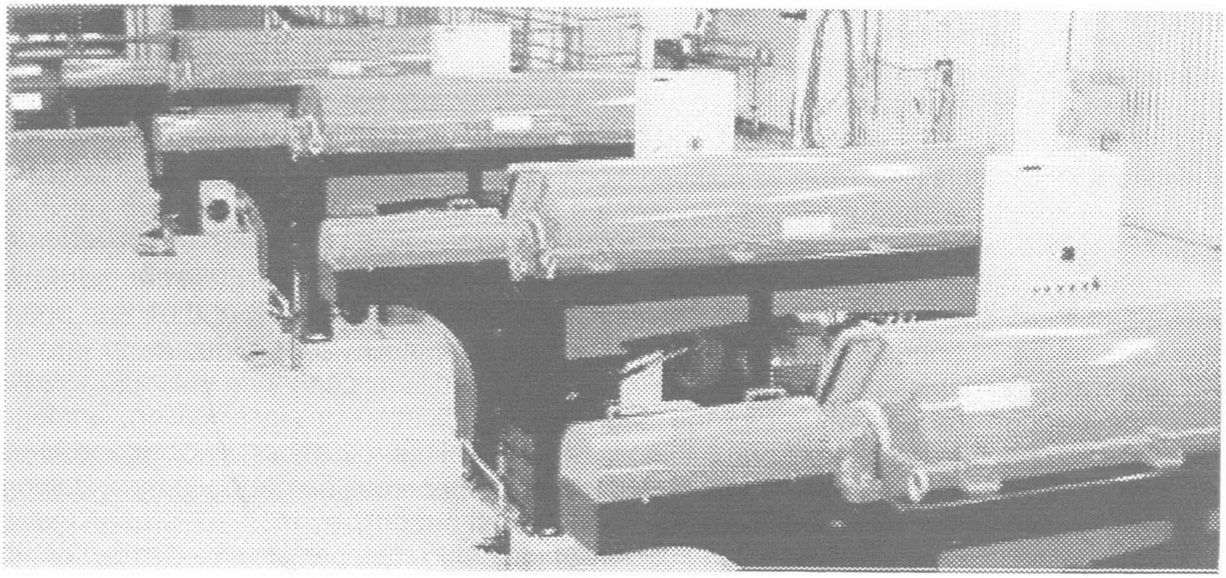


Figure 2-12. Four decanter centrifuges (provided courtesy of NOXON).

Feed material specifications -

Specific gravity - Specific gravity of particulate should be more dense than fluid in order to discharge in the underflow.

Solids content - No feed limitations were found in vendor literature. Svarovsky (1990) indicates decanter (scroll type) centrifuges are limited to 2 to 50 percent solids by volume, disk centrifuges are limited to 2 to 6 percent solids by volume, and tubular bowl centrifuges are limited to less than 1 % solids. The feed slurry can range from 1 to 70% solids, but must be uniform both in solids content and input rate for optimum performance.

Washwater - May generally be employed if required. Typical application of washwater in soil washing would occur when using centrifuge as a classifier.

Particle-size ranges - Centrifuges can clarify down into the sub-micron range. Maximum size should be discussed with the vendor.

Characteristics - Centrifuges have small footprints compared to settling basins or lamella clarifiers.

Capacity - Decanter centrifuges: 1 to 200 m^3 slurry/hr. Disk centrifuges: 2 to 225 m^3 slurry/hr. Drum centrifuges: 9 to 15 m^3 slurry/hr.

Type - There are two main types of centrifuges: sedimentation centrifuges and centrifugal filters. The vendor literature reviewed included three types of sedimentation centrifuges: decanter, disk, and tubular bowl centrifuges; no information was found on centrifugal filters in the collected literature. Decanter centrifuges have a horizontal drum with an independently rotating auger to move settled sludge to discharge. Decanter and disk centrifuges are primarily continuous devices while tubular bowl centrifuges are continuous, semi-continuous, or batch, depending on equipment design. A centrifugal filter is a solids/liquid separator that uses a bowl rotating at high speeds. The slurry is discharged into the bowl; the solids form a bed against the screen on the inner wall of the bowl; and the liquid passes through the solids and out the system. The solids either collect and are removed as a batch or are continuously removed while the drum is rotating.

Waste/product streams - Centrifuges produce an underflow in the form of a sludge or slurry containing the particulate clarified or classified from the feed. The overflow or centrate is the clean liquid that does not contain the most settleable particles.

Operating variables/parameters - In all continuous and semi-continuous centrifuges, the flow rate through the unit will affect the degree of clarification or classification, analogous to reducing the residence time in a settling basin. Machines are generally designed to operate at one drum or disk rotational frequency which may sometimes be changed by switching belts or gears. Settling velocity of particles is influenced not only by the acceleration induced by rotation, but also by size, shape, and density of the particulate, particle-size distribution, density and viscosity of the fluid, and solids content. Some units are available allowing flocculant addition; shear forces will generally disperse flocculated material entering the centrifuge, but flocculation may be performed within the acceleration field. Other important parameters for design and operation are desired cake dryness and filtrate clarity.

In continuous units, the rate of centrate (clarified liquid) discharge relative to feed may be adjusted to alter sludge concentration. In decanter centrifuges, the sludge concentration is affected by the speed of the rotating auger relative to the drum and the height of the dam controlling settling distance.

Size - Units in reviewed literature were within the following size ranges including drives and supports:

1300 to 6260 mm length x 620 to 1635 mm width x 800 to 3370 mm height (decanter)
1525 to 3200 mm length x 915 to 1855 mm width x 1675 to 2870 mm height (disk)
660 to 1270 mm length x 406 to 1270 mm width x 2032 to 2921 mm height (drum)

Cost – capital and operating - The centrifuges described in Western Mine Engineering (1996) appear to be primarily designed for coarse material dewatering. The typical feed size range referenced for the centrifuges given is 150 μm (100 mesh) to approximately 76 mm, at 30 to 40% moisture or less. Capacities range from 25 to 325 tons solids/hour, with capital costs ranging from approximately 76 to 142 thousand dollars and operating costs from approximately 4 to 7 dollars per hour. Cost per ton solids capacity per hour decreases with increasing capacity, ranging from a low of approximately $400 to a high of $3050. Other assumptions on which these cost ranges were based are contained in Western Mine Engineering (1996). Installed capital costs for solid bowl centrifuges for wastewater applications using 8 pounds of polymer per ton are estimated by EPA in 1998 dollars:

20 gpm	$253,000
100 gpm	$470,000
500 gpm	$1,019,000

O&M costs in 1998 dollars for two municipal wastewater treatment plants using solid bowl centrifuges were $31.97 and $95.12 per ton of dry solids.

General comments - Centrifuges enhance sedimentation by increasing the force acting on the particles through centrifugal acceleration; the magnitude of this force is often expressed in multiples of the acceleration of gravity or "g"s. The decanter centrifuges reviewed produce between nominally 1,900 and 5,600 g, and the disk centrifuges produce between nominally 3,900 and 10,000 g. Insufficient data were available to estimate the force produced by the tubular drum centrifuges. Centrifuges must be supplied stable support in accordance with vendor recommendations.

Flowsheets - Centrifuges may be considered for dewatering applications, typically applied to the fines fraction. Centrifuges would typically be placed after hydrocyclones in a soil treatment train.

Vendors - SANBORN Technologies
Noxon
Dorr-Oliver Inc.
Veronesi Separatori s.p.a.
Separators, Inc. (used/reconditioned)

Rotary Vacuum Filters

Two common types of rotary vacuum filters are disc and drum filters. Vacuum drum filtration is a continuous process in which a drum covered with filter media is partially submerged in a slurry, and a vacuum is applied to the inside of the drum, causing flow through the drum. Solids cake forms on the outside of the filter and is scraped off. The continuous filters can be divided into two basic categories: those forming their cake against gravity, normally called bottom feed, and those forming their cake with gravity, sometimes called top feeding or top loading. Rotary disc filters, as in Figure 2-13, consist of filter elements (discs) mounted vertically on a central shaft and connected to a vacuum filter valve. As the panels rotate, they go through similar pick-up and dewatering operations as on drum filters. At the discharge point, the cake removal is assisted by means of blades or knives. The cake is discharged by a scraper blade mounted parallel to the drum surface. Cake discharge is assisted by a blow back of compressed air through the geotextile. A rotary vacuum filter may be considered in soil remediation projects for dewatering of the sand and/or clay fraction. The use of a rotary drum filter for dewatering of the clay fraction will require the use of filtering aids, and its performance will be less efficient as compared to a belt filter press, plate and frame filter press or centrifuge.

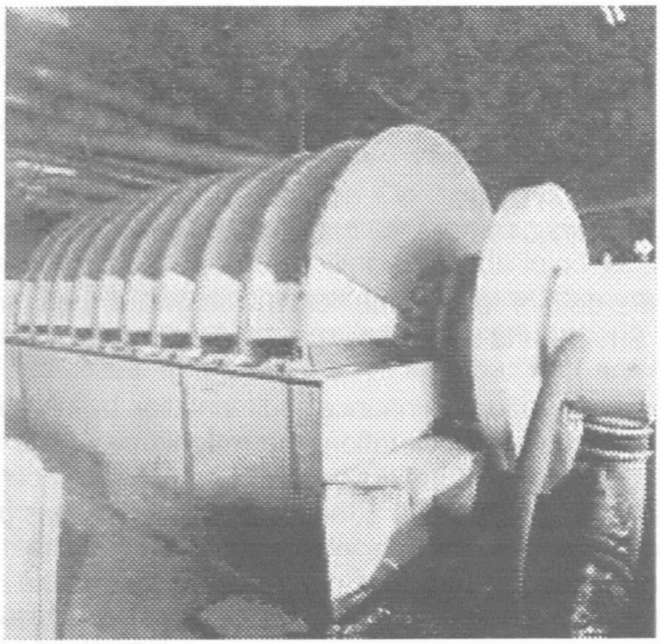


Figure 2-13. Rotary disc filter (Minerals Processing Technologies Inc.).

Feed material specifications -

Specific gravity - None specified.

Solids content - Any density that is pumpable and that can maintain particle suspension, economically the highest density practical. Filters almost always follow a thickener.

Washwater - None specified.

Particle-size ranges - Range zero to 20 mesh (Petersen Filters Corp.).

Capacity - Rotary vacuum filters are sized on filtration rates determined by laboratory and or pilot work and are reported in units of lbs/hr/ft^2. Horsepower ranges from 30 to 610 HP (Petersen Filters Corp.).

Waste/product streams - Cake, 15 to 30 percent moisture. Aqueous filtrate may contain fine suspended solids and dissolved contaminants.

Operating variables/parameters - Operating parameters are the use of filtering aids, percent vacuum, the geotextile, rotational speed, and thickness of filter cake.

Size - Drum filters 2 ft dia x 9 inches length (0.6096 m by 22.86 cm) (pilot) to 14 ft dia x 18 ft length (6 ft^2 to 792 ft^2 or 4.27 m to 5.49 m). Disc filters 4 ft (1.22 m) dia x 1 disc (pilot) to 12.5 ft (3.81 m) dia x 14 discs (25 ft^2 to 3080 ft^2) (Petersen Filters Corp.).

Cost - capital and operating - Maintenance costs vary widely with abrasiveness and corrosiveness of slurry. Primary operating cost is power. Capital cost ranges from approximately $25,085 to $501,709 US 1998 (including accessories, excluding installation) (Petersen Filters Corp.).

General comments - One technician can monitor several filters at once. Rotary vacuum filters have limited application in soil and sediment treatment despite their widespread use in industrial applications. It is generally not possible to justify the higher capital and operating costs for the improvement in cake properties for a low value product or waste stream.

Flowsheets - Rotary vacuum filters would typically be considered for final dewatering of fines after a thickener such as a lamella clarifier.

Vendors - Petersen Filters Corporation

Filter Presses

Filter presses express liquid by compressing filter cake against geotextile. The resulting cake acts like a filter media resulting in much finer retention than that resulting from the pore size of the filter. Two common types are belt filter presses and plate and frame presses.

The belt filter press is a continuous device that separates solids from liquids using three sequential processes: solids conditioning, gravity dewatering and pressure filtration. In solids conditioning, a polymer is mixed with the slurry to neutralize the electrical charges between the solids, thus allowing the solid particles to form small lumps called flocs. In gravity dewatering, the flocculated slurry is discharged onto a moving belt, and the free liquid is allowed to drain through the belt by gravity. In pressure filtration, the gravity dewatered sludge is pressed between two belts and is passed through a series of rollers with decreasing diameters. The decreasing diameters gradually increase the pressure exerted on the sludge, causing additional solids/liquid separation. The process variables affecting belt filter press design and performance are sludge characteristics, feed solids concentration, sludge age, sludge feed rate, and polymer dosing. The sludge characteristics determine the roller pressure required to obtain a dry filter cake. The feed solids concentration and feed rate determine the size of the belt press and will cause poor performance if the parameters are out of the design range.

The age of the sludge can cause poor filtration as flocs tend to break down with time. The belt filter press can be used in applications that require water removal from a fine soil fraction (< 200 microns).

A plate and frame filter press is a batch solids/liquid separator that uses a series of plates covered with a filter media. Plate and frame type filters use the pressure of the incoming slurry as the driving force for filtration. A slurry is pumped under pressure between the plates with the liquid passing through the filter media to the drain zone. When the filter pressure (typically 100 psig) is reached, the slurry pump is stopped; air is blown through the filter cake for drying; and the cake is dropped to a conveyor for removal. A cake of up to 8 inches (20.32 cm) thick can be produced, but for soil remediation applications a 1- to 3-inch (2.54 to 7.62 cm) thickness is usually desired. In most applications, the cake dryness can range between 40 to 65% solids. Parameters that affect the design and operation of a plate and frame filter are solids feed consistency, throughput rates, filterability of the solids and desired filter cake dryness. The plate and frame press is more labor intensive than other filter systems but can handle large fluctuations in feed slurry. The plate and frame filter can be used in most soil remediation applications for solids/liquid separation.

Feed material specifications -

Specific gravity - Not limited.

Solids content - Belt filter presses are applicable from 1 to 40% solids in the slurry feed (Olin and Preston 1995).

Washwater - Presses are generally equipped for washwater. However, washing will have limited application in soil/sediment remediation since the principal application is dewatering.

Particle-size ranges - WASTE-TECH indicates a maximum feed size of 100 microns for their Python Press.

Characteristics - The finer the material, the more quickly the filter will blind. Thus, clays are more problematic than coarse soils.

Capacity - The maximum hydraulic loading rate for belt filter presses tends to be around 50 gpm/m (11.4 m^3/hr/m), with belt widths ranging form 0.5 to 3 m (Viessman and Hammer 1993).

Type - Literature reviewed included belt filter presses and a Python Pinch Press. The mechanisms for compression vary from vendor to vendor as well as the maximum pressure exerted on the cake. The belt filter presses are continuous with moving cloth. The Python Pinch Press is semi-continuous with a stationary geotextile.

Waste/product streams - Filter presses produce a dry cake of soil/sediment solids. Expressed water and washwater must be disposed of or recycled and may contain fine solids and dissolved contaminants.

Operating variables/parameters - Operation of presses is quite dependent on the feed material. Material properties can often be amended by additives to affect porosity of the cake. The concentration and feedrate of the sludge are important input variables which affect the speed or cycle of the press and the pressure applied.

Size - The belt filter presses found in the vendor literature require a floor area of 151" x 126" to 259" x 165" (384 cm x 320 cm to 658 cm x 419 cm).

Cost - capital and operating - EPA estimates cost of a 40 to 50 gpm filter press at $343,500 and a 80 to 100 gpm filter press at $470,000 in 1998 dollars representing 1 and 2 meter widths, respectively. EPA's limited survey also indicated that contracted costs for filtering are typically in the range of $3 to $11 per hundred gallons of feed.

Cost information for belt filter presses in Western Mine Engineering (1996) are provided for units with belt widths ranging from 3.0 to 12.0 feet (0.914 to 3.658 m). Capital costs range from approximately $88,000 to $173,000, and operating costs from $3.05 to $6.10/hr. Estimated capacities given are for various coal circuits. Capacity ranges from 11 to 33 tons/hr for a circuit with feed material composed of 90% ash and over 80% less than 325 mesh. Unit capacity costs were roughly estimated from this information to range from $4570 to $9150/ton/hr. Other assumptions on which these cost ranges were based are contained in Western Mine Engineering (1996).

Plate and frame filter presses are described in terms of nominal size and corresponding filtration area and volume. The pressure filters described in Western Mine Engineering (1996) range from 30 sq ft to 798 sq ft (3 sq m to 74 sq m), and 1 to 30 cu ft filtration volume (0.028 to 0.850 cu m). Capital costs range from approximately $13,200 to $122,000, and operating costs from approximately $0.50 to $6.60/hr. Corresponding unit costs are then approximately $150 to $460/sq ft filtration area, with unit cost decreasing with increasing size. Other assumptions on which these cost ranges were based are contained in Western Mine Engineering (1996).

General comments - EPA (1994b) indicates that belt filter presses are generally the best suited devices for mobile treatment systems. Furthermore, contract filter services are generally available. Characterization tests are generally required to size the unit.

Flowsheets - Filter presses are generally the final stage of sludge dewatering.

Vendors - Waste-Tech Inc.
LAROX
Bethlehem Corporation

Screens

A solid/liquid separation differs from grading screening (solid/solid separation). Screens are used for dewatering for materials ranging from coarse down to about 0.1 mm but are most commonly applied to material below 1 mm (Osborne 1990). For material greater than 0.5 mm in diameter, effective drainage with no material losses through the screen can be achieved with screen apertures smaller than the smallest particle size. For finer materials, a range of particle sizes in the feed is necessary to facilitate formation of a filter bed. The coarser particles bridge the screen apertures, creating a cake, which retains fine particles while passing the water through the cake. In general, this requires an aperture size 40% larger than the mean particle size (Osborne 1990).

In cases where the specific gravity of the solid and liquid are similar, a fixed screen with low flow rate will perform better than a moving screen. This will not typically be the case in soil/sediment remediation operations. Efficiency of this operation will vary with screen type, material characteristics, and solid to liquid ratio. A typical dewatering configuration is a classifying cyclone followed by a sieve bend and a flat or inclined deck type screen. The function of the cyclone is to present a feed low enough in fluid volume to permit drainage by capillary action (Osborne 1990). In the case of less than 0.5 mm material, this translates to 30 to 40% fines.

Hydroseparators

Hydroseparators are devices that serve two purposes: clarification and separation. A simple hydroseparator is a vertical tank with a tapered bottom for solids removal and an overflow collector to collect the clarified liquid or the finer fraction from separation. To act as a clarifier the upward liquid velocity must be such that the smallest particle can settle against the current. A polymer can be used to increase the settling velocity and the thickening of the clarified solids. The use of hydroseparators for separation was previously discussed under hydraulic classifiers.

Screw Classifiers

A screw classifier is a separation device that consists of a sloped bottom tank with parallel sides equipped with one or two spirals mounted parallel to the tank bottom. The rotating spiral provides agitation for the pool and a conveyance mechanism to the sand discharge for the settled sand. Sands drain as they are conveyed. A separation of fine particulate is made by a constant agitation of the solids in the pool and the upflow of water to the overflow weirs. The oversize fraction (sand) with 80% solids can be obtained. Factors that affect the design and operation of the screw classifier are liquid viscosity, specific gravity, and flow rate of the liquid phase. Soil parameters that affect the design and operation of the unit are chemical and physical composition, density, feed rate, particle-size distribution, and desired separation size. In soil remediation applications the screw classifier can be used to remove up to a 100-mesh particle from the soil or dewater for further processing or as a plant discharge.

Auxiliary Equipment

This section will address types of auxiliary equipment that are required in virtually all fully functional soil washing plants. Other auxiliary elements of an operating soil washing facility such as pads, electrical service, security, road access and decontamination facilities are adequately covered in other facilities and environmental engineering references and thus will not be addressed in detail in this document. However, most of these elements will be necessary for the successful completion of the project and should be considered in any cost estimation or planning exercise.

Conveyors

A belt conveyor is a transport device consisting of a continuous rubber or fabric belt supported by pulley assemblies at each end and idlers and troughing rollers along the profile. The rollers, idlers, and pulleys are mounted in a support frame structure suitable to maintain belt alignment. Belt conveyors are used as an economic transport for soil through the plant. Belt conveyors in a soil washing plant can range from a short horizontal stationary conveyor used to move soil internally, to a radial stacker to pile and stage processed soils. Design criteria should include environment, belt type, slope, belt trough and width, belt speed and material transported. Weighing belts are also available.

Process Tanks

Soil washing plants require tanks for process storage of slurries, sludges and process water. These can be a simple horizontal or vertical cylindrical tank for process water or a sophisticated sludge consolidation/holding tank. Process tanks in a soil washing plant are used to isolate equipment and allow various unit operations to operate independently. An example can be the sludge press. In some operations, the sludge production is greater than the sludge dewatering system can process. Scheduling the dewatering operation to more operating hours than the main processing plant can accommodate the production rate differences. Buffering of process flows can also prevent upsets and pulsating discharge streams that affect downline equipment feed streams. Design parameters for process should include material stored, flow rates in and out, and desired holding volume and time.

Sumps and Pumps

Liquid sumps and pumps are needed in a soil washing process to transfer slurries in the plant. Sumps are usually open vessels used to collect flows from one or more sources and provide a flooded suction to pumps for proper operation. The sumps are typically slanted bottom tanks and are designed to channel any solids in the process stream to the inlet of the pump. Most pumps used in a soil washing plant are either centrifugal or positive displacement type. Centrifugal pumps are used to transfer slurries with low viscosities. Consolidated or thickened sludges require a positive displacement pump. Typical subtypes of this pump type are diaphram and screw pumps. The design criteria for pumps for soil washing include slurry characteristics, system piping requirements and required pressure or flow of the receiving equipment.

Controls

Process controls for a soil washing plant can be as sophisticated as a Programmable Logic Controller (PLC) monitoring and controlling all phases of the process to a simple manual valve control adjusting and maintaining tank levels. PLC systems can monitor and maintain tank levels, process flows, pressures, temperatures and make decisions based on input parameters. The drawback to this system is the cost, additional effort for process changes and maintenance of the sensors, controllers and hardware. Manual control plants are usually less complicated to operate, and the equipment can be easily modified, replaced or removed without any control changes. The manual control system is less costly than a PLC system but may cost more in the manpower needed to monitor and control the process. A plant design that relies on both manual and automatic controls along with sensors and alarms to aid in manual control is a compromise that usually is the best design for soil washing plants.

Weighing Devices

Weighing of the soil in a soil washing plant can easily be done by either of two methods. Hauling soil in trucks and weighing of each truck prior to placing soil in a feed staging area is used in some operations. This method can quantify the soil treated but cannot indicate plant feed rates for plant control. The preferred method for weighing material processed is using a conveyor belt weigh scale. This device mounts on a belt conveyor and measures the weight of load on a moving belt. The weight scale has the capability to display the feed rate in real time but also can integrate the feed rates for a total feed processed. These scales can be adjusted to deliver an accuracy of within 0.5%.

3 Treatment Trains and Cost Estimation

This chapter discusses how the unit processes discussed earlier can be combined to form an overall physical separation process. Factors that may affect performance, typical treatment trains (soil washing plants), and estimation of costs are addressed.

Factors Affecting Soil Washing Cost Effectiveness

The technical and economic viability of soil washing is quite varied depending on site-specific factors. There is no single "recipe" for application of soil washing, and effectiveness may depend on one or more factors. Some of the most significant are discussed below.

Type and Mechanism of Contamination

Contaminants distribute differently, depending upon the manner in which they are introduced to the soil or sediment. A firing range soil, for example, may have particulate lead throughout, as well as lead deposited by smearing and chemically sorbed metals solubilized by leaching. Although fines are typically considered to have the highest associated contaminant concentrations, sands may not be entirely clean in grossly contaminated environments or where the contaminants, such as oil and grease, are sticky or viscous. A review of site history is, therefore, essential before beginning any lab or field work with the site materials.

Volume of Material to be Processed

Because site preparation and mobilization/demobilization costs are relatively insensitive to the volume to be processed, low volume projects will reflect much higher unit costs than high volume projects.

Clay Content

Soil washing is generally only economical when clay and organic content is low. A significant portion of the cost attributable to clays is a result of increased dewatering costs. For sediment reclamation projects, where dewatering may be accomplished in lagoons rather than settlers or filter presses, this cost factor may be significantly reduced provided adequate storage area is available to meet the requirements of extended settling times. Clay content may result in diminished processing rates, however, with respect to separation and extraction processes.

Organic Content

Natural organic materials act as sinks for contamination. Organic materials are not confined to a single size range and may result in high contaminant concentrations in mineralogical fractions that would otherwise be relatively uncontaminated.

Preliminary Cost Analysis

The importance of conducting the preliminary feasibility evaluation in a manner that is representative of field operations cannot be overstressed. For example, wet sieving is commonly used for preliminary contaminant distribution studies. While the information obtained in this manner is useful for preliminary evaluation of process feasibility, the separation is not representative of what can be achieved in the field using, for example, hydrocyclones. A stepwise approach to feasibility evaluations, beginning with bench scale testing and progressing to pilot scale, is therefore advisable. Evaluating the material to be processed in a manner representative of what the process will "see" in the field is important. If materials are to be blended, they should be composited for feasibility evaluations as well. However, this requires advance planning of excavation operations; sufficient staging area, and blending equipment. Compositing must be approached very carefully. If no blending is planned, then each matrix must be separately evaluated.

Degree of Heterogeneity of Soil/Sediment Deposit

Small scale testing, such as bench and pilot scale feasibility tests, may not fully address the effects of heterogeneity within the soil/sediment deposit to be processed. In some cases, additional pilot testing may be required, even after operations have progressed to full scale, to assess different matrices encountered during excavation. Blending operations may be required, as previously mentioned.

Treatment Trains

Due to the complexity of soil contamination, physical separation treatment trains may be equally complex. In Chapter 1, Figure 1-1 gives an overview of how physical separation equipment can be put together to create a physical separation treatment train. Three examples of realistic configurations of increasing complexity are discussed below.

Treatment Train 1, Simple Physical Separation

One of the simplest treatment train configurations is shown in Figure 3-1. This treatment train is designed to make a simple physical separation of the field oversize, the process oversize, and the sand and fines. The configuration is appropriate for situations where there is a desire to minimize the volume of material stored in a confined disposal facility (CDF) and where there may be an opportunity to recycle oversize materials and sand. This configuration assumes that the oversize and sand products meet the specified treatment standards without treatment. The quality of the products must be confirmed in treatability studies performed on actual feed materials.

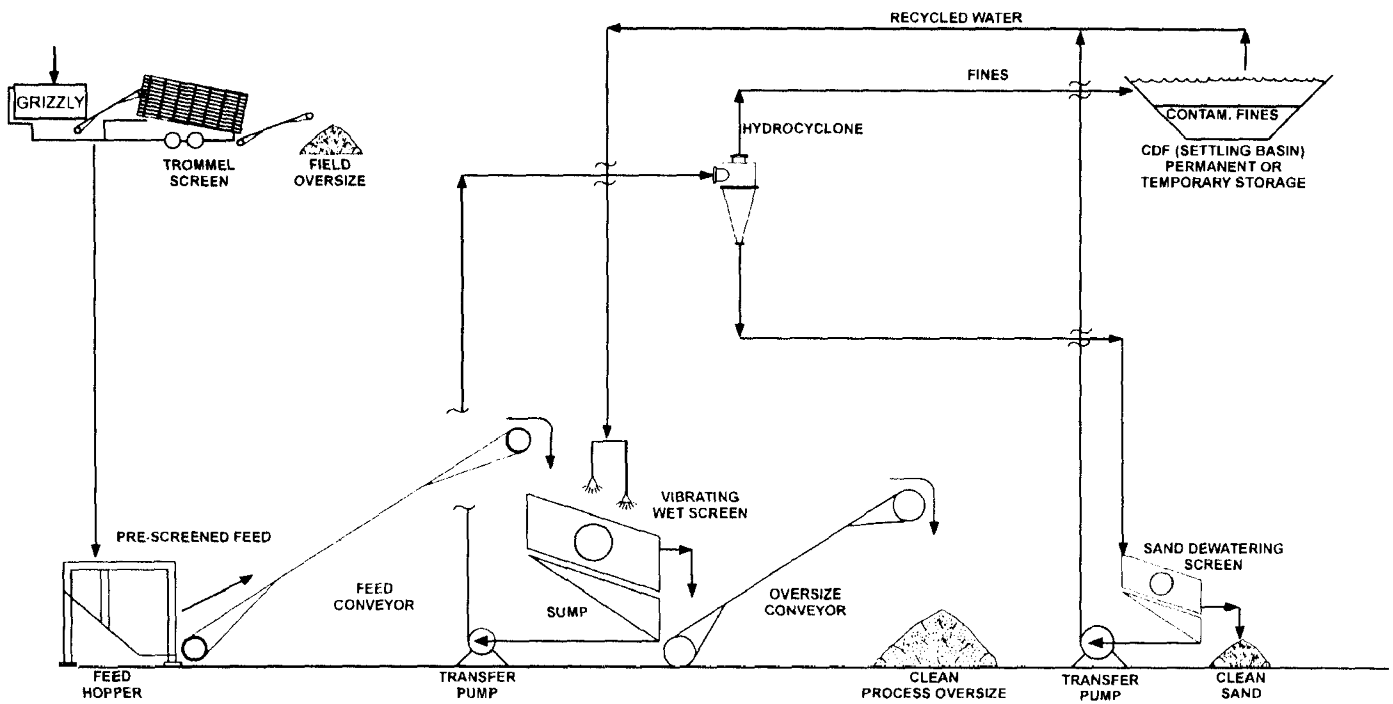


Figure 3-1. Treatment Train 1, simple physical separation. (same as figure 1-3)

Treatment Train 2, Physical Separation

Treatment Train 2 (Figure 3-2) is similar to Treatment Train 1 with the exception that a density separation step has been added on the sand stream after hydrocyclone separation. In this case, the feed material has a contaminant in the sand stream that exhibits physical density differences from the sand and can be removed by the use of a spiral concentrator or mineral jig. This contaminant may be either more or less dense than the sand and is often represented by lead (as a heavy) or naturally occurring organic matter (as a light). Oversize products are similarly removed, and it is the intention of this flowsheet to reuse or recycle the recovered products meeting the treatment standards. Contaminated fines are returned for storage to the CDF.

Treatment Train 3, Treatment with Fines Extraction

In Figure 3-3, all of the features of Treatment Train 2 are included. Oversize products are removed; separations of the sand and fines are performed with the hydrocyclone; and the sand is density separated. In this case, a decision has been made to avoid the use of the CDF and further treat the sand and fines. Also, the sand usually needs additional treatment to achieve the required standards. Froth flotation has been added to function in conjunction with surfactants to remove residual contaminants from the sand. The froth concentrate is recombined with the fines. The fines are thickened in a lamella clarifier and are further treated with wet oxidation to destroy remaining organic contaminants. A final wet oxidation step is included as an example of the way nonphysical technologies can be integrated into soil washing plants.

Case Studies

Some actual treatment trains with varying levels of complexity can be found in the case studies presented in Chapter 4.

Cost Estimating

Estimating treatment costs is perhaps the most difficult task facing the planner and design engineer. Because physical separation is still a young technology as a soil or sediment remediation technique and because costs are always highly site specific, dependable cost numbers are the most difficult information to obtain. Equipment vendors are often reluctant to provide generic equipment cost ranges, and few are published. Planning-level cost estimates can be approached, however, in a number of different ways so that the economics of separation technologies can be compared to other treatment or management alternatives. A tiered approach is recommended, beginning with the least labor intensive estimating method and progressing to the most detailed and certain methods, if it appears to be justified. Four approaches in increasing order of effort and expected reliability follow:

- Extrapolating unit costs ($/unit volume soil/sediment) from case studies of other projects.

- Application of various multipliers to equipment cost estimates to obtain rough total project costs.

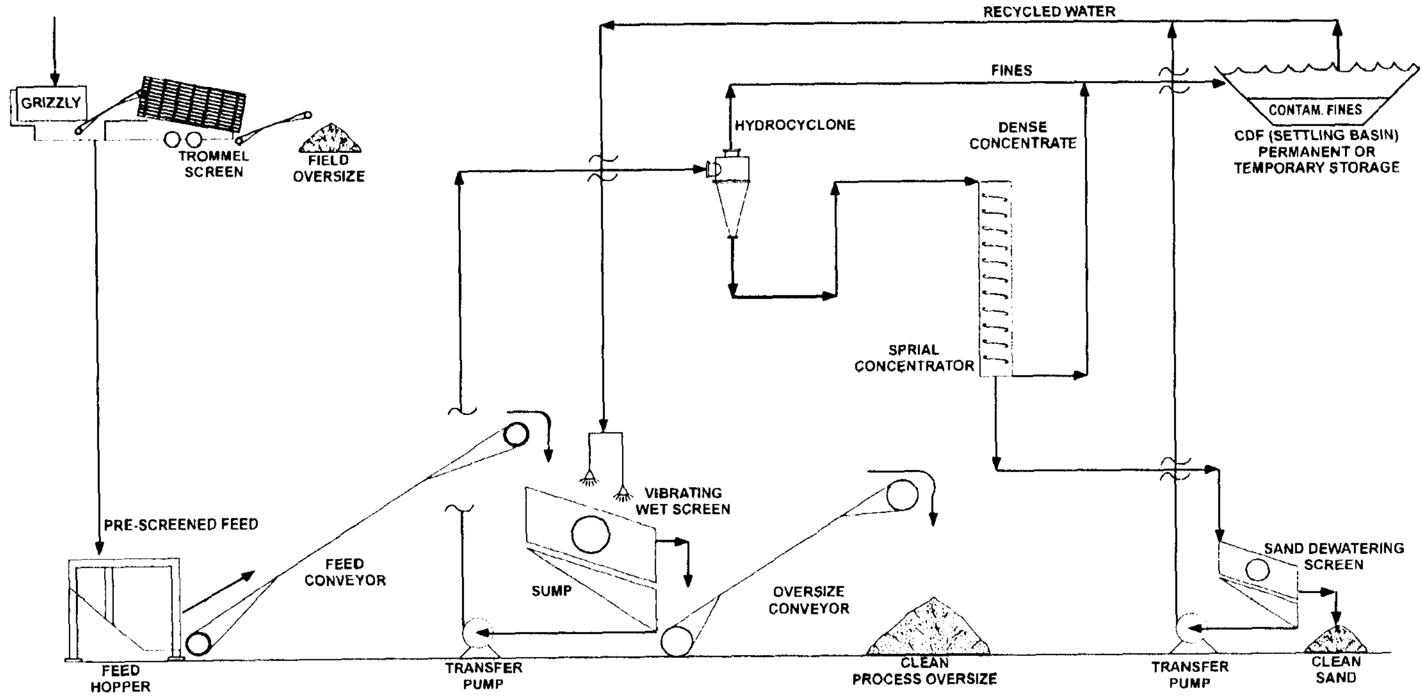


Figure 3-2. Treatment Train 2, physical separation.

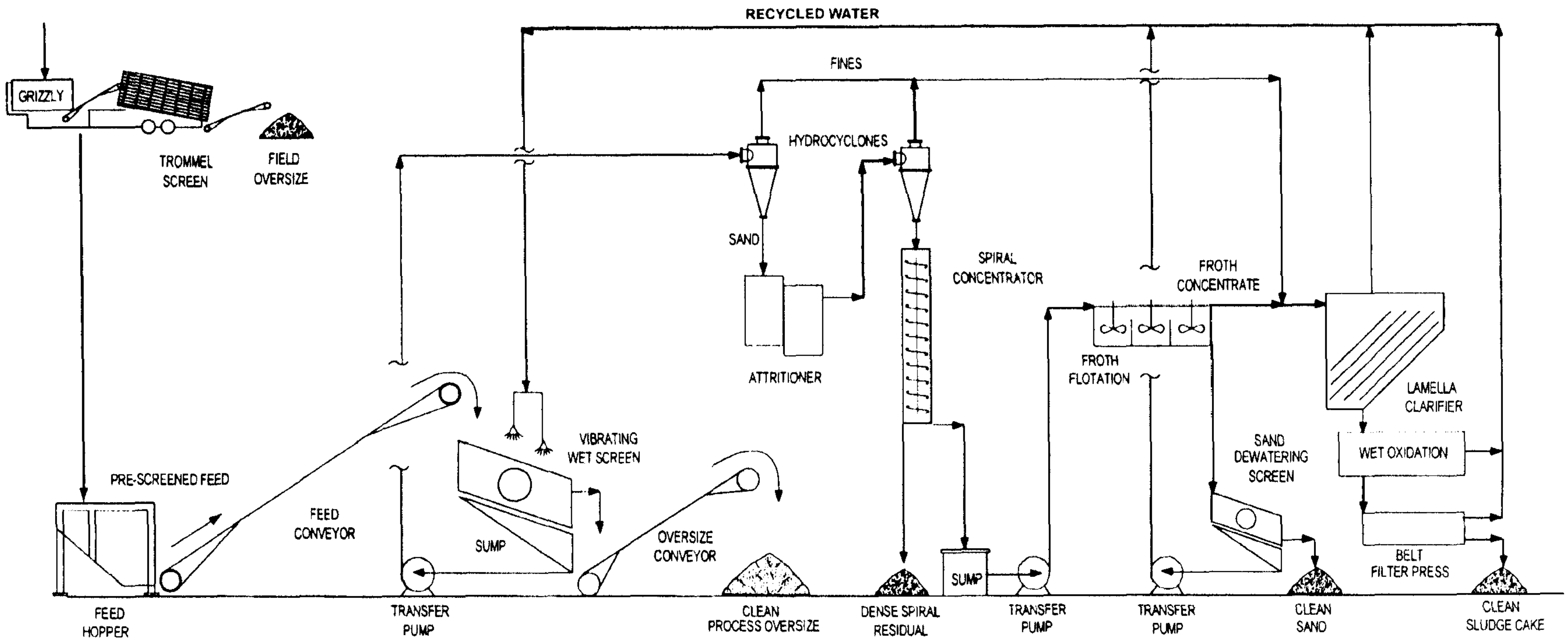


Figure 3-3. Treatment Train 3, treatment with fines extraction.

- Extensive, design level, estimation of project requirements.
- A&E proposals.

Case Studies as a Cost Estimating Tool

A range of unit costs for physical separation can be obtained from a review of case studies. Care must be exercised to determine what is included in reported costs (site preparation, mobilization-demobilization, equipment purchase and operation versus fully contracted operations, processing volume, and site specific conditions that may have influenced costs) to arrive at meaningful unit costs that can be applied to other sites. The value of this as a first step in developing cost estimates is obtaining an indication for the sensitivity of physical separation costs to processing volume, technical complexity, and site considerations. Because of the extreme variability that is normally encountered in reported unit treatment costs, this is typically not a definitive cost estimating tool, however.

Equipment Cost Multipliers for Total Project Cost Estimation

Equipment capital and operating costs can be developed from cost estimating guides (e.g., Western Mine Engineering 1996) or from vendor specifications and quotes. In both cases, at least a preliminary treatment train must be developed identifying major pieces of equipment. Developing this treatment train, in turn, requires at least preliminary site and material data acquisition efforts. Costs developed based on equipment recommendations and estimates obtained from vendors for site specific requirements will undoubtedly have a higher level of certainty than costs developed from generic data. Vendors may require more extensive site data; however, the information gathering effort is offset by shifting the burden of specifying and costing the equipment to the vendor.

Once costs for all the major equipment have been estimated, estimating the total capital cost of the project (including design, engineering, installation, and ancillary equipment of the entire facility) by multiplying this base cost by a factor typical for the industry is often helpful. Cost of installation is often proportional to the cost of the major equipment. The factor estimates costs such as piping, foundations, painting, etc. typical to all installations. Factor estimates are available for the source of expense (Perry 1984) from which components could be increased or eliminated depending on site complexity or accounting (e.g., not including corps labor in costs). Care should be taken that the equipment costs are all estimated on the same basis so inflation and delivery are taken into account. Without a typical factor for remediation or mining plants, a factor of 4.1 (Perry 1984) may be a reasonable approximation for physical separation.

By applying this methodology, the remediation engineer can quickly evaluate the tradeoffs in capital expenditure and O&M costs with plant throughput. In addition, a reasonable equipment recovery value for short-term projects could be incorporated in economic evaluation. This may be useful to evaluate equipment which may be used on subsequent projects or to approximate an anticipated use fee if a vendor is to perform the project.

Extensive, Design Level Estimation

Extensive, design-level estimation of site preparation requirements, mobilization-demobilization and operating schedules, manpower, supplies and materials requirements, and capital and operating cost estimates for individual pieces of equipment is likely to give more precise results than the previous two estimating methods and is ultimately necessary. However, itemized estimation may require a time and manpower investment that may not be justifiable in early planning-level cost estimating efforts. The treatment train and material take-offs must be more fully developed. Even then, there is an inherent level of uncertainty in all cost estimates, no matter how rigorously prepared because site conditions may necessitate process or schedule changes and impact costs. The technical and field expertise of the estimator will also be a factor. The level of effort justified for initial planning-level comparisons then must be measured against the additional accuracy that can be expected in light of these unknowns. Itemized cost estimating also parallels the effort that A&E firms preparing project proposals will invest and may be duplicative and premature for planning-level comparison of alternatives.

Itemized cost estimates for the three treatment train scenarios (Figures 3-1 through 3-3) are presented in Table 3-1. The details of these cost calculations are shown in Appendix A.

A&E Proposals

Requests for proposals (RFPs) from reputable A&E firms with experience in physical separation will likely provide the closest estimate of actual project costs. However, because of the influence of site-specific conditions on treatment costs, contractors may not be willing to provide a fixed fee bid. The planners should develop some preliminary cost estimates as a reference so that bids which clearly underestimate the complexity and difficulty of the proposed project can be identified, and excessive change orders and cost overruns can be avoided. While RFPs will ultimately provide the most precise estimate of project costs, they represent a significant time investment on the part of the preparer, require completion of treatability studies for determination of design requirements, and are typically not obtained until there is relative certainty that the project will proceed to bid.

Table 3-1. Itemized Cost Estimates of Three Treatment Train Scenarios.

Cost Component	Scenario 1	Scenario 2	Scenario 3
Mobilization, Site Preparation, Demobilization	140,000	140,000	315,000
Plant Depreciation	120,000	240,000	510,000
Plant Labor	292,775	425,010	623,364
Travel and Per Diem	108,714	108,714	217,429
Utilities	90,000	90,000	180,000
Plant Consumables	114,092	174,092	474,092
Maintenance	120,000	120,000	240,000
Process Sampling	30,000	30,000	50,000
Project Administration	50,000	50,000	50,000
Contractor Overhead and Profit	284,419	362,184	700,115
Total	1,350,000	1,740,000	3,360,000
1998 Unit Price, $/ton	22.50	29.00	56.00

Assumptions:

Processing rate is 25 tons per hour
Feed soils or sediments are delivered to the processing plant by others.
No residual disposal is provided.
Processing plant is owned by the contractor and depreciated.
A 50,000 cubic yard project is the baseline.

4 Case Studies

This chapter presents summaries of several case studies where soil separation has been used for treatment of a variety of contaminated soils and sediments. Case studies are briefly summarized to facilitate identification of important correlations, such as volume, treatment objectives, complexity of treatment trains and cost. The objective is to provide a general background in common practice, representative treatment trains, potential limitations and problems with the technology, as well as documented successes. The following case studies are taken from US Army Corps of Engineers sites, ARCADIS Geraghty & Miller experience, and literature.

US Army Corps of Engineers

Twin Cities Army Ammunition Plant, Minneapolis, MN

Site History: World War II - present: Munitions production facility (no longer active)
Site F: former open burning area
Unspecified date: Classified as Minnesota's #1 Superfund Site

Contaminants and Treatment Objectives:

Analyte	Contaminant Levels	Treatment Objectives
Lead	1600 ppm avg 86,000 ppm max	40 ppm initially 175 ppm negotiated 300 ppm enforceable standard
Antimony	Not given	4 ppm
Cadmium	Not given	4 ppm
Chromium	Not given	100 ppm
Copper	Not given	80 ppm
Mercury	Not given	0.3 ppm
Nickel	Not given	45 ppm
Silver	Not given	5 ppm

Project Volume: Not given
6-15 ton per hour processing rate

Site Ownership: Department of Defense - Army
Federal Cartridge Co. - Operating Contractor

Consultants/Contractors: Bescorp
COGNIS
Wenck Associates, Keith W. Benker, P.E., project manager

Project Status & Outcome: Completed.

Most soil returned to site following treatment. One year before closure, contractors were estimating that 95% of the soil would pass the enforceable lead standard of 300 ppm. Remaining soil was to be landfilled. The treatment was less successful for the other metals and could not achieve the stringent background-based cleanup goals. Cleanup levels based on health risk, roughly 10 to 100 times higher than objectives, are potentially achievable.

Design processing rate was 20 tons per hour. Higher contaminant concentrations and clay content were encountered at the site. At the time of publication (Benker 1994), soil was being processed at 6 to 15 tons per hour.

Treatment Train: Bulk material entered a hopper and then a trommel. The oversize material was then handpicked for munitions or cartridges. The undersize went through sand-fines separation. The fines were then extracted (Terramet, a proprietary soil leaching process developed by COGNIS). The sand went through a spiral classifier and jig for metal fragment removal before counter current extraction. The cleaned material was then dewatered and re-blended. Spent leachate from the counter current extraction went through an electrochemical reduction system where the metals were precipitated into a cake, and the cleaned leachate was recycled.

Costs: None given

Information Source(s): Benker 1994.

USAE District, Jacksonville, Canaveral Harbor, FL

Site History: Not given.

Contaminants and Treatment Objectives: The US Army Corps of Engineers, Jacksonville District, was requested by the Canaveral Port Authority (CPA) to assess hydrocyclone technology for possible use in the maintenance dredging/disposal operation at Canaveral Harbor. According to the State of Florida beach quality sand was defined as containing less than 10 percent fine-grained materials. (Fine-grained materials are typically considered to be less than 63 to 75 microns, depending upon the classification system, although the Florida definition of fines was not cited.) The project proposed to integrate dredging with processing.

Analyte	Contaminant Levels	Treatment Objectives
Uncontaminated materials	N/A	< 10% fines

Project Volume: Not given.

Site Ownership: Not given.

Consultants/Contractors: Not given.

Project Status: January 1994 - Workshop involving Port Dredging industry, hydrocyclone industry, State and US Army Corps of Engineers representatives. Concern over interdependence of processing rates between the dredging operation and the processing operation and the present availability of lower cost disposal options prevented progression beyond feasibility planning for a pilot study.

Treatment Train: Proposed maximum density separators (MDS) - hydrocyclone with vacuum applied to overflow.

Costs: Not given.

Comments: Not given.

Information Source(s): Heibel et al. 1994

USAE District, Jacksonville, Miami River, FL

Site History: Not given.

Contaminants and Treatment Objectives: This was a small pilot run to determine the feasibility of partitioning sand and silt and to determine the characteristics of the sand. Samples were prescreened through a 3/8-inch screen and then fractionated using #100, 200, and 325 mesh screens. Grain size analysis indicated 19 to 52% sand and highest contaminant levels in the less than 200 mesh (75 micron) fraction.

Analyte	Contaminant Levels	Treatment Objectives
Heavy metals	Not given	Not given

Project Volume: Five - 30 gallon samples were tested.

Site Ownership: Not given.

Consultants/Contractors: METRPO, Inc., Bartow, FL - MDS separation testing.

Project Status: March 1997 - Bottom samples collected from various locations in the project area.

April 1997 - Samples were processed through a 6-inch (15-cm) MDS test stand, for a 200 mesh split (75 microns). Two to three 5-gallon drums of sample were mixed with approximately 100 gallons of untreated groundwater (11 to 15% solids). Underflow percent solids were generally 70 to 75%. Visually, the sands appeared clean. Both underflow (sand) and overflow (fines) samples underwent chemical and bioassay sampling. The overflow demonstrated two distinct phases: a high organic settlable material and non-settlable colloidal phase.

Sediment bioassays indicated that the sand was non-toxic, suitable for commercial grade sand. Use as beach material seems unlikely because of negative public perception. Supernatant was also non-toxic. The settled organic rich overflow was thought to be suitable for use as a sealing cap between layers at an upland confined landfill. Flocculation studies of the colloidal suspension indicated that rapid settling can be achieved and a clear, non-toxic supernatant produced, with the use of cationic polymers.

Pilot project - Planned.

Treatment Train: Proposed Pilot: Water jet and eductor pump with a grizzly screen to slurry and remove clamshell dredged sediments from a scow into a feed weir. Slurry would be processed through a 12-inch (30-cm) MDS stand with 550 gpm capacity at 20 percent solids. Predicted feed split at 50 gpm underflow, 70% solids and 500 gpm overflow at 11.5 % solids. Storage capacity requirements: 150 cy/hr or 2500 cy/16 hr day. A 0.25-acre disposal area six feet in depth, or 3000 cy scow, was proposed. Assumptions: 1 to 2 days settling time for organic solids, one day drainage and excavation time, one day processing through hydrocyclone, and a four bin disposal site, or four scows to permit continuous operation.

Costs: Not given.

Comments: The proposed Miami River pilot demonstration project has not been implemented because of the stringent sediment disposal constraints imposed by Dade County, Department of Environmental Resources Management (DERM). DERM's criteria are sometimes greater than two orders of magnitude more stringent than the standard EPA TCLP criteria. Although well below national TCLP criteria, the MDS-produced underflow sand did not meet the stringent DERM criteria for clean fill, and the overflow material did not meet DERM's landfill disposal criteria.

Information Source(s): Personal Communication: Mr. Mitch A. Granat, USAE District, Jacksonville, telephone conversation, August 1997 and e-mail communication, October 1998.

USAE District, Jacksonville, Fort Myers, FL

Site History: Not given.

Contaminants and Treatment Objectives: Clean, non-toxic sediments were used in a demonstration on 21-23 September 1998.

Analyte	Contaminant Levels	Treatment Objectives
Heavy metals	Clean	Not given

Project Volume: Not given.

Site Ownership: Not given.

Consultants/Contractors: Not given.

Project Status: Grain size and TCLP results are awaited. Pending procurement of a Water Quality Certificate from the State, production application using a 14-inch (36-cm) pipeline dredge and several 24-inch (61-cm) MDSs to dredge and process Ft. Myers maintenance dredged material is planned for spring of 1999.

Treatment Train: A six-inch (15-cm) slurry pump was used to pump in-situ slurry from adjacent to the Ft. Myers Beach Navigation Channel through a ½-inch (1.27-cm) grizzly into a 30 second tank feeding a 12-inch (30-cm) maximum density hydrocyclone.

Costs: Not given.

Comments: Total processing time was about 4 hours, some of which was pumping straight water. A pile of beach sand was produced and an almost filled retention site of about 30 by 70 ft (9 by 21 m).

Information Source(s): Personal Communication: Mr. Mitch A. Granat, USAE District, Jacksonville, October 1998.

USAE District, Detroit, Erie Pier Demonstration, MN

Site History:

- Duluth-Superior Harbor designated by the International Joint Commission as one of 43 Areas of Concern in the Great Lakes Basin due partially to contaminated sediments.
- Erie Pier handles > 76,000 m^3 of dredged material annually from Duluth-Superior Harbor.
- 1988 - dredged material washing procedure implemented.

Contaminants and Treatment Objectives: Soil washing was implemented on a trial basis to evaluate the feasibility of recovering sand for use as construction fill, thus reducing the volume of dredged material to be stored in the CDF.

Analyte	Dredged Material (avg.)	Washed Material (avg.)
Total solids, %	55.0	86.0
Silts/clays (passing No. 200 sieve), %	69.0	14.0
Total volatile solids, %	2.81	0.58
PCBs, mg/kg	0.10	< 0.02
Oil & grease, mg/kg	762	263
Total organic carbon, mg/kg	19,300	2,206
Arsenic, mg/kg	1.64	0.866
Cadmium, mg/kg	2.98	1.10
Chromium, mg/kg	31.7	10.3
Copper, mg/kg	32.6	22.0
Iron, mg/kg	22,200	7,220
Lead, mg/kg	65.2	17.4
Mercury, mg/kg	0.108	0.0136
Nickel, mg/kg	20.4	7.62
Zinc, mg/kg	84.8	20.8
Cyanide, mg/kg	0.098	0.06
Ammonia nitrogen, mg/kg	278	164

Project Volume: Not given.

Site Ownership: US Army Engineer District, Detroit.

Consultants/Contractors: Not given.

Project Status: Testing demonstrated the washed sand to be suitable for use as construction fill. As a result, the washed material is no longer required to undergo extensive testing before removal from the CDF. It must only meet the criterion for use as fill (< 15% fines). Soil washing is now incorporated as a contractual requirement and is performed annually. An average of 20 to 25% of the Erie Pier dredged material is removed each year and used as construction fill in projects near Duluth-Superior Harbor.

Treatment Train: Dredged material was off-loaded in a catchment area. Water from the CDF pond was pumped over the dredged material to create a slurry that was allowed to flow down a sluiceway constructed from previously dredged material. Heavy particles settled out in the sluiceway, and the fines were carried to the ponded area. The washed sand was recovered from the sluiceway with a front-end loader.

Costs: Not given.

Comments: Not given.

Information Source(s): Olin and Bowman 1996.

USAE District, Detroit, Saginaw River Pilot Scale Demonstration, MI

Site History:

- Navigational reach of Saginaw River, and Saginaw Bay. Sediments were freshly dredged for the pilot and stockpiled in the Saginaw Bay confined disposal facility.
- 1988 Michigan Department of Natural Resources (MDNR) Remedial Action Plan
- Designated as one of 43 Great Lakes Areas of Concern (AOC) (1987 amendments to the Clean Water Act, Section 118(c)(3) & Great Lakes Water Quality Board of the International Joint Commission).

Contaminants and Treatment Objectives: According to EPA (USEPA 1994a), most contamination is a result of agricultural run-off and municipal and industrial discharges in Flint, Saginaw, Bay City and Midland, Michigan. Sediments are considered contaminated but not toxic or hazardous as defined by regulatory definitions of the Toxic Substance Control Act (TSCA) or the Resource Conservation and Recovery Act (RCRA). A wide variety of contaminants are found in these sediments, including polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dichloro-diphenyl-trichloro-ethane (DDT), polybrominated biphenyls (PBB), poly-chloro dioxins, and a variety of metals. PCBs in the navigation channel are typically in the < 0.1 to 5 mg/kg range. Some "hot spots" have PCBs exceeding 500 mg/kg (MDNR 1988). Chemical analysis of material used as feed material for the pilot is given in the following table (USEPA 1994a).

Analyte	Contaminant Levels (mean)	Separated Sand (mean)	Separated Fines (mean)	Separated Organics (mean)
PCB	1182 ng/g	214 ng/g	2156 ng/g	3860 ng/g
Cd	0.50 mg/g	0.06 mg/g	1.64 mg/g	1.16 mg/g
Cr	23.9 mg/g	10.8 mg/g	88 1 mg/g	33.6 mg/g
Cu	17.9 mg/g	6.3 mg/g	63.6 mg/g	40.8 mg/g
Hg	0.061 mg/g	0.008 mg/g	0.199 mg/g	0.210 mg/g
Ni	11.5 mg/g	3.3 mg/g	43.2 mg/g	36.4 mg/g
Pb	20.4 mg/g	7.42 mg/g	70.8 mg/g	41.4 mg/g
Zn	96.1 mg/g	17.7 mg/g	431 mg/g	191.4 mg/g

Project Volume: Approximately 800 cubic yards dredged.

Site Ownership: Not given.

Consultants/Contractors: Bergmann USA
Thermo Analytical Inc./Environmental Research Group

Project Status:

Sep 16 - Oct 1, 1991: Site Preparation
Oct 3-9, 1991, May 2-8, 1992: Dredging and Transport of Feed Material
Oct 15-28, 1991: Erection of Pilot Plant
Oct 31 - Nov 1, 1991, May 17 - Jun 1, 1992: ARCS Treatment and Sampling
May 30 - Jun 3, 1992: SITE Treatment and Sampling
Jun 4-5, 1992: Site Closure
Sep 9-15, 1992: Disassembly of Pilot Plant

Treatment Train:

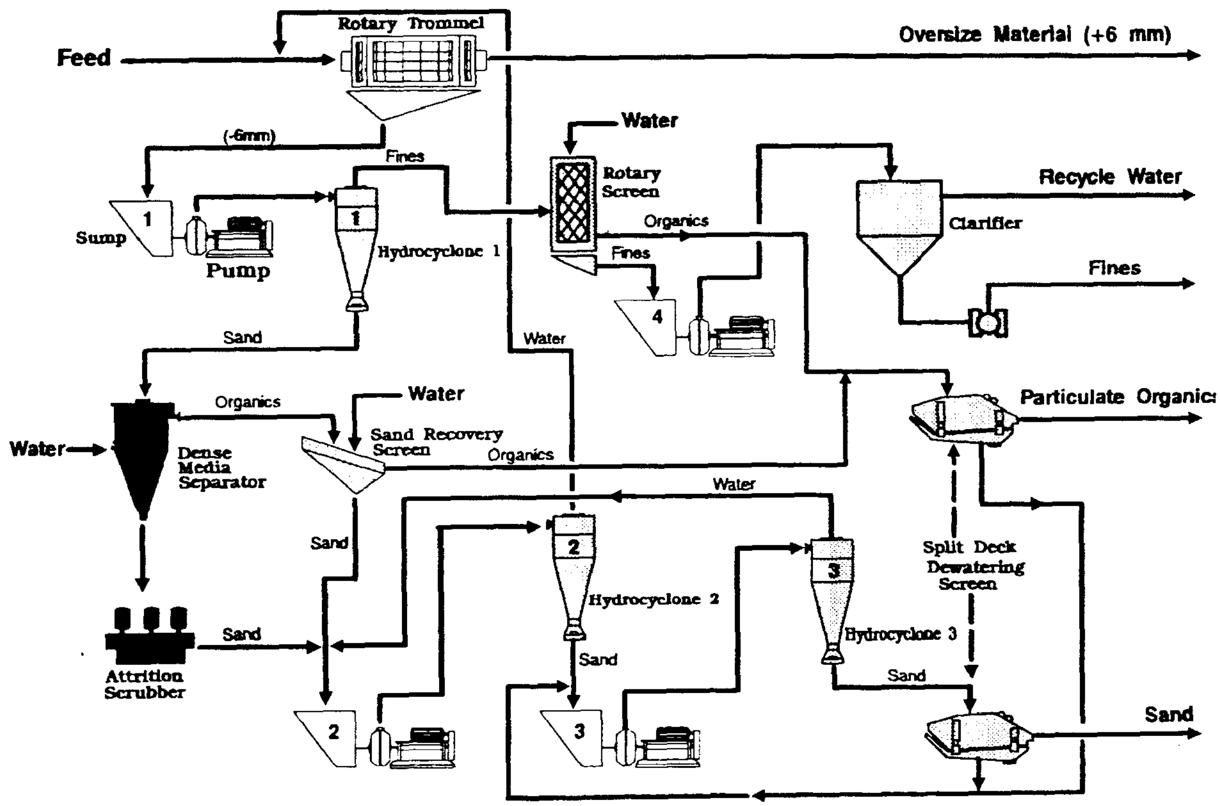


Figure 4-1. General process flow diagram for the Bergmann USA System used at Saginaw Bay, MI (USEPA 1994a).

Costs:

Activity	Approximate Cost
Project Management	$ 75,000
Health and Safety Plan	5,000
Sampling and Analysis Plan	10,000
Site Preparation	51,000
Sediment Excavation Including Tug, Barge, and Sediment Sampling to Locate Site	40,000
Grain-size Demonstration Including Vendor, Shipping, Equipment Rental (Barge, Tug, Crane, Loader), COE Field Support and Site Preparation	148,000
Sample Collection During Demonstration	32,000
Sample Analysis	146,000
Data Analysis and Report Preparation	40,000
Total	547,000

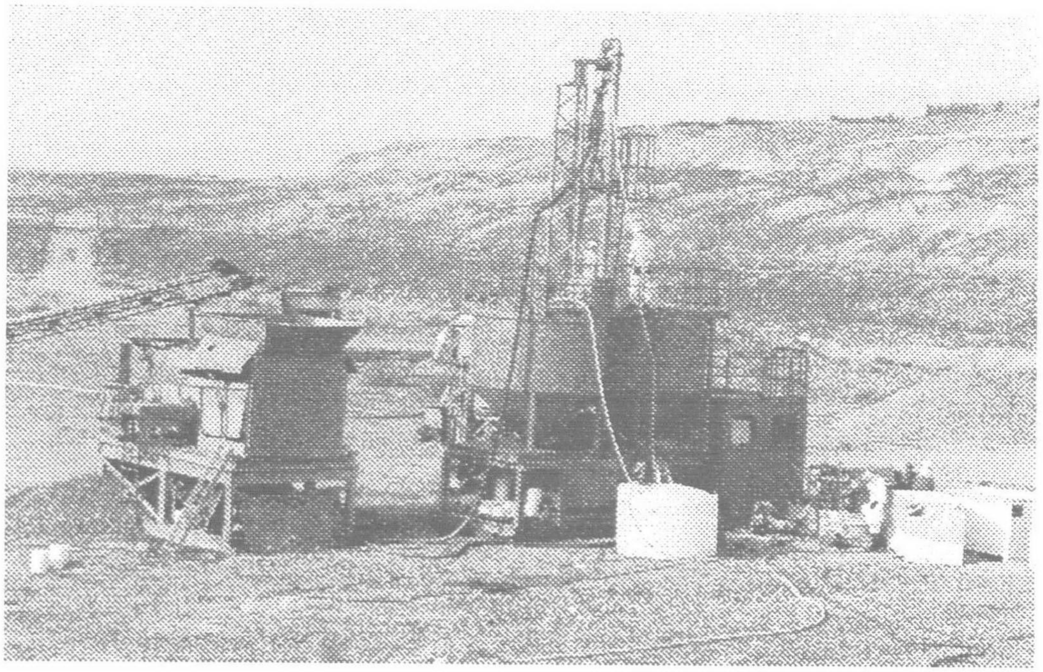
Note that in this demonstration, site preparation costs are greatly elevated by the location of the demonstration on an island.

Comments: One lesson learned from the pilot scale demonstration is that when clay is present, preprocessing should be done to eliminate formation of "clay balls" during removal of oversized materials using a log washer, high pressure sprayer, or similar device.

Information Source(s): USEPA 1994a, MDNR 1988

ARCADIS Geraghty & Miller

The Hanford Site, Richland, WA



Client
Westinghouse-Hanford Company

Project Services
Soil Washing

Contact
Ronald D. Belden
Senior Engineer
(509) 373-1982

Figure 4-2. View of soil washing pilot plant at the Hanford site.

Contaminants:
- Uranium, Metals, Organics

Quantity of Soil:
- 380 tons

Operations Period:
- March 1994 - July 1994

This was the first soil washing pilot study performed at the United States Department of Energy Hanford, Washington, site. The ART Division was responsible for all phases of the pilot study including:

- Mobilization and setup of the pilot plant
- Plant shakedown
- Preparation of site manuals including: Site Operations Manual, Quality Assurance Project Plan, and Test Procedures
- Performance of the three phases of the soil washing pilot test
- Plant decommissioning and decontamination
- Project Technical Report

The objective of this pilot study was to evaluate the capability and effectiveness of soil washing on soils at the 300-FF-1 Operable Unit (OU). Specifically, the pilot test was designed to determine the capability of soil washing to reduce the volume of contaminated material to < 90% by weight and to meet the specified treatment standards. The results of the soil washing operation were incorporated into the Phase III Feasibility Study in the context of evaluating soil washing for full-scale remediation at specified areas of the site.

The test was conducted on soils contaminated with low-level uranium, metals and organics. Contamination originated from nuclear weapons production operations at the site from World War II until 1975. Soils from two areas within the OU were processed:

1) 300 tons of soil containing metals, organic materials and low-level uranium and,
2) 80 tons of soil containing elevated concentrations of copper and uranium.

The tests for the 300 tons of soil were conducted in three segments: 1) the pre-test run, 2) the verification run, and 3) the replication run, as follows:

1) The pre-test run provided for startup of the equipment and initial processing of soil. Adjustments and fine-tuning to the plant were made, based on the results of the pre-test run. During this run, 50 tons of soil were processed.

2) The goal of the verification run was to demonstrate that the equipment and process could achieve the specified 90% reduction by weight of contaminated material and to meet the treatment standards. During this run 125 tons of soil were processed.

3) The goal of the replication run was to confirm that the results achieved in the verification run could be replicated. During this run, an additional 125 tons of soil were processed.

A test on 80 tons of soil containing significantly higher levels of uranium due to the presence of a uranium-copper carbonate precipitate was also performed. Attrition scrubbing was tested on these soils to achieve improved treatment performance.

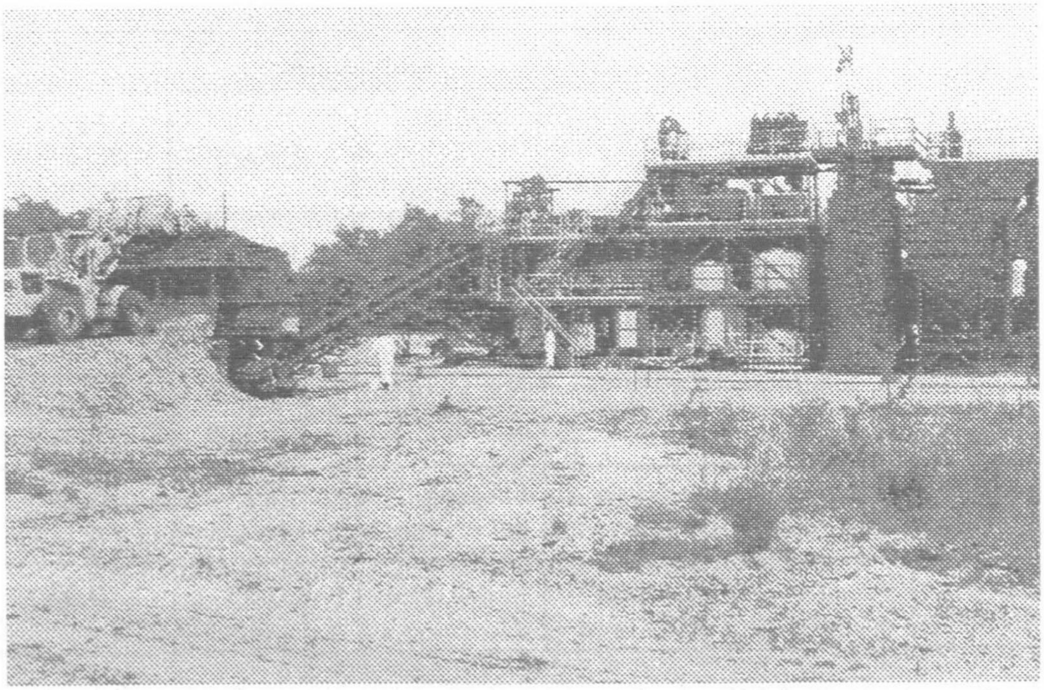
The pilot plant utilized at this site had a throughput capacity of 10 to 15 tons per hour in a mobile, easily erectable configuration. The plant consisted of a feed hopper, a double-decked wet screen, hydrocyclones, attrition scrubber, sand dewatering screen, sludge thickening and dewatering units, and the required supporting peripheral equipment. The pilot study was successful in meeting the goal of > 90% reduction by weight and was also successful in achieving the specified test performance standards.

Upon completion of the tests, ART submitted a written report to Westinghouse-Hanford Company for incorporation into the Feasibility Study.

The following test results were attained.

		Concentration			
Contaminant	Test Performance Standard	Feed	Process Oversize (Clean)	Sand (Clean)	Fines (Residual)
Cu (ppm)	11,840	2,800	199	1,180	22,000
U-238 (pCi/g)	50	132	5.5	28.5	1,660
U-235 (pCi/g)	15	4.5	0.3	1.4	58
Cs-137 (pCi/g)	3.0	0.13	0.05	0.3	0.68
Co-60 (pCi/g)	1.0	0.08	< 0.04	< 0.06	0.93

King of Prussia Technical Corporation Site, Winslow Township, NJ



Client
The King of Prussia Technical Corporation Cooperating Group

Scope of Services
Soil Washing

Contact
Frank J. Opet
Chairman, King of Prussia Technical Corporation Cooperating Group
(609) 384-7222

Figure 4-3. The soil washing plant in operation at the King of Prussia site.

Contaminants:

- Heavy Metals - Chromium, Copper and Nickel

Quantity of Soil:

- 19,200 tons

Operations Period

- June - October 1993

Background

The King of Prussia (KOP) Technical Corporation Site is located in Winslow Township, New Jersey, about 30 miles southeast of Philadelphia. The site is situated on approximately ten acres within the Pinelands National Reserve and adjacent to the State of New Jersey's Winslow Wildlife Refuge. The KOP Technical Corporation purchased the site in 1970 to operate an industrial waste recycling center. The operation was not successful, and in 1985, the site was placed on the National Priorities List. In 1990, a Record of Decision (ROD) was issued for the site, and soil washing was specified as the cleanup technology to be used for remediating the soils. A group of Potentially Responsible Parties was issued a unilateral Administrative Order to implement the requirements of the ROD.

Preliminary Activities

Two major preparatory steps were taken prior to beginning full-scale soil washing activities:

1) a treatability study to determine the applicability of soil washing to the site, and
2) a "demonstration run" of actual site soils prior to final design of the soil washing plant.

During the Treatability Study, site soils were separated into particle-size fractions, and particle-size distribution curves were constructed. Each resulting fraction was analyzed for the target contaminants, and bench-scale studies were conducted to determine the treatment unit operations to be implemented in the full-scale operation.

Demonstration Run

Because this was a new technology to the United States Environmental Protection Agency (USEPA), some questions were left from the treatability and bench-scale studies. Therefore, to fully confirm the effectiveness of the technology on KOP soils, a "demonstration run" was planned and implemented for actual KOP site materials at the ARCADIS Heidemij Realisatie full-scale fixed facility in Moerdijk, The Netherlands. With EPA and VROM (the equivalent Dutch agency) approval, 165 tons of KOP site soils were shipped to Moerdijk. A one-day treatment operation was performed with the equipment configured as recommended in the preliminary design for the KOP soil washing plant. The operation was successful in demonstrating the effectiveness of soil washing in treating the KOP soils. Soils were remediated to levels well below the ROD-specified standards.

Preparation for Full-Scale Operations

Following the demonstration run, the firm of SALA International was contracted by ART to manufacture a 25-tons-per-hour soil washing plant, and the plant was delivered to the site in May 1993. After erection of the plant on-site, a pilot run was conducted on 1,000 tons of contaminated soils excavated from the site. The pilot run was successful, again with cleanup levels well below the ROD-specified standards. As a result, USEPA granted prompt approval to proceed with full-scale remediation.

Full-scale operations at the KOP site began on June 28, 1993. The project was performed with full EPA oversight and in accordance with the approved Site Operations Plan. The process and products were controlled by on-site X-ray fluorescence using previously prepared site matrix-matched standards and confirmed by off-site CLP analysis. Correlation between the approaches was excellent. The soil washing operation was completed on October 10, 1993, and the facility was disassembled and removed from the site. The project treated 19,200 tons of soil with a volume reduction of greater than 90% on a dry solids basis. The overall analytical results were as follows.

		Avg. Conc. (mg/kg)		
Contaminant	Feed Range (mg/kg)	ROD Standard	Clean Product	Residual Product
Nickel	300-3,500	1,935	25	2,300
Chromium	500-5,500	483	73	4,700
Cooper	800-8,500	3,571	110	5,900

Awards Received for Work at the King of Prussia Site

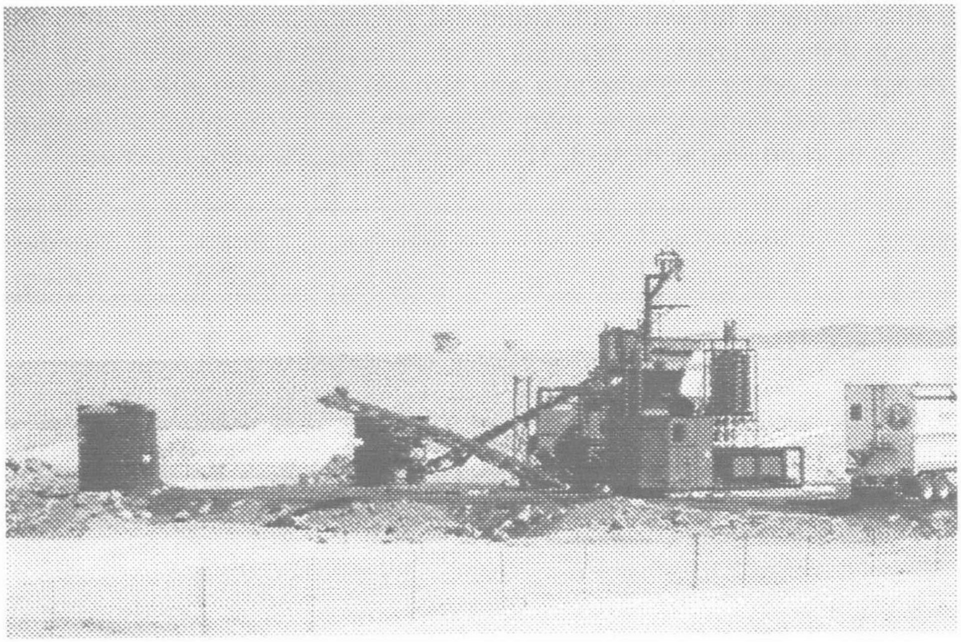
The soil washing capabilities have been recognized with three major environmental engineering awards for the soil washing operation at the King of Prussia Superfund site, Winslow Township, New Jersey.

- American Academy of Environmental Engineers "Excellence in Environmental Engineering" Honor Award for Operations/Management.

- Hazmacon Award "Best Site Remediation Nationwide."

- *Engineering News-Record* "Those Who Made Marks."

FUSRAP, Maywood, NJ



Client
Environcare of Utah, Inc.

Project Services
Soil Washing

Contact
Al Rafati
Vice President
(801) 532-1330

Figure 4-4. Pilot plant at the Envirocare of Utah site, Clive, Utah.

Contaminants:
- Radium, Thorium

Quantity of Soil:
- 1,000 tons

Operations Period:
- August 1997 - November 1997

A pilot-scale demonstration of soil washing was performed on soils from the U.S. Department of Energy's FUSRAP site in Maywood, NJ. Appropriate soils were identified at the Maywood site and shipped to the Envirocare low-level radioactive waste disposal site at Clive, Utah, for processing. Separations were made on the basis of radioactivity levels; materials higher than the treatment target were staged for the additional testing and served as the feed soil for the demonstration.

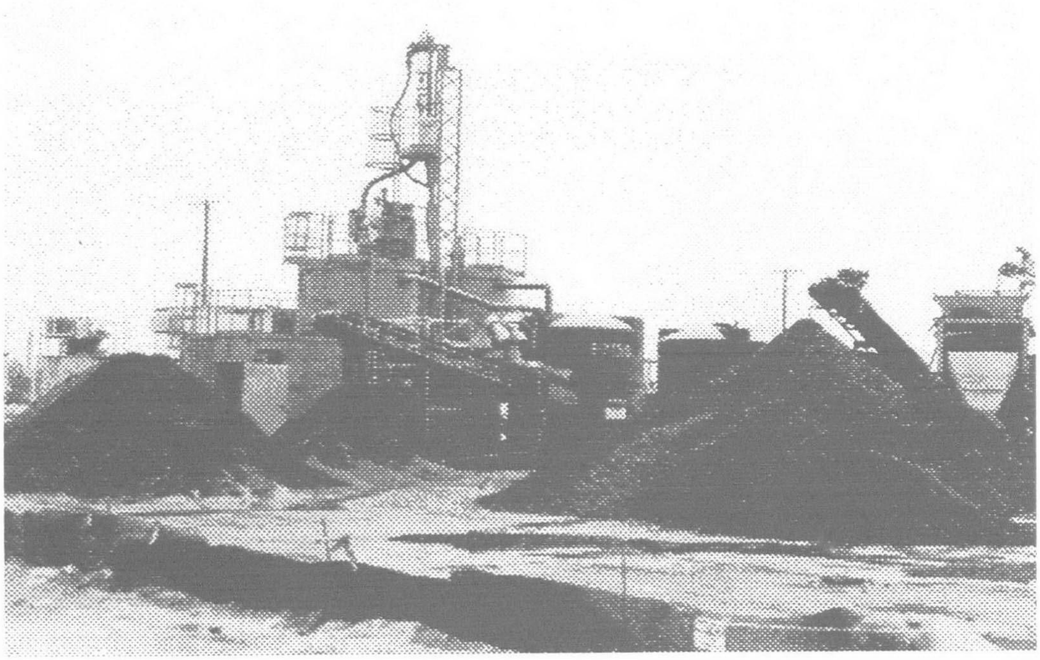
The pilot plant was mobilized to the Envirocare site from Ashtabula, Ohio. While the plant was in transit, the site was prepared and a holding pad was constructed by the Envirocare site contractor, Broken Arrow, Inc. The plant components were prepared outside the radiologically controlled area and moved into the work area. The plant was then erected on the pad; utility connections were made; and testing was completed. Operating plans, health and safety plans, and a sampling and analysis plan were prepared to support the work.

Soil exceeding the treatment standards was pre-screened at 2" (5.08 cm) using a Reed Screen-All. Material > 2" was staged for analysis as clean material, and material < 2" was staged for introduction into the treatment plant.

The treatment plant for this project consisted of a feed hopper, a double-decked wet screen, sump and pump arrangements for water management, hydrocyclones, spiral concentrators, liquid/solids separation units, and dewatering equipment. The plant was operated by company personnel with direct support from Envirocare and Broken Arrow, the site contractor. The project goal of a volume reduction of more than 80% based upon the physical separation of uranium, radium, and thorium was achieved. The following results were attained.

Contaminant	Feed Soil (pCI/g)	Sand (pCI/g)	Oversize (pCI/g)	Fines (pCI/g)	Standard (pCI/g)
Ra-226	1.5	90.6	0.5	4.7	-
Th-232	15.1	4.1	3.6	49.1	-
Total Activity	16.7	4.7	4.1	53.8	5.0

The Monsanto Company, Everett, MA



Client
The Monasanto Company

Project Services
Soil Washing

Contact
Bruce Yare
Manager, Remedial Technology
(314) 694-6370

Figure 4-5. View of the soil washing plant at the Everett site.

Contaminants:
- Bis (2-ethylhexyl) phthalate (BEHP)
- Phthalic anhydride process residues (PAPR) containing Naphthalene

Quantity of Soil:
- 9,600 tons

Operations Period:
- May 1996 - November 1996

The Monsanto Company operated a chemical plant at this 84-acre brownfield site from the mid-1800s to 1992. Manufacturing activities resulted in soil impacted with Naphthalene, BEHP, arsenic, lead and zinc. Since operations ceased, the plant facilities have been dismantled or demolished, and the site was remediated for construction of a 650,000 square foot shopping mall. Monsanto performed the cleanup at this site under the Massachusetts Contingency Plan.

Preparations for soil treatment operations began in May 1996 with a treatability study to provide data for design of the plant. The study showed that the fines fraction (< 2 mm) contained BEHP, and the oversize fraction (> 2 mm) contained PAPR. The process flow diagram design included a trommel, feed hopper, double-decked wet screen, hydrocyclones, attritioning, secondary hydrocycloning, sand dewatering, fines thickening and consolidation, sludge dewatering, and jig. The fines stream was further treated in bioslurry reactors.

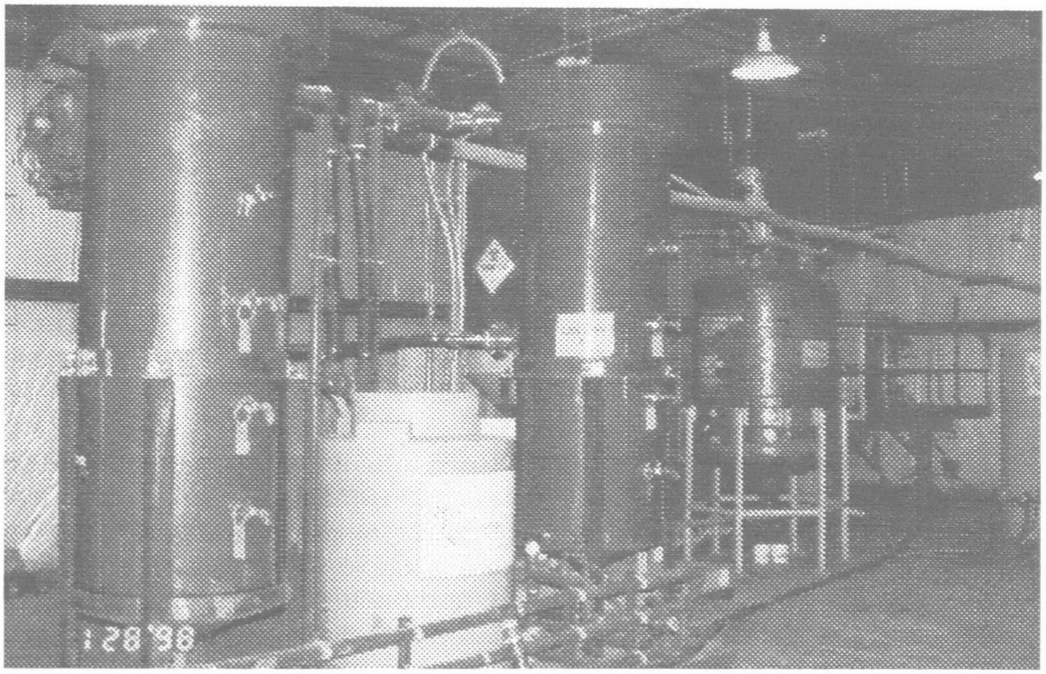
The 15 tons-per-hour soil washing plant was mobilized to the site and configured in accordance with the optimized process flow diagram. Soils consisting primarily of oversize and coarse material with less than 20% silt and clay, including construction debris, demolition rubble and other fill, were excavated from several areas around the site and delivered to the plant for processing. The soil was field-screened to remove gross oversize material, producing a plant feed < 2". This material was fed into the plant and through the wet screening unit, producing a process oversize > 2 mm, and a wet slurry < 2 mm. The process oversize, containing PAPR, was staged outside the plant for further treatment. The wet slurry was fed to the hydrocyclone separation unit, producing a coarse sand fraction and a fines fraction. The coarse sand fraction was directed to a dewatering screen and, after testing, was returned to the site as clean backfill. The fines fraction was degraded in a bioslurry system operated by another contractor. The oversize material > 2" contaminated with naphthalene concentrations higher than treatment targets was further treated by attritioning. The following results were attained.

PAPR SOILS	Feed Range (mg/kg)	Treated Soil (mg/kg)			Treatment Goal (mg/kg)
		Oversize	Sand	Fines*	
Naphthalene	5,000-40,000	22,000	520	2,900	3,000
BEHP	-	-	-	-	-

BEHP SOILS	Feed Soil (mg/kg)	Treatment Soil (mg/kg)			Treatment Goal (mg/kg)
		Oversize	Sand	Fines*	
Naphthalene	< 3,000	160	39	3,300	3,000
BEHP	5,000	2,700	390	10,000	3,000

* Fines treated in bioslurry reactors

The RMI Titanium Company Extrusion Plant, Ashtabula, OH



Client
RMI Environmental Services

Project Services
Soil Washing and Extraction

Contact
James W. Henderson
Division Manager
(440) 993-1973

Figure 4-6. Pilot plant-ion exchange tanks and precipitation tank.

Contaminants:

- Uranium

Quantity of Soil:

- 20,000 tons

Operations Period:

- August 1995 - Ongoing

Background

The RMI Titanium Company (RMI) Extrusion Plant is located in Ashtabula Township, approximately one mile south of Lake Erie, in the northeast corner of the State of Ohio. The 28.5-acre property is privately owned by the RMI Titanium Company. RMI held contracts with the U.S. Department of Energy (DOE) and its predecessor agencies to process uranium metal into forms for use in nuclear and non-nuclear weapons production at the Ashtabula site. A decontamination and decommissioning (D&D) plan for the site has been approved by the U.S. Nuclear Regulatory Commission.

During uranium extrusion operations from 1962 to 1988, particulate uranium was discharged from roof vents and stacks to the surrounding soil. The DOE owns half the buildings on the site and is responsible for funding the cleanup of all contamination associated with work performed under its contracts with RMI Titanium Company.

The cleanup of the site is being conducted under the RMI Decommission Project (RMIDP) sponsored by the DOE Office of Environmental Restoration (EM-40). EM-40 established the Innovative Treatment Remediation Demonstration (ITRD) Program to help accelerate the adoption and implementation of new and innovative soil and groundwater remediation technologies.

Technical Summary

The RMI site generally consists of high clay-content soils, which added to the complexity of the project. Because the contaminants tend to bind to the fine soil fractions and because these fractions make up a high percentage of the Ashtabula soils, typical soil treatment technologies, such as physical separation, are not effective at this site because they do not result in significant volume reduction of the contaminated soils.

In 1996, the ITRD Program sponsored a bench-scale treatability study on RMIDP soils to explore alternatives to a baseline remediation approach of excavation, transport, and off-site disposal. After extensive experimentation, the processing approach narrowed on a carbonate-bicarbonate process which demonstrated a viable technical and cost-beneficial alternative. Efficiencies of up to 90% were attained, and the treatment standard of 30 pCi/g, as established in the D&D plan for the site, was met. The potential benefit of the process is its ability to treat the fine fractions of the soil matrix and separate the uranium contamination from the soil matrix, thereby significantly reducing the volume of contaminated soil requiring off-site disposal.

To validate the results of the treatability study, the DOE Ashtabula Environmental Management Project (AEMP) office and the ITRD program co-sponsored a pilot project in January and February 1997. The primary objectives of the pilot project were to prove that chemical extraction could be successful on a large scale and to obtain operational data to support full-scale soil remediation.

The equipment was erected and operated in a portion of an existing on-site building. The design consisted of an innovative mix of existing processes. During the project, 38 batches (approximately 64 tons) of soil were processed. The soil was loaded into a rotary batch reactor with a heated carbonate-bicarbonate solution to form a 30% solids slurry. The leaching solution was allowed to contact the soils for 1 to 2 hours. A wet screening process separated oversize material (> 1 mm), and the remaining slurry was transferred into sequential thickeners to separate soils from the uranium-bearing liquids. The soil fraction was dewatered by filter press and underwent no further treatment. The radiological activity of these treated soils was measured by x-ray fluorescence (XRF) and verified by alpha spectroscopy to determine the effectiveness of the chemical extraction process. An ion-exchange system was used to remove the uranium from the liquid. The uranium eluted from the ion exchange resin, and a "yellowcake" product was recovered by chemical precipitation. Key parameters that were varied included feed-soil type and activity, reaction temperature, and leaching time. Important information that was studied for full-scale operations included leaching performance, ion exchange performance, resin loading, resin regeneration, and uranium precipitation. The system is close looped, and no adverse air or water problems were created as a result of the process.

Results

- Ashtabula soils can be effectively treated for uranium by using a sodium carbonate extraction process.

- Removal efficiencies of up to 94% were achieved, with a volume reduction of up to 95%.

- All soils selected for treatment met the free release standard of 30 pCi/g.

- Full-scale implementation of the process would result in significant schedule reduction and cost savings for the DOE over the baseline approach.

- As a result of the pilot project, planning and design to initially process 20,000 tons is underway.

- This was the first time that this process had been successfully implemented on a DOE site with uranium contamination.

Benefits

Cleanup of RMIDP soils is a component of the D&D plan for the site. Full-scale implementation of the chemical extraction process will result in significant cost savings and acceleration of schedule over the planned remedy of excavation and off-site disposal of the soil. Soil meeting the 30 pCi/g cleanup level for total uranium, expected to equal 90+% of the processed soil, will be released as clean material for backfill on the site, thus minimizing the volume of soil requiring off-site disposal, and avoiding purchase of backfill material.

Because of a unique combination of facility resources, operating experience of the participants, and deployment strategies, the site is positioned to be an excellent candidate for success in a new mission built around providing processing services for contaminated media for DOE and other sites in the future.

Results are tabulated below.

				Treated Soil		Removal Efficiency	
Pile	Area	Uranium Activity of Feed by Alpha Spec (pCi/g)	Leaching Time (hours)	XRF (pCi/g)	Alpha Spec (pCi/g)	XRF (%)	Alpha Spec (%)
2	Run 1 Area D	129	1	8	12	94	91
3	Run 2 Area D	90	2	11	12	88	87
4	Run 1 Area C	133	1	10	13	92	90
5	Run 2	145	1	17	4	88	90
					Average	90	89

Lordship Point, Stratford, CT

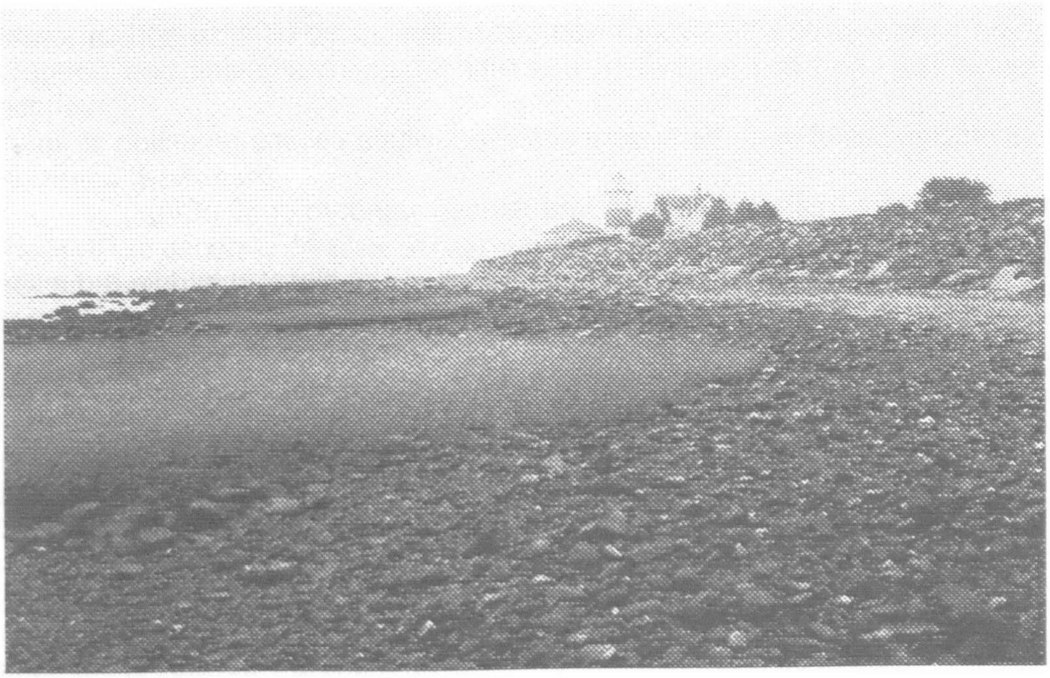


Figure 4-7. View of land and marine areas to be remediated at Lordship Point.

Client
American Marine Constructors, Inc.

Project Services
Soil Washing - Marine and Land Based

Contact
Jack Parmater
(616) 926-1717

Contaminants:
- Lead shot and target fragments

Quantity of Soil:
- 300,000 cubic yards soil and sediment

Operations Period:
- October 1996 - Ongoing

In late 1996, the ART Division of ARCADIS Geraghty & Miller was subcontracted by American Marine Constructors, Inc., a comprehensive marine construction, dredging, and specialty heavy construction services company, to provide marine-based and land-based treatment equipment for the removal of lead shot and trap/skeet target fragments from over 300,000 cubic yards of sediment and soil at the former Remington Arms Gun Club located at Lordship Point in Stratford, Connecticut. American Marine is prime contractor to DuPont Environmental Remediation Services (DERS). The site borders Long Island Sound and was formerly a trap and skeet shooting range where lead shot was directed over the Sound. As a result of those activities, the lead shot and target fragments have been deposited in the sediment and intertidal zone surrounding the property.

Remediation of the property and adjacent Sound areas will be conducted using standard dredging and excavation procedures, with the dredged and excavated sediment being processed through a plant to separate the lead shot and target fragments from the sediments.

The project consists of the following major activities.

- Process Design and Project Work Plans
- Application for Permits
- Process Plant Fabrication
- Mobilization of Process Plant
- Process Plant Validation Test
- Mobilization of Excavation and Dredging Equipment
- Excavation/Dredging Operation
- Process the materials to extract the lead shot and target fragments
- Return of remediated sediment to their approximate original location
- Transport of the lead shot to an approved off-site recycler
- Transport of the target fragments and organic material to the designated solid waste landfill
- Demobilization
- Site restoration

ART/American Marine prepared and submitted the process design and project work plans to DERS for approval. The process plant design has been approved by DERS and is now at the permitting phase. The design shows in detail the location of the plant, the process flow diagram and mass balances for the land-based and marine-based operations. The plant comprises the following major units.

- Triple deck vibrating wet screen for size separation
- Fine and coarse mineral jigs for density separation
- Underflow scavenger columns

ART's responsibilities also include process plant fabrication, mobilization of the process plant to the site, plant validation test, operation of the plant and dismantling and removal from the site. American Marine will mobilize the excavation and dredging equipment to the site and perform the dredging and excavation and preliminary screening of plant feed.

Permitting activities by DERS are underway and are continuing at this time. On-site remediation is expected to begin in 1998. All project activities are scheduled for completion in 1999.

Remediation will begin with excavation of material from the intertidal zone and will be accomplished using conventional land-based equipment. After these sediments have been excavated, they will be transported to the land-based process plant for removal of the lead shot, target fragments, organic material, and man-made debris. The remediated soil will be replaced in its approximate original location. Unremediated material containing dense plant growth or other living and non-living organic materials will be processed to separate the non-organic material from the organic and will be cleaned of lead shot, target fragments. Large rocks with adhered unremediated sediment will be washed and the sediment processed through the plant. The cleaned rocks will be returned to their original location with the remediated soil. Residual products will be containerized for recycling and disposal.

Following completion of the land-based remediation, the process plant will be mounted on a barge for the marine-based remediation phase of the project. Dredging will be accomplished from the low tide mark to a distance of approximately 600 feet (183 m) from shore to a maximum sediment depth of approximately 10 feet (3 m). Dredged sediment will be processed through the plant for removal of the lead shot, target fragments and debris, and the remediated sediments will be replaced at approximately the original location by discharge from the barge. Rocks segregated during the dredging operation will be placed back in their approximate original location. Large rocks will be left in place and sediments dredged from around the rock. Again, residual products will be containerized for recycling and disposal.

Recovered lead shot will be containerized and transported to an approved off-site facility for recycling. Target fragments will be disposed at a solid waste landfill. Upon completion of remediation activities, the process plant will be demobilized and removed from the site. All land-based disturbed areas will be restored to original conditions according to the Site Restoration Plan. Wetland areas will be replanted with native species and native grass, and cover will be re-established.

Literature

Escambia Treating Company Superfund Site, Pensacola, FL

Site History:

1943-1982: Treated wood products using pentachlorophenol (PCP) and creosote
Nov. 1992: Demonstration of mobile Volume Reduction Unit (VRU)
Present: Undergoing a Superfund cleanup being managed by EPA Region IV

Contaminants and Treatment Objectives: The mobile VRU was developed to demonstrate the capabilities of soil washing and to provide data that facilitate scale-up to commercial-size equipment.

Analyte	Contaminant Levels	Treatment Objectives	Results (Average % Reductions)		
			Condition 1	Condition 2	Condition 3
PCP	140 ppm	> 90 % removal	76	92	97
Creosote - fraction PAH	550-1,700 ppm	> 90 % removal	70	83	90

Project Volume: 3600 lbs.

Site Ownership: Not given.

Consultants/Contractors: US EPA Risk Reduction Engineering Laboratory (RREL).

Project Status: Not given.

Treatment Train: After excavation, soil was processed through a ¼" screen before fed to the VRU. The < ¼" soil was transferred to a feed surge bin and then conveyed through a screw conveyor to a trommel screen miniwasher at 100 lbs/hr with filtered wash water being sprayed onto the screen (2-mm slot opening). Flow was adjusted up to an approximately 13 to 1 overall water-to-soil ratio. Two vibrating screens (set at 2 mm and 0.150 mm for the demonstration) were used to segregate the soil into various size fractions. Overflow from the miniwasher (containing the courser solids) falls onto the 2-mm vibrascreen. The underflow is pumped to the second (0.150 mm) vibratory screen.

The overflow from the 2-mm vibratory screen flowed by gravity to a recovery drum. The overflow from the second vibratory screen (0.150 mm to 2 mm) was gravity fed to the recovery drum. The underflow from the second vibrascreen (< 0.150 mm) drained into a mixing tank and was pumped to a CPI (Corrugated Plate Interceptor). Materials lighter than water flow over a weir in the CPI and drain into a drum for disposal. CPI-settled solids are discharged to a recovery drum. A slurry containing fines < 38 mm overflows the CPI and gravity feeds into a mixing tank and is further pumped to a static mixer where flocculating chemicals are added. The slurry is then discharged to the floc chamber and then overflows into the clarifier where the bottom solids are augured to a drum for disposal. Clarified water is polished using cartridge-type polishing filters and activated carbon so that it can be recycled.

Costs: No cost information was given for the demonstration. However, from the demonstration, it was estimated that cost for a 10-tph VRU that was on-line 90% of the time would be $171/ton to process 10,000 tons, or $137/ton to process 20,000 tons, or $106/ton to process 200,000 tons.

Comments: Water and energy usage for the demonstration at 100 lb/hr feed rate were 66 kWh/ton and 71 gph of water (with no recycling).

Information Source(s): USEPA 1993.

Bench-Scale Study at New York University at Buffalo, Buffalo, NY

Site History: Seven soils from industrial sites were tested. The locations of the soils were not given.

Contaminants and Treatment Objectives: All seven soils were contaminated with Pb.

Soil	Contaminant Levels, mg Pb/kg	Treatment Objectives, mg Pb/kg	Unwashed Jig/Table Tailings, mg Pb/kg	Washed Jig/Table Tailings, mg Pb/kg
1	11,933	250	2,185 +1,477	203 + 16
2	2,307	1000	1,401 + 196	611 ± 67
3	5,913	1000	1,535 + 210	200 ± 12
4	3,199	250	2,195 ± 477	1218 ± 82
5	4,808	1000	1,369 ± 166	98 ± 8
6	1,394	1000	500 ± 73	391 ± 38
7	4,249	1000	2,755 ± 214	1,033 ± 55

Project Volume: Not given.

Site Ownership: Not given.

Consultants/Contractors: Not given.

Project Status: Not given.

Treatment Train: The soils were wet-sieved to produce coarse (4 to 20 mesh) and fine (20 to 200 mesh) soils. Fine sand was processed by tabling and coarse sand by jigging. The tailings were combined for analysis. Soil washing tests were also conducted in which the jigged or tabled soils were mixed with hydrochloric acid at pH = 1, 25°C, and liquid to solid ratio of 20 for a duration of 24 hours, and then filtered for analysis.

Costs: Not given.

Comments: Soils consisted mostly of coarse and fine sands.

Information Source(s): Van Benschoten et al. 1997.

Feather River Site, Oroville, CA

Site History: 1948-Present: Chemical preserving of railroad ties and telephone poles
1984: Listed, Superfund National Priorities List

Contaminants and Treatment Objectives:

Analyte	Contaminant Levels	Treatment Objectives[1]
Pentachlorophenol (PCP)	Not given	17 ppm
Polynuclear Aromatic Hydrocarbons (PAHs)	Not given	0.19 ppm (carcinogenic PAHs)
Dioxins	Not given	30 ppt
Heavy metals - arsenic, chromium, copper	Not given	Not given

[1] 1992 federal cleanup agreement

Project Volume: Approximately 250,000 cubic yards.

Site Ownership: Beazer East, Inc., Michael Tischuk Project Manager.

Consultants/Contractors: Dames & Moore, Jeff Bensch Project Manager
Westinghouse Remediation Service Inc.

Project Status: Bench scale testing and a 400-ton pilot were completed by Westinghouse Remediation Service. Current project status is unknown.

Treatment Train: Unknown.

Costs: Bench-scale treatability studies, Pilot studies, Full scale treatment
Total cost (1994): $78 million (Daniels 1994).

Comments: Treatment levels were established based on a 1987 risk based assessment using the assumption of possible future residential use of the site. Beazer asserts that this assumption resulted in extremely conservative values for the site. Beazer cited two other superfund sites with less stringent treatment requirements: 1) Beazer-owned, Houston wood treating plant, PAHs target level 700 ppm, and 2) American Creosote Works Superfund Site, Pensacola, FL, groundwater PAHs level 1100 ppb vs 0.007 ppb PAHs and 0.53 ppq dioxins at Oroville, CA.

Information Source(s): Daniels 1994.

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Appendix A: Detailed Cost Estimates

ART *A Division of Geraghty & Miller, Inc.*
Soil Washing Cost Estimate
WES Scenario 1

KEY ASSUMPTIONS	
Soil Mass (cy)	50,000
Density (tons/cy)	1.2
Soil Processed (tons)	60,000
Plant Size (tons/hour)	25
Shift Schedule (days/week-hours/day)	5-10
Plant Availibility (%)	80%
Treatment Duration (weeks)	60
Mobilization/Site Preparation/Demobilization (weeks)	9
Total Project Duration (weeks)	69
Feed - Dry Solids Concentration (%)	87%
Sludge - Dry Solids Concentration (%)	50%
ESTIMATED TREATMENT PRICES	
Mobilization (Plant)	99,000
Site Preparation	61,000
Plant Depreciation	198,000
Plant Labor	661,000
Utilities	148,000
Chemicals / HAS	99,000
Maintenance	198,000
Office Expense	89,000
Process Analytical (Plant)	37,000
Demobilization (Plant)	71,000
Insurance	0
Contingency	50,000
Total Estimated Treatment Price	**$1,711,000**
Estimated Treatment Price, $ / Ton	**85 - 100**
TOTAL ESTIMATED PROJECT COSTS	**$1,723,000**
Estimated Project Cost, $ / Ton	**85 - 100**

OPERATING ASSUMPTIONS
this estimate focuses on treatment only:
- Excavation and Prescreening to -2" not included
- Process Analytical not included
- Sludge (residual) disposal/treatment not included

Proforma
PROJECT: WES Scenario 1

Key Assumptions:

Volume (Cubic Yards)	50,000					
Density	1.2					
Mass (Tons)	**60,000**					
Production (Tons/Hour)	25	Pilot Plant				
Shift Schedule - # of Shifts	1	(Days/Wk):	7	(Hrs/Day):	10	
Plant Availibility	80.0%					
Treatment Duration (Weeks)	42.9	(Months):	9.9	(Years):	0.8	
Mobilization (Weeks)	5.0					
Demobilization (Weeks)	4.0					
Total Project Duration (Wks)	51.9	(Months):	12.0	(Years):	1.0	
Feed - Dry Solids Conc (%)	87.0%					
Sludge - Dry Solids Conc (%	50.0%					

REVENUE	Total
Soil Volume (tons)	60,000
Processing Fee Per Ton	22.50
Total Site Revenue	1,350,000
COST OF OPERATIONS	
Project Labor	292,775
Travel / Per Diem	108,714
Plant Depreciation	120,000
MOB, Site Prep, Demob	140,000
Excavation, Prescreening	0
Transportation	0
Plant Consumables	114,092
Equipment Rental	0
Maintenance	120,000
Utilities	90,000
Process Sampling	30,000
Sludge Disposal	0
Sludge Transportation	0
Security	0
Insurance	0
Contingency	50,000
Total Cost of Operations	1,065,581
Cost / ton	17.76
*****GROSS PROFIT*****	**284,419**
*****GROSS PROFIT %*****	**21.1%**

OPERATING COSTS

Direct Plant Labor 35.0%

Schedule In Weeks:

Title	Name	Number	Sal+Fringes	Pre-Mob	Mob	Run Time	De-Mob	Report Writing	# Adj.	Total Time	Sal. /wk
Plant Manager	Carl Seward	1		1.0	5.0	42.9	0.0	0.0	0.0	48.9	
Plant Engineer	Randall Lipham	1		0.0	5.0	42.9	4.0	0.0	0.0	51.9	
Asst Plant Eng	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Shift Supervisor	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Plant Operator	Local Hire	1		0.0	5.0	42.9	4.0	0.0	0.0	51.9	1275
Plant Operator	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1275
Trommel Operator	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1275
Heavy Equip Operator	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1275
Laborer	Local Hire	1		0.0	5.0	42.9	4.0	0.0	0.0	51.9	1275
Secretary	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	600
Subtotal		4	292,775	1.0	20.0	171.4	12.0	0.0	0.0	204.4	

Total Out-of-Town Labor Time: 151.6 Weeks

Project Management Labor

Title	Name	Number	Sal+Fringes	Pre-Mob	Mob	Run Time	De-Mob	Report Writing	% Adj.	Total Time
Plant Engineer	ART Employee	0		0.0	0.0	0.0	0.0	0.0	0%	0.0
Process Eng	Eric G	0		1.0	5.0	2.0	0.0	0.0	100%	8.0
Process Eng Back-up	Marc Pruijn	0		0.0	0.0	0.0	0.0	0.0	0%	0.0
Chemist	Frank Corden	0		0.0	0.0	0.0	0.0	0.0	0%	0.0
Subtotal		0	0	1.0	5.0	2.0	0.0	0.0		8.0 Wks

*****TOTAL PROJECT LABOR***** **292,775**

Salaries per Phase:

Phase	Direct	Indirect	Total
Pre-Mob	2,129	1,623	3,752
Mob	28,845	8,116	36,961
Run Time	247,240	3,246	250,487
De-Mob	14,561	0	14,561
Report Writing	0	0	0
Total	292,775	12,986	305,761

*****Travel / Per Diem***** $1,000 /wk **108,714**

Travel Weeks For:

	Weeks	
Plant Labor	100.7	(Includes Pre-Mob)
Mgmt Labor	8.0	
Total	108.7	

*****Plant Depreciation***** $/ton 2.00 **120,000**

*****MOB/DEMOB and Site Prep*****

Mobilization/Erection	60,000
Site Prep (Building,Pads,Asphalt, Liner, Bins)	37,000
Revegetation	0
Demob	43,000
TOTAL	**140,000**

Site Prep Details	
Site Grading	5,000
Liner	0
Asphalt/Stone	0
Building	0
Building & Sludge Pad	20,000
Power Extension	5,000
Water Extension	2,000
Office Prep	0
Miscellaneous	5,000
Installation of Well	0
TOTAL	37,000

Mob	Details	Demob	
30,000	Trucking	30,000	per Vineland Pro Forma
0		0	
25,000	Assembly/Disassembly		
0	Dieren	0	per A.E. Steel Erectors
0	Edmonton	0	
0	Wastewater Disposal	8,000	
0		0	
5,000	Misc	5,000	
60,000	TOTAL	43,000	

***Excavation/Stage/Prescre	0.00	$/ton	0	Labor 0 / Equip 0 / Misc 0
Transportation	0.00	$/ton	0	

Plant Consumables

Field Office Expense			54,092
Chemicals	0.00	$/ton	0
Health and Safety	1.00	$/ton	60,000
			114,092

Field Office Detail:

Supplies	3,500	/Mo.	
Furniture	3,500		
Office Rent	728	/Mo.	per WHC GE Capital

Equipment Rental 0

Generator:	0	/mo.
Baker Tank:	0	/mo.
Compressor:	0	/mo.
Boiler:	0	/mo.
Steam Cleaner:	0	/day
Mobs:	0	each
Loader:	0	/wk.
Filter Press:	0	/day
	0	mob
Transformer:	0	/?

Equipment Maintenance 2.00 $/ton 120,000

Utilities

Electrical(2000KVA)	1.00	$/ton	60,000	
Water (35gpm)	0.50	$/ton	30,000	
Septic Service	0.00	$/mo	0	
Diesel	0.000	$/gallon	0	for 1 loader and 1 trommel
TOTAL UTILITIES			90,000	

IN PROCESS SAMPLING

Process and Residuals Analytical	30,000
Treatability Studies	0
TOTAL	30,000

RESIDUAL MANAGEMENT

Sludge Disposal:

# of tons	Disp $/ton (Incl. Tax)		
0	150	Hazardous	0
0	90	Non - Haz	0
			0

Sludge Transportation:

# of tons	$/Load		
0	400	Hazardous	0
0	150	Non - Haz	0
			0

Project Data Sheet

Project Name:	WES Scenario 1	**Project Bid Price:**		
Project Number:		***Type:***	Soil Washing	
			Time & Materials plus Fee	
Project Address:		**Subcontractors:**		
Site Phone Number:	403-450-1478	**Plant Used:**	Pilot Plant	
Site FAX Number:	403-450-0909	***Tonnage:***	60,000	
Time Frame:		**Additional Equipment:**		
Start			Trommel	Own
End			Mob	$0
			Gravity Jig	$0
			Mob	$0

Other Contacts:

Name	**Position**	**Phone**	**FAX**
Conference Room	n/a		
	Site Construction Manager		
	Project Manager		
	Technical Manager		

Apartment Address:

Apartment Phone:

Apartment FAX:

2.1 Treatment Train 2, Cost Estimate Summary

ART *A Division of Geraghty & Miller, Inc.*
Soil Washing Cost Estimate
WES Scenario 2

KEY ASSUMPTIONS	
Soil Mass (cy)	50,000
Density (tons/cy)	1.2
Soil Processed (tons)	60,000
Plant Size (tons/hour)	25
Shift Schedule (days/week-hours/day)	5-10
Plant Availibility (%)	80%
Treatment Duration (weeks)	60
Mobilization/Site Preparation/Demobilization (weeks)	9
Total Project Duration (weeks)	69
Feed - Dry Solids Concentration (%)	87%
Sludge - Dry Solids Concentration (%)	50%
ESTIMATED TREATMENT PRICES	
Mobilization (Plant)	99,000
Site Preparation	61,000
Plant Depreciation	395,000
Plant Labor	879,000
Utilities	148,000
Chemicals / HAS	198,000
Maintenance	198,000
Office Expense	89,000
Process Analytical (Plant)	37,000
Demobilization (Plant)	71,000
Insurance	0
Contingency	50,000
Total Estimated Treatment Price	**$2,225,000**
Estimated Treatment Price, $ / Ton	**85 - 100**
TOTAL ESTIMATED PROJECT COSTS	**$2,237,000**
Estimated Project Cost, $ / Ton	**85 - 100**

OPERATING ASSUMPTIONS

this estimate focuses on treatment only:

- Excavation and Prescreening to -2" not included
- Process Analytical not included
- Sludge (residual) disposal/treatment not included

Proforma

PROJECT: **WES Scenario 2**

Key Assumptions:

Volume (Cubic Yards)	50,000				
Density	1.2				
Mass (Tons)	**60,000**				
Production (Tons/Hour)	25	Pilot Plant			
Shift Schedule - # of Shifts	1	(Days/Wk):	7	(Hrs/Day):	10
Plant Availibility	80.0%				
Treatment Duration (Weeks)	42.9	(Months):	9.9	(Years):	0.8
Mobilization (Weeks)	5.0				
Demobilization (Weeks)	4.0				
Total Project Duration (Wks)	51.9	(Months):	12.0	(Years):	1.0
Feed - Dry Solids Conc (%)	87.0%				
Sludge - Dry Solids Conc (%)	50.0%				

REVENUE	Total
Soil Volume (tons)	60,000
Processing Fee Per Ton	29.00
Total Site Revenue	1,740,000
*****COST OF OPERATIONS*****	
Project Labor	425,010
Travel / Per Diem	108,714
Plant Depreciation	240,000
MOB, Site Prep, Demob	140,000
Excavation, Prescreening	0
Transportation	0
Plant Consumables	174,092
Equipment Rental	0
Maintenance	120,000
Utilities	90,000
Process Sampling	30,000
Sludge Disposal	0
Sludge Transportation	0
Security	0
Insurance	0
Contingency	50,000
Total Cost of Operations	1,377,817
Cost / ton	22.96
*****GROSS PROFIT*****	**362,183**
*****GROSS PROFIT %*****	**20.8%**

OPERATING COSTS

Direct Plant Labor

Title	Name	Number	Sal+Fringes (35.0%)	Pre-Mob	Mob	Run Time	De-Mob	Report Writing	# Adj.	Total Time	Sal. /wk
Plant Manager	Carl Seward	1		1.0	5.0	42.9	0.0	0.0	0.0	48.9	
Plant Engineer	Randall Lipham	1		0.0	5.0	42.9	4.0	0.0	0.0	51.9	
Asst Plant Eng	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Shift Supervisor	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Plant Operator	Local Hire	1		0.0	5.0	42.9	4.0	0.0	0.0	51.9	1275
Plant Operator	Local Hire	1		0.0	5.0	42.9	4.0	0.0	0.0	51.9	1275
Trommel Operator	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1275
Heavy Equip Operator	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1275
Laborer	Local Hire	2		0.0	5.0	42.9	4.0	0.0	0.0	51.9	1275
Secretary	Local Hire	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	600
Subtotal		6	425,010	1.0	25.0	214.3	16.0	0.0	0.0	256.3	

Schedule In Weeks. Total Out-of-Town Labor Time: 151.6 Weeks

Project Management Labor

Title	Name	Number	Sal+Fringes	Pre-Mob	Mob	Run Time	De-Mob	Report Writing	% Adj.	Total Time
Plant Engineer	ART Employee	0		0.0	0.0	0.0	0.0	0.0	0%	0.0
Process Eng	Eric G	0		1.0	5.0	2.0	0.0	0.0	100%	8.0
Process Eng Back-up	Marc Pruijn	0		0.0	0.0	0.0	0.0	0.0	0%	0.0
Chemist	Frank Corden	0		0.0	0.0	0.0	0.0	0.0	0%	0.0
Subtotal		0	0	1.0	5.0	2.0	0.0	0.0		8.0 Wks

TOTAL PROJECT LABOR **425,010**

Salaries per Phase:

Phase	Direct	Indirect	Total
Pre-Mob	2,129	1,623	3,752
Mob	41,595	8,116	49,711
Run Time	356,526	3,246	359,772
De-Mob	24,761	0	24,761
Report Writing	0	0	0
Total	425,010	12,986	437,996

Travel / Per Diem $1,000 /wk **108,714**

Travel Weeks For:	Weeks	
Plant Labor	100.7	(Includes Pre-Mob)
Mgmt Labor	8.0	
Total	108.7	

Plant Depreciation $/ton 4.00 **240,000**

MOB/DEMOB and Site Prep

Mobilization/Erection	60,000
Site Prep (Building,Pads,Asphalt, Liner, Bins)	37,000
Revegetation	0
Demob	43,000
TOTAL	**140,000**

Site Prep Details

Site Grading	5,000
Liner	0
Asphalt/Stone	0
Building	0
Building & Sludge Pad	20,000
Power Extension	5,000
Water Extension	2,000
Office Prep	0
Miscellaneous	5,000
Installation of Well	0
TOTAL	37,000

Mob	Details	Demob	
30,000	Trucking	30,000	per Vineland Pro Forma
0		0	
25,000	Assembly/Disassembly		
0	Dieren	0	per A.E. Steel Erectors
0	Edmonton	0	
0	Wastewater Disposal	8,000	
0		0	
5,000	Misc	5,000	
60,000	TOTAL	43,000	

2.2 Treatment Train 2, Detailed Cost Estimate

***Excavation/Stage/Prescre	0.00	S/ton	0	Labor 0 / Equip 0 / Misc 0
Transportation	0.00	S/ton	0	

Plant Consumables			–					
Field Office Expense			54,092	Field Office Detail:	Supplies	3,500	/Mo.	
Chemicals	1.00	S/ton	60,000		Furniture	3,500		
Health and Safety	1.00	S/ton	60,000		Office Rent	728	/Mo.	per WHC GE Capital
			174,092					

			–			
Equipment Rental			0	Generator:	0	/mo.
			–	Baker Tank:	0	/mo.
				Compressor:	0	/mo.
***Equipment Maintenance**	2.00	S/ton	120,000	Boiler:	0	/mo.
			–	Steam Cleaner:	0	/day
				Mobs:	0	each
Utilities				Loader:	0	/wk.
Electrical(2000KVA)	1.00	S/ton	60,000	Filter Press:	0	/day
Water (35gpm)	0.50	S/ton	30,000		0	mob
Septic Service	0.00	S/mo	0	Transformer:	0	/?
Diesel	0.000	S/gallon	0	for 1 loader and 1 trommel		
	TOTAL UTILITIES		90,000			
			–			

IN PROCESS SAMPLING		
Process and Residuals Analytical		30,000
Treatability Studies		0
	TOTAL	30,000
		–

RESIDUAL MANAGEMENT

Sludge Disposal: # of tons	Disp S/ton (Incl. Tax)		
0	150	Hazardous	0
0	90	Non - Haz	0
			0

Sludge Transportation: # of tons	S/Load		
0	400	Hazardous	0
0	150	Non - Haz	0
			0

2.3 Treatment Train 2, Project Data Sheet

Project Data Sheet

Project Name:	WES Scenario 2	**Project Bid Price:**		
Project Number:		***Type:***	Soil Washing	
			Time & Materials plus Fee	
Project Address:		**Subcontractors:**		
Site Phone Number:	403-450-1478	**Plant Used:**	Pilot Plant	
Site FAX Number:	403-450-0909	***Tonnage:***	60,000	
Time Frame:		**Additional Equipment:**		
Start			Trommel	Own
End			Mob	$0
			Gravity Jig	$0
			Mob	$0

Other Contacts:

Name	Position	Phone	FAX
Conference Room	n/a		
	Site Construction Manager		
	Project Manager		
	Technical Manager		

Apartment Address:	
Apartment Phone:	
Apartment FAX:	

ART *A Division of Geraghty & Miller, Inc.*
Soil Washing Cost Estimate
WES Scenario 3

KEY ASSUMPTIONS	
Soil Mass (cy)	50,000
Density (tons/cy)	1.2
Soil Processed (tons)	60,000
Plant Size (tons/hour)	25
Shift Schedule (days/week-hours/day)	5-10
Plant Availibility (%)	80%
Treatment Duration (weeks)	60
Mobilization/Site Preparation/Demobilization (weeks)	9
Total Project Duration (weeks)	69
Feed - Dry Solids Concentration (%)	87%
Sludge - Dry Solids Concentration (%)	50%
ESTIMATED TREATMENT PRICES	
Mobilization (Plant)	140,000
Site Preparation	226,000
Plant Depreciation	840,000
Plant Labor	1,385,000
Utilities	296,000
Chemicals / HAS	692,000
Maintenance	395,000
Office Expense	89,000
Process Analytical (Plant)	62,000
Demobilization (Plant)	153,000
Insurance	0
Contingency	50,000
Total Estimated Treatment Price	**$4,328,000**
Estimated Treatment Price, $ / Ton	**85 - 100**
TOTAL ESTIMATED PROJECT COSTS	**$4,349,000**
Estimated Project Cost, $ / Ton	**85 - 100**

OPERATING ASSUMPTIONS
this estimate focuses on treatment only:
- Excavation and Prescreening to -2" not included
- Process Analytical not included
- Sludge (residual) disposal/treatment not included

Proforma

PROJECT: **WES Scenario 3**

Key Assumptions:

Volume (Cubic Yards)	50,000					
Density	1.2					
Mass (Tons)	**60,000**					
Production (Tons/Hour)	25	Pilot Plant				
Shift Schedule - # of Shifts	1	(Days/Wk):	7	(Hrs/Day):	10	
Plant Availibility	80.0%					
Treatment Duration (Weeks)	42.9	(Months):	9.9	(Years):	0.8	
Mobilization (Weeks)	5.0					
Demobilization (Weeks)	4.0					
Total Project Duration (Wks)	51.9	(Months):	12.0	(Years):	1.0	
Feed - Dry Solids Conc (%)	87.0%					
Sludge - Dry Solids Conc (%)	50.0%					

*****REVENUE*****	Total
Soil Volume (tons)	60,000
Processing Fee Per Ton	56.00
Total Site Revenue	3,360,000

*****COST OF OPERATIONS*****	
Project Labor	623,364
Travel / Per Diem	217,429
Plant Depreciation	510,000
MOB, Site Prep, Demob	315,000
Excavation, Prescreening	0
Transportation	0
Plant Consumables	474,092
Equipment Rental	0
Maintenance	240,000
Utilities	180,000
Process Sampling	50,000
Sludge Disposal	0
Sludge Transportation	0
Security	0
Insurance	0
Contingency	50,000
Total Cost of Operations	2,659,885
Cost / ton	44.33
*****GROSS PROFIT*****	**700,115**
*****GROSS PROFIT %*****	**20.8%**

OPERATING COSTS

Direct Plant Labor 35.0%

Title	Name	Number	Sal+Fringes
Plant Manager	Carl Seward	1	
Plant Engineer	Randall Lipham	1	
Asst Plant Eng	Local Hire	0	
Shift Supervisor	Local Hire	0	
Plant Operator	Local Hire	2	
Plant Operator	Local Hire	2	
Trommel Operator	Local Hire	0	
Heavy Equip Operator	Local Hire	0	
Laborer	Local Hire	3	
Secretary	Local Hire	0	
Subtotal		9	623,364

Schedule In Weeks:

Pre-Mob	Mob	Run Time	De-Mob	Report Writing	# Adj.	Total Time	Sal. /wk
1.0	5.0	42.9	0.0	0.0	0.0	48.9	
0.0	5.0	42.9	4.0	0.0	0.0	51.9	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	5.0	42.9	4.0	0.0	0.0	51.9	1275
0.0	5.0	42.9	4.0	0.0	0.0	51.9	1275
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1275
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1275
0.0	5.0	42.9	4.0	0.0	0.0	51.9	1275
0.0	0.0	0.0	0.0	0.0	0.0	0.0	600
1.0	25.0	214.3	16.0	0.0	0.0	256.3	

Total Out-of-Town Labor Time: 151.6 Weeks

Project Management Labor

Title	Name	Number	Sal+Fringes
Plant Engineer	ART Employee	0	
Process Eng	Eric G	0	
Process Eng Back-up	Marc Pruijn	0	
Chemist	Frank Corden	0	
Subtotal		0	0

Pre-Mob	Mob	Run Time	De-Mob	Report Writing	% Adj.	Total Time
0.0	0.0	0.0	0.0	0.0	0%	0.0
1.0	5.0	2.0	0.0	0.0	100%	8.0
0.0	0.0	0.0	0.0	0.0	0%	0.0
0.0	0.0	0.0	0.0	0.0	0%	0.0
1.0	5.0	2.0	0.0	0.0		8.0 Wks

*****TOTAL PROJECT LABOR***** **623,364**

Salaries per Phase:

Phase	Direct	Indirect	Total
Pre-Mob	2,129	1,623	3,752
Mob	60,720	8,116	68,836
Run Time	520,455	3,246	523,701
De-Mob	40,061	0	40,061
Report Writing	0	0	0
Total	623,364	12,986	636,350

*****Travel / Per Diem***** $2,000 /wk **217,429**

Travel Weeks For:	Weeks	
Plant Labor	100.7	(Includes Pre-Mob)
Mgmt Labor	8.0	
Total	108.7	

*****Plant Depreciation***** $/ton 8.50 **510,000**

*****MOB/DEMOB and Site Prep*****

Mobilization/Erection	85,000
Site Prep (Building,Pads,Asphalt, Liner, Bins)	137,000
Revegetation	0
Demob	93,000
TOTAL	**315,000**

Site Prep Details	
Site Grading	5,000
Liner	0
Asphalt/Stone	0
Building	80,000
Building & Sludge Pad	40,000
Power Extension	5,000
Water Extension	2,000
Office Prep	0
Miscellaneous	5,000
Installation of Well	0
TOTAL	137,000

Mob	Details	Demob	
30,000	Trucking	30,000	per Vineland Pro Forma
0		0	
50,000	Assembly/Disassembly	50,000	
0	Dieren	0	per A.E. Steel Erectors
0	Edmonton	0	
0	Wastewater Disposal	8,000	
0		0	
5,000	Misc	5,000	
85,000	TOTAL	93,000	

***Excavation/Stage/Prescre	0.00	$/ton	0	Labor 0 / Equip 0 / Misc 0
Transportation	0.00	$/ton	0	

Plant Consumables

Field Office Expense			54,092	Field Office Detail:	Supplies	3,500	/Mo.	
Chemicals	5.00	$/ton	300,000		Furniture	3,500		
Health and Safety	2.00	$/ton	120,000		Office Rent	728	/Mo.	per WHC GE Capital
			474,092					

Equipment Rental			0	Generator:	0 /mo.
				Baker Tank:	0 /mo.
				Compressor:	0 /mo.
Equipment Maintenance	4.00	$/ton	240,000	Boiler:	0 /mo.
				Steam Cleaner:	0 /day
				Mobs:	0 each
Utilities				Loader:	0 /wk.
Electrical(2000KVA)	2.00	$/ton	120,000	Filter Press:	0 /day
Water (35gpm)	1.00	$/ton	60,000		0 mob
Septic Service	0.00	$/mo	0	Transformer:	0 /?
Diesel	0.000	$/gallon	0	for 1 loader and 1 trommel	
	TOTAL UTILITIES		180,000		

IN PROCESS SAMPLING

Process and Residuals Analytical		50,000
Treatability Studies		0
	TOTAL	50,000

RESIDUAL MANAGEMENT

Sludge Disposal:

# of tons	Disp $/ton (Incl. Tax)		
0	150	Hazardous	0
0	90	Non - Haz	0
			0

Sludge Transportation:

# of tons	$/Load		
0	400	Hazardous	0
0	150	Non - Haz	0
			0

Project Data Sheet

Project Name:	WES Scenario 3	**Project Bid Price:**			
Project Number:		***Type:***	Soil Washing		
			Time & Materials plus Fee		
Project Address:		**Subcontractors:**			
Site Phone Number:	403-450-1478	**Plant Used:**	Pilot Plant		
Site FAX Number:	403-450-0909	***Tonnage:***		60,000	
Time Frame:		**Additional Equipment:**			
Start			Trommel		Own
End				Mob	$0
			Gravity Jig		$0
				Mob	$0

Other Contacts:

Name	Position	Phone	FAX
Conference Room	n/a		
	Site Construction Manager		
	Project Manager		
	Technical Manager		

Apartment Address:	
Apartment Phone:	
Apartment FAX:	

Appendix B: Equipment and Technology Sources

The following is a 1998 worldwide alphabetical listing of manufacturers and distributors of physical separation equipment, consulting/contracting firms having expertise or capability in physical separation equipment selection and operation, and other information sources. Every effort was made to ensure that this was a comprehensive listing. However, due to project constraints or lack of response from some entities, some firms have undoubtedly been omitted. Product lines of any of the companies listed may be broader than indicated. Only those products and services considered relative to physical separation and for which information was provided are listed here. Given the dynamic nature of business and consulting, any business listing is bound to be obsolete within a short period unless continuously updated. The following listing will serve as a starting point; however, the user is encouraged to pursue all information sources available to identify other equipment and technology sources. See for example the other information sources at the end of this appendix. In addition to the consulting firms listed here, many of the equipment manufacturers and distributors are also equipped to assist with pilot testing and design recommendations. The user is strongly encouraged to ascertain the performance record of both companies and equipment. Inclusion here is not an endorsement.

Aaron Equipment Company
735 E. Green Street
Bensenville, IL 60106
(630) 350-2200
(630) 350-9047 (fax)

Products: Centrifuges

Alfa Laval Separations, Inc.
North American Headquarters
955 Mearns Road
Warminster, PA 18974-0556
(800) 862-0508
(215) 443-4112 (fax)

Products: Centrifuges

Allied Colloids Inc. (Allied Colloids Americas)
P.O. Box 820
2301 Wilroy Road
Suffolk, VA 23439
(757) 538-3700
(757) 538-3989 (fax)

Products: Chemical reagents (flocculants/coagulants, filtration aids, dust control, flotation reagents, and others)

Bailey-Parks Urethane
184 Gilbert Avenue
Memphis, TN 38106
(901) 774-7930
(901) 774-8444 (fax)

Product Line: Hydrocyclones

Baker Tanks
(800) BAKER 12

Product Line: Containment rental nationwide, mobile and stationary

Barrett Centrifugals Inc.
Box 15059
Worcester, MA 01615-0059
(508) 755-4306 or (800) 228-6442
(508) 753-4805 fax

Products: Centrifuge technology for recovery of industrial fluids, solid/liquid separation

Bateman Equipment Limited (BEQ)
see OSNA Equipment Inc.

Belleville Wire Cloth Co., Inc.
18 Rutgers Ave.
Cedar Grove, NJ 07009
(201) 239-0074
(201) 239-3985 (fax)

Product Line: Wire cloth

Benemax Mining Chemicals
Glenn Corporation
325 Cedar Street
St. Paul, MN 55101-1013
(612) 292-1234 or (800) 453-6267
(612) 221-1926 (fax)

Product Line: Chemical reagents (flotation, dispersants, wetting agents, flocculants, solvents, and others)

Bergmann, A Division of Linatex, Inc.
1550 Airport Road
Gallatin, TN 37066-3739
(615) 230-2217
(615) 452-5525 (fax)

Products: Commercial soil and sediment washing systems

Bethlehem Corporation
25th and Lennox Streets
Easton, PA 18045
(610) 258-7111
(610) 258-8154
bethcorp@bethcorp.com

Product line: Tower filter press

Bird Machine Company, Inc.
100 Neponset Street
South Walpole, MA 02071-9103
(508) 668-0400
(508) 668-6855 (fax)

Products: Centrifuge and filtration equipment

Brandt/EPI
P.O. Box 2327 77305-2327
2800 N. Frazier 77303
Conroe, TX
(409) 756-4800
(409) 756-8102 (fax)

Product Line: Linear motion screen separators, decanting centrifuges, hydrocyclones, dewatering systems

Carpco, Inc.
4120 Haines Street
Jacksonville, FL 32206
(904) 353-3681
(904) 353-8705 (fax)

Product/Service Line: Testing/equipment for: Spirals, concentrating tables, Mozley multi-gravity separator, Floatex classifier, Mozley hydrocyclones. Equipment only: Jigs and centrifugal jigs.

CESL
Cominco Engineering Services Ltd
1636 West 75th Avenue
Vancouver, B.C.
Canada V6P 6G2
(604) 264-5610/264-5500
(604) 264-5555 (fax)

Expertise/Services: Operating internationally in the mining, pulp, paper and petrochemical industries. Process equipment supply, metallurgical and environmental testing and engineering, including: column flotation, oil/water separation, organic recovery, waste/water treatment (acid rock drainage and metals contaminated industrial effluents)

Compass Wire Cloth
629 Ryan Avenue
P.O. Box 305
Westville, NJ 08093
(609) 853-7616, or (609) 583-1387 ,or (800) 257-5241

Product Line: Wire cloth

Continental Conveyor & Equipment Company
P.O. Box 400
Winfield, AL 35594
(205) 487-6492
(205) 487-4233
Telex 59769

Product Line: Conveyors, conveyor idlers, dynamic modeling of conveyor systems

Dorr-Oliver Inc.
612 Wheeler's Farm Rd
P.O. Box 3819
Milford, CT 06460-8719
(203) 876-5400
(203) 876-5412

Product Line: Hydrocyclones, flotation equipment, belt filters, sand horizontal pan filter, stationary inclined screens, Hydrosizer multi-pocket classifier, Monosizer single-pocket classifier, decanter centrifuges, MERCO Disc-nozzle centrifuges

EIMCO Process Equipment
1951 Creelman Avenue
Vancouver, B.C., Canada V6J 1B8
(604) 731-7030
(604) 738-8818

Product Line: WEMCO flotation cells

Encyclon Inc.
6705 14th Avenue
Kenosha, WI 53143
(414) 654-0032
(414) 657-7435

Product Line: Cyclonic filtration systems (Hydrocylones), Oil skimmers

Ferguson Perforating and Wire Company
130 Earnest Street
Providence, RI 02905
(401) 941-8876
(401) 941-2950 (fax)
1-800-341-9800
TELEX: 92-7539

Product Line: Perforated metal/screening materials

Filtration /Treatment Systems, LTD.
204 First Avenue South
Third Floor
Seattle, Washington 98104
(206) 652-2424
(206) 652-9333 (fax)

Products: Lamella and reactor clarifiers, rotary vacuum filter, filter press, basket centrifuges, etc.

Floatex Separations Ltd.
Buswell's House
Crick, Northampton
NN6 7TT UK
0788 822387/823754
0788 823753 (fax)

Product Line: Floatex density separator (hydroseparator)

Flottweg GmbH
P.O. Box 1160
D-84131 Vilsbiburg
Germany
+49 -8741/301-0
+49 -8741/301-3 00 (fax)

Products: Decanter centrifuges, belt presses

Fluid Systems Inc.
2808 Engineers Road
Belle Chasse, LA 70037
(504) 393-1804
(504) 393-7080 (fax)
1-800-232-1804 (USA only)
fsinola@aol.com

Products: Shaking screens

Franklin Miller
60 Okner Parkway
Livingston, NJ 07039
(201) 535-9200
(201) 535-6269 (fax)

Products: Size reduction equipment (crushers, shredders, delumpers)

Gilson Company, Inc.
P.O. Box 677
Worthington, Ohio 43085-0677
(614) 548-7298 or (800) 444-1508
(614) 548-5314 (fax) or (800) 255-5314 (fax)

Product Line: Laboratory scale testing screens, rifflers, etc.

Graver Water Systems Inc.
750 Walnut Avenue
Cranford, NJ 07016
(908) 653-4200
(908) 653-4300 (fax)

Product Line: Lamella clarifier

Hendrick Screen
3074 Medley Rd
P.O. Box 22075
Owensboro, KY 42304-2075
(502) 685-5138
(502) 685-1729 (fax)

Product Line: Sludge thickeners, screen components

Humphreys (A division of Carpco, Inc.)
4120 Haines Street
Jacksonville, FL 32206
(904) 353-3681
Telex. 5-6367

Product Line: Wilfley concentrating tables, spirals

IHC Holland
PO Box 204-3360
AE Sliedrecht
The Netherlands
TEL.+31(184)411555 - TELEX 26734
TELEFAX +31(184)411884

Products: Washing, classification and separation plants for the sand and gravel industry

Infilco Degremont Inc. (IDI)
P.O. Box 71390
Richmond, VA 23255-1390
(804) 756-7600
(804) 756-7643 (fax)
1-800-446-1150

Products/Services: Full service equipment and system design and supply, pilot testing, treatability studies for wastewater. Clarifiers, filters, thickeners.

Innovat Limited
P.O. Box 61018
Oakville, ON L6J 7P5 Canada
(905) 469-1062 (fax)
innovat.limited@sympatico.ca

Product Line: Leaching vats

JETFLOTE Pty Limited
Engineering Building EB
University Drive
Callaghan, NSW 2308 Australia

Product Line: Wastewater engineering and design featuring Jameson cell floatation

Johnson Screens
(a U.S. Filter Company)
P.O. Box 64118
St. Paul, MN 55164
1-800-VEE-WIRE
(612) 638-3184
johnsonscreens.com/

Product Line: Vibrator screens

Knelson Gold Concentrators, Inc.
20321-86 Avenue
Langley, B.C.
Canada V3A 6Y3
(604) 888-4000
(604) 888-4001 (fax)

Products: Knelson concentrators

Krebs Engineers
5505 West Gillette Road
Tucson, AZ 85743
(520) 744-8200
(520) 744-8300 (fax)

Product Line: Hydrocylones, Krebs VariSieve (variable sieve bend), Liquid/Liquid Separators

Lakefield Research
185 Concession St.
Postal Bag 4300
Lakefield, ON, Canada K0L 2H0
(705) 652-2000
(705) 652-6365

Services: Pilot plant testing: flotation, spirals, tables, centrifugal separators. Water and solids characterization.

Larox
8655 East Via de Ventura Rd
Suite G227
Scottsdale, AZ 85258
(602) 922-2444
(602) 922-8470 (fax)

Product Line: Belt pressure filters

Macon Wire/DEWCO
2913 Joycliff Road
Macon, GA 31211-2805
(912) 745-5419
(912) 741-1394 (fax)
1-800-768-9155

Product Line: Vibro-separators (circular shaking screens)

McNichols Co.
2161 Kingston Court
Marietta, GA 30067-8901
(770) 952-0800
(770) 952-0858 (fax)
1-800-237-3820

Product Line: Wire cloth, perforated metal, expanded metal

Merrick Industries, Inc.
10 Arthur Drive
Lynn Haven, FL 32444
(904) 265-3611
(904) 265-9768 (fax)

Products/Services: Gravimetric heavy duty weigh feeder, other material feeders and controllers, belt conveyor scales, water treatment systems, material testing

METPRO Supply Inc.
1550 Centennial Blvd.
Bartow, FL 33830
(813) 533-7155
(813) 533-7401 (fax)

Product Line: Hydrocyclones, static screens, vibrating screens, pumps, tanks, stackers, crushers

Midwestern Industries, Inc.
P.O. Box 810
Massillon, OH 44648-0810
(330) 837-4203
(330) 837-4210 (fax)

Product Line: Vibrating screens, porta-sifters, gyra-vibratory separators, scalpers (grizzlies), wire cloth

MIM Technologies GPO
Box 1433
Brisbane Qld 4001 Australia
+617 3833 8394
+617 3833 8311 (fax)

Product Line: Jameson flotation cell

Minerals Processing Techniques, Inc. (MPTI)
P.O. Box 545
Auburn, NH 03032
(603) 483-5686
(603) 483-0315 (fax)

Product Line: Disk filters

Mozley (Richard Mozley Limited)
Cardrew, Redruth
Cornwall, TR15 ISS, UK
+44 (0)1209 211081
+44 (0)1209 211068 (fax)

Products/Services: Multi-gravity separators, hydrocyclones

Newark Wire Cloth Company
351 Verona Avenue
Newark, New Jersey 07104-1798
(201) 483-7700
(201) 483-6315 (fax)
1-800-221-0392

Product Line: Wire cloth, sieves, strainers

Noxon
Box 100 24
S-434 21 Kungsbacka, Sweden
+46 300-710 65 (telephone)
+46 300-196 04 (fax)

Products: Decanter centrifuges

Osna Equipment
7550 West Yale, #B-100
Denver, CO 80227
(303) 985-0238
(303) 985-0624 (fax)

Product Line: Flotation machines, linear screens/vibrating screens, belt filters, grizzlies, feeders, auxiliary equipment (agitators, mixers), magnetic separators

Outokumpu Mintec OY Automation
P.O. Box 84
SF-02201 Espoo, Finland
+358 0 4211 (telephone)
Telex 123677 omin sf
Telefax 358 0 421 2614

Product Line: Automatic elemental analysis (XRF real time analysis of product streams), particle-size analysis of continuous processes

Peterson Filters Corporation
1949 South 3rd West
P.O. Box 606
Salt Lake City, Utah 94110
(801) 407-7761

Product Line: Rotary vacuum filters (disc and drum type), flocculators, attritioning equipment

Phillips Chemical Company
309 Short Street
Bartlesville, OK 74004
(918) 661-0323
(918) 661-5174 (fax)
TELEX: 49-2455

Product Line: Flotation chemicals

Pleiger Plastics Company
P.O. Box 1271 - Crile Road
Washington, PA 15301-1271
(412) 228-2244
(800) PLEIGER
(412) 228-2253 (fax)

Product Line: Impact beds, polyurethane parts, including transport rollers, liners, hydrocyclone internals, valve balls

Powerscreen of Florida, Inc.
P.O. Box 5802
Lakeland, FL 33807-5802
(941) 687-7153
(941) 680-1289

Product Line: Portable screening and washing equipment, trommels

RAHCO International
N. 8700 Crestline
P.O. Box 7400
Spokane, WA 99207-0400
(509) 467-0770
(509) 466-0212 (fax)

Products/Services: System design and equipment manufacture for environmental remediation and bulk material handling

Richard Mozley Limited
Cardrew, Redruth, Cornwall TR 15 1SS
United Kingdom
(01209) 211081
(01209) 211068 (fax)

Product Line: Manufacturer, Mozley Hydrocyclones

RMS-Ross Corporation
44325 Yale Road West
Chilliwack, BC V2R 4H2
(604) 792-5911
(604) 792-7148 (fax)

Product line: Jigs

SANBORN Technologies
9 Industrial Drive
Medway, MA 02053-1796
(508) 533-8800
(508) 533-1440 (fax)

Products: Turbo separators (high-efficiency industrial centrifuges)
Soli Pac Separators (solids removing centrifuges)

Separators, Inc.
747 E. Sumner Ave.
Indianapolis, IN 46227
(317) 786-7832
(317) 782-3384 (fax)
(800) 233-9022

Products/Services: Centrifuges (sales/service of reconditioned units), test centrifuges, process test engineers, consultation

SWECO Products, Division of Emerson Electric Company
7120 New Buffington Road
Florence, KY 41022
800-849-3259
(606) 727-5122 (fax)

Product Line: Vibrating screens, sieve bends

T-Systems International, Inc.
7545 Carroll Road
San Diego, CA 92121-2401
(619) 578-1860
(619) 578-2344 (fax)

Products: T-Tape (perforated tape for heap leaching)

Technequip Limited (Subsidiary of Fuller-Traylor Inc.)
297 Garyray Drive
Toronto, Ontario, Canada M9L 1P2
(416) 749-3991
(416) 749-9767 (fax)

Product Line: Hydrocylones, Tech-Taylor valves

Techpro Mining Products Limited
2125 Wyecroft Rd.
Oakville, Ontario, Canada, L6L 5L7
(905) 847-6620
(905) 847-9052 (fax)

Products/Services: Laboratory/pilot plant/process equipment: Attrition equipment, conveyors, filters, flotation cells, jigs, spirals, thickeners, heavy media separation systems, hydrocyclones, hydraulic classifiers. Pilot plant/process design. Equipment refurbishing and rebuilding, removal or relocation, supervision, installation supervision, plant liquidation and appraisals.

Tessenderlo Kerley, Inc.
(Headquarters)
2801 W. Osborn Road
Pheonix, AZ 85017
(800) 669-0559
(602) 528-0683 (fax)

Products: Sulfur chemicals for the mining industry including xanthates, filter aids, depressants, cyanide destruction chemicals

Technical and Laboratory Services
2840 W. Twin Buttes Rd
Sahuarita, AZ 85629
(520) 791-2940
(520) 625-8091 (fax)

Products: Chemical reagents (Flotation, filter aids, water treatment)

TOYO Pumps
3807 Howland Ave.
Schofield, WI 54476
(715) 359-3428
(715) 359-9828 (fax)

Product Line: Slurry pumps

Triple/S Dynamics Inc.
P.O. Box 151027 75315-1027
1031 S. Haskell Ave. 75223
Dallas, Texas
(214) 828-8600
(214) 828-8688 (fax)
1-800-527-2116

Product Line: Trommels, vibrating screens, conveyors, fluidized-bed dry separator

Veronesi
Via Don Minzoni, 1
40050 Villanova di Castenaso
Bologna, Italy
(051) 6054511 (telephone)
Telex 511029 VERSEP I
(051) 6053183 (fax)

Products: Self-cleaning centrifuges (food and beverage applications)

Warman International, Inc.
2701 South Stoughton Rd.
Madison, WI 53716
(608) 221-2261
(608) 221-5810 (fax)

Product Line: Slurry pumps, slurry valves, hydrocyclones, agitators

Waste-Tech Inc.
1931 Industrial Drive
Libertyville, IL 60048
(708) 367-5150
(708) 367-1787 (fax)

Product Line: High pressure dewatering equipment (Python pinch press)

Wedge Wire
P.O. Box 157
22069 Fairgrounds Rd
Wellington, OH 44090
(216) 647-3341
(216) 647-5887 (fax)
1-800-344-9473

Product Line: Screening material

WesTech
P.O. Box 65068
Salt Lake City, Utah 84165-0068
(801) 265-1000
(801) 265-1080 (fax)

Product Line: Clarifiers, thickeners, belt, disc and pressure filters, screw type and reciprocating rake classifiers

Western Mine Engineering Inc.
222 West Mission Ave., Suite 218
Spokane, WA 99201
(509) 328-8023
(509) 328-2028 (fax)
1-800-400-MINE

Services: Mine and mill equipment cost estimating guide, software.

The Western States Machine Co.
1798 Fairgrove Ave.
Hamilton, OH 45011
(513) 863-4758
(513) 863-3846 (fax)

Products: Centrifuges

Westfalia Separator, Inc.
100 Fairway Ct.
Northvale, NJ 07647
(201) 767-3900
(201) 784-4399 (fax)

Products: Centrifuges

Westpro Sales Inc.
1760 Bonhill Road
Mississauga, Ontario, Canada L5T IC8
(905) 795-9606
(905) 795-9608 (fax)
1-800-667-1111
sales@westproequip.com

Product line: Remanufactured equipment: crushers, flotation cells, vibrating screens, filters, hydrocyclones

Witco Corporation
One American Lane
Greenwich, CT 06831-2559
(800) 948-2695
(203) 552-2893 (fax)

Products: Chemical reagents (Flotation, surfactants, dust suppression, and others)

W.S. Tyler Inc.
3200 Bessemer City Rd
P.O. Box 8900
Gastonia, NC 28053-9065
(704) 629-2214
(704) 865-6533 (fax)
1-800-238-9537

Product Line: Vibrating screens, high-speed, high-capacity screens, rock screens, circle throw vibrating machine, solution (dewatering) screen.

Yardney Water Management Systems, Inc.
6666 Box Springs Blvd.
Riverside, CA 92507-0736
(909) 656-6716
(800) 854-4788
(909) 656-3867 (fax)
Product Line: Sand media filters, Multi-media filters, Centrifugal separators

Other Information Sources

"Innovative Site Remediation Technology: Soil Washing/Soil Flushing"
Edited by William C. Anderson, Monograph Task Group Chair: Michael J. Mann, American Academy of Environmental Engineers,1993.

Information: Appendix A, List of vendors and contacts

SEDTEC (Sediment Technology Directory)
c/o Ian Orchard
Environment Canada
4905 Dufferin St, 2nd Floor
Downsview, Ontario M3H 5T4
(416) 739-5879
(416) 739-4342 (fax)
csrp@aestor.am.doe.ca

Information: Directory of contaminated sediment removal and treatment technologies

Vendor Information System for Innovative Treatment Technologies (VISITT)
US EPA Office of Solid Waste and Emergency Response, Technology Innovation Office
http://clu-in.com/visitt.htm

Information: A database of innovative treatment technologies compiled by USEPA, Version 6.0 December 1997