The Beneficial Reuse of Dredged Material for Upland Disposal

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EXECUTIVE SUMMARY

Dredging activities in southern California are necessary for maintenance of existing navigation channels, and construction of new port and harbor facilities. This continued need to dredge will produce millions of cubic yards of material each year throughout the southern California area. Much of this material will be determined to be not suitable for unconfined aquatic disposal due to unacceptable levels of chemicals in the sediments. The Contaminated Sediment Task Force in southern California has recognized that a need exists to develop a comprehensive strategy to deal with contaminated sediments generated in the dredging process. Part of this strategy will be to develop beneficial reuse and rehandling capabilities in the region, especially for contaminated dredge material. Contaminated dredge material can be reused in a variety of beneficial ways including fill material, both for construction and environmental projects, and as a raw material for construction products such as bricks, blocks, tiles, aggregates and topsoils.

The reuse of dredged material, whether contaminated or not, requires a centralized containment facility to dewater sediment and provide a location for rehandling. Several general designs exist for rehandling facilities, while the most common is a pond surrounded by heavy diked walls. Effective management of a rehandling facility will require staff skilled in engineering, sediment handling, and water quality. Dredge mateial can be reused using a variety of technologies available today. These technologies, many of which have been demonstrated in pilot projects, can be separated into four distinct categories: (1) Contaminant Separation; (2) Contaminant Destruction; (3) Contaminant Reduction; and (4) Contaminant Stabilization. Separation methods include thermal techniques such as desorption and vitrification. Both methods can be useful in removing contaminants from the sediment matrix, but are cost intensive, and require large energy input. Destructive removal of contaminants involves chemical treatments to react contaminants, and can target specific contaminant mixes such as halogenated compounds. Methods designed to reduce the contaminant load such as sediment washing, and solvent extractions. Stabilization methods are designed to immobilize contaminants and are used to formulate the base material for products such as bricks, tiles, and aggregates.

In order to proceed with a concerted reuse/rehandling strategy in the southern California area, a comprehensive management strategy needs to be developed that addresses the end user community, logistics related to sediment movement, dewatering, and reuse, and suitable reuse technologies. Finally, a financial plan involving all the stakeholders will be necessary to provide the necessary capital for a reuse/rehandling effort in the southern California area.

1.0 INTRODUCTION

The continued need to dredge, both for maintenance of existing channels and to construct new terminals, channels, and waterways, will produce millions of cubic yards of dredge material each year throughout the southern California area. Of these millions of cubic yards of material, some will be determined to be suitable for unconfined aquatic disposal (SUAD) and some will be determined to be not suitable for unconfined aquatic disposal (NUAD). Disposal options for both SUAD and NUAD material are limited, especially in a highly populated area such as that found in southern California. Until recently, dredged sediment was seen strictly as a waste product of the dredging process, particularly when determined to be NUAD material. Dredge material is increasingly seen today as a resource, and strategies and methodologies for the beneficial reuse of dredge material are being developed throughout the world. The southern California dredging and regulatory community has recently formed the Contaminated Sediment Task Force (CSTF) to address dredging issues. The CSTF is made up of federal, state, and local regulatory agencies, the dredging community (e.g., ports and harbors), and various environmental groups. The CSTF in southern California has recognized the need to develop a long-term strategy for managing contaminated sediments. One of these management strategies is to explore and develop upland disposal and beneficial reuse options for contaminated material generated from the southern California area. The purpose of this report is to document and present the state-of-the-art in technologies for the beneficial reuse of dredge material in upland disposal options.

The ability to reuse dredge material is important because it reduces offshore disposal of SUAD material and provides an alternative to disposal of NUAD material in landfills that are already becoming overtaxed. Disposal options for NUAD material are limited, especially in the southern California area. Most NUAD material must be disposed of on-site (i.e., used for fill at a port or harbor), or shipped offsite. These options are often very expensive. It should be pointed out that dredged material determined to be NUAD may be suitable for many beneficial upland uses. The NUAD determination only relates to unconfined aquatic disposal, and aquatic criteria are much more conservative than human health criteria. NUAD material is most often not a concern for human health risk. Only on very rare occasions is marine sediment contaminated to a level that would classify it as a human health risk, or require hazardous waste handling and disposal.

Several large-scale reuse projects are underway in California utilizing technology currently available and include operations throughout the Bay Area (*ENTRIX et al., 1991*; *EPA et al., 1998*; *Jones & Stokes, 1998; USACE/POAK, 1994; USACE, 1999*); Port of Los Angeles (Pier 400); Port of Long Beach (West Basin); and Moss Landing Harbor (*HLA, 1999*). These projects have provided disposal alternatives enabling large deepening, standard maintenance, and emergency dredging projects to go forward in the absence of suitable offshore disposal alternatives, or the expensive use of upland landfill options. Several challenges exist, however, to the efficient and cost-effective reuse of dredge material. One challenge is in identifying the end-user community and communicating the suitability of marine sediments as an alternative to otherwise available fill material. Several attempts have been undertaken in northern California to identify the end-users of dredge material (*POAK, 1999a,b,c*). These have been met with mixed results. Sediment reuse projects involve a unique set of engineering challenges involving the rehandling of material that must be met prior to efficient reuse. These include determining the need to dewater sediment in a holding pond or facility, specific pond location, pond design, sediment transport methodology, and materials separation techniques. These challenges must be met in order to develop an efficient and cost-effective reuse project. Finally, after the rehandling issues are dealt with, another challenge in identifying the most suitable reuse technology for a given application must be addressed. Reuse technologies vary from simple (e.g., mixing, drying), to

complex (e.g., high-temperature vitrification) and depend on the degree of contamination and the sediment's physical characteristics. Currently, dredge material is reused in both volumetric (i.e., landfill) and construction fill projects. Smaller scale projects have attempted to use dredge material in formulated soils for landscaping purposes as well.

2.0 CONTAINMENT AND REHANDLING TECHNOLOGIES

After material is dredged from a project site, it must be placed into a containment area that will facilitate the efficient dewatering of the material, or will keep the dredged material from migrating. Several different containment designs have been employed throughout the industry. These include contained aquatic disposal (CAD) facilities and confined disposal facilities (CDF; Figure 1). Typical CAD sites are located within the aquatic environment. CAD sites are not generally considered beneficial reuse projects because they are typically used only to contain NUAD material. Typically these are containment pits or sub-surface diked areas and are generally capped with clean material. Placement can be made within a channel or waterway or along the shoreline. One beneficial use of this type of placement is to increase the subtidal shallow water habitat of a region. The Port of Oakland (*Hartman, 1997*) has proposed the use of a large CAD site in Oakland Middle Harbor to contain several million cubic yards of material and increase shallow water habitat, including threatened eelgrass beds and fish nursery areas. This is a good example of a CAD site utilized in a beneficial manner.

The more beneficial type of facility when considering the reuse of dredge material is a CDF facility. CDF sites can be more economical than open water disposal and are the most common option for containment of NUAD material, although many throughout the United States are used to contain SUAD material. CDF facilities can be placed in-water to form islands, along the shoreline as fill, and most commonly, in an upland setting (Figure 1). They are typified of large diked areas having heavy filled walls with rip-rap or rock armor. They are favored because they can maintain efficient contaminant pathway control, facilitate efficient long-term monitoring of the dredge material and dewatering effluent, and allow easy access to material for removal and reuse. These advantages come from the accessibility of the facility, being built behind diked walls. Consideration must be made in the location of the site as to the ultimate use of the material (i.e., the final destination of material) and the efficiency of delivery of material to the facility. Upland CDF facilities are best placed close to a waterway that will allow timely and cost-effective offloading of material.

The most efficient offloading methods are slurry pumping and clamshell delivery directly to the pond. Delivery methods and rates to a CDF are regulated by several factors. The accessibility or distance of a CDF from the offloading site is the primary determinant of offloading rate. Facilities that are directly accessible to barge traffic can efficiently accept material using a clamshell or other mechanical delivery system. When direct access is not possible material is mixed with water and pumped as a slurry to the CDF. Pumping requires access to a large pump with a constant power source, right-of-way for pipelines, and a large water source. Figure 2 shows the large pump barge Liberty offloading a sediment scow to the

Sonoma Baylands CDF facility in the Bay Area. The *Liberty* is owned and operated by Dutra Construction in San Rafael, California. The size of a facility will also help determine the type and rate of delivery. Smaller facilities will fill faster and delays may be necessary for dewatering, especially if using slurry delivery systems.

Dewatering of dredge material from a containment facility is critical to the operation of a CDF. As dredge material settles, associated pore water and slurry water are extruded and must be discharged. Figure 3 shows a large CDF facility after a season of drying. Large cracks in the sediment can be seen as the material settles and dries. The dewatering flow may contain contaminants and this may affect the ability to discharge water back to the ocean or harbor. Discharges to waters of the State are regulated under the Clean Water Act (CWA) Section 404. Discharge also requires a Section 401 water quality certification or waste discharge permit from the State. Figure 4 shows a discharge weir at the Galbraith CDF in Oakland, CA. Water quality of the decant water from dewatering operations at CDF facilities in California are regulated through a NPDES discharge permit obtained through the local Regional Water Quality Control Board. In order to avoid excessive dewatering, or when most of the water has been extracted, the dredge material within the CDF may be augmented with drying agents or mechanically manipulated to facilitate drying. Once material is dried to a manageable consistency it can be moved off-site for reuse.

One innovative mechanism to remove water from dredged material was employed on the St. Lawrence River in Canada (*EC, 1995*). This program was a small-scale demonstration program that treated approximately 5,000 cubic meters of sediment along the river. The project utilized a rotary press to remove water. The continuously operating press was fed a sediment slurry from a dredge operating in the waterway. The rotary press reduced the volume of sediments 5 to 10 times and the dryness level went from 15 percent to 72 percent of total particulate matter during dewatering.

Dredged material, especially that from ports and harbors, is generally fine grained; however, many areas contain large amounts of sand. Some areas may even contain larger gravel and rocks. Each of these different grain size characteristics may be thought of as a separate resource. Fine-grained material, when combined with stabilizers, can be used to form products ranging from cements, to construction materials (see below). Sands can be used to augment structural fill, or used directly as beach replenishment material. Finally, gravel and rocks can be used as sub-base aggregate. Since most contamination is typically found in the fine-grained fractions, separation of sands can provide a clean resource. Efficient separation of these resources can be done in a variety of ways, depending on the goal or expected final use. Before the dredged material can be separated into its grain size fractions, the water must be removed, as described above. Following dewatering the dry, or nearly dry, dredged material can be removed from a containment area and separated into its major fractions.

Separation of dredge material into its grain-size fractions can be a simple consequence of the containment pond configuration, or it may be accomplished through mechanical separators. As material is placed into containment facilities, there is a natural separation of material as finer grained material is carried into the deeper portions of the pond and sandier material is retained near the discharge point. Sand can then be mined from the containment pond with little effort. This, however is not the most efficient process, and recovery of sand generally must wait until the pond has dried sufficiently to facilitate removal. Sediment may be separated using mechanical sieves that are either fixed or rotating to remove sands and larger fractions.

3.0 BENEFICIAL USES FOR CONTAMINATED DREDGE MATERIAL

Industrial, municipal, and commercial users make up the majority of end users of dredged material as a beneficial resource. Several ongoing projects currently utilize these sectors. Industrial users represent the largest sector in terms of numbers of potential users (*POAK, 1999a*) while municipal users probably make up the largest users on a per-cubic yard basis (*USACE, 1999*). Commercial users have embraced dredge material on a much smaller basis and have generally utilized pilot projects to determine marketability of products.

In Northern California, the Port of Oakland has funded a study to identify a regional upland dredged material reuse/rehandling facility (*POAK, 1999a,b,c*) for the San Francisco Bay area. As part of this project a study of the end user communities in the San Francisco Bay area was conducted that included a detailed survey of the construction and redevelopment community. Surprisingly, the results of this survey showed that there was very little enthusiasm in the industrial and commercial communities to utilize dredge material as a resource, especially with NUAD material. Citing the incidence of contamination in the material, industrial users did not see a large user base for material. This included construction fill users as well as general fill users (*POAK, 1999a*). The POAK report concluded that there is clearly the need to educate the end user community as to the risks involved with reuse of dredge material before it will be widely accepted from a public standpoint. This includes addressing the misunderstanding or misinterpretation of the NUAD label by the public. A concerted outreach effort to educate the public on the real risks of NUAD material is warranted to help dispel the notion that NUAD material is "hazardous" or a health hazard.

Even with little recognition on the part of the industrial and commercial communities as to the public acceptance of dredge material as a raw material, many industrial uses of dredge material have been identified. Construction and non-construction (volumetric) fill applications provide the greatest primary use base for sediments in the industrial sector. In addition to fill, industrial uses for material include secondary uses such as mixes, cement bases, and building materials (e.g., bricks) formulated from dredged material. Many of these uses require technologies to stabilize or reduce the contaminant and salt loads typical of marine sediments. One area that readily utilizes dredged material is the sand mining industry. Clean sand is utilized from many areas and includes construction sand and beach replenishment. The agriculture industry has demonstrated a willingness to utilize dredge material as a base for formulated growing soils, especially for freshwater dredge material.

Municipal uses of dredge material include beach nourishment, landfill capping, recreational fill, and habitat development uses. The large CDF facility maintained by the USACE in San Francisco Bay at the Port of Sonoma in Sonoma County, California, utilized SUAD dredge material from the Port of Oakland to restore a wetland previously used as farmland (*ENTRIX et al., 1991*). In a similar project, the USACE and the Port of Oakland are utilizing NUAD and SUAD material to cover the existing runways and restore an area of historical wetland at the old Hamilton Army Airfield in Marin County, California (*Jones & Stokes, 1998*). Many municipalities have utilized SUAD material for beach nourishment projects. This involves utilization of material that is generally greater than 80 percent sand (*USACE, 1987*). Once CDF facilities are filled they can be reused for a variety of activities. The Port of Oakland is currently utilizing the largest CDF in the Bay Area to raise and provide the foundation for a municipal golf course (*USACE/POAK, 1994*).

Commercial markets for dredge material are differentiated from the industrial and municipal end users in their use of sediments as a raw material for a saleable product. These products are often sold to industrial and municipal users, however the technology for the product formulation often resides within the commercial user field. Commercial users have developed tiles, glass, cement blocks, bricks, and potting soils from dredge material. The commercial technology used to make these products is described below.

4.0 GEOTECHNICAL CONSIDERATIONS

One of the most common uses of dredge material is in the construction process for fill, capping and as a raw material for construction materials such as building blocks and cement. The characterization and testing of a dredged material must be matched to a particular beneficial reuse. Reuse in construction purposes requires matching tests to specific project related requirements such as those maintained in local building codes. A number of physical, chemical, and biological tests have been described by the USACE (*Winfield and Lee, 1999*) to characterize sediment for beneficial reuses including construction and engineering applications. Table 1 presents physical and engineering tests recommended for dredged material to determine suitability for construction and engineering applications.

There are currently no regulations that prohibit blending dredge material for construction projects. Blending would accomplish a dilution of contaminants and, more importantly, could provide a better matrix for fill projects. For example, blending clean sandy material with fine-grained NUAD material may produce a better fill product with lower overall contaminants. While individual construction projects may be regulated under local building codes, most fill operations in California will fall under guidance specified by the State. Specifically, fill that will be subject to traffic, such as at container terminals, roads, and for general landfill operations should follow guidelines specified in the Caltrans Highway Design Manual (CHDM; *Caltrans, 1995*). The CHDM provides standard characteristics required for subbases and bases to be used in structural sections. The primary aspect in determining the suitability of material for construction or structural fill is the gravel factor (G_f). The G_f expresses the relative value of various materials as compared to gravel. Gravel factors of various types of base material is presented in Table 2. Under State guidance, asphalt, portland cement, a combination of portland cement and pozzolanic materials, lime, and other cementing or stabilizing agents may be combined with selected soils or native materials to improve their stability and strength as load carrying elements (*Caltrans, 1995*). This could include dredged material used as a component of structural fill. The type and amount of stabilizing agent used with different materials (i.e., dredged material from different sources) should be determined through bench tests using available resources. Cost comparisons can be then be made to determine the most efficient method for development of stabilized material.

5.0 INNOVATIVE TECHNOLOGIES FOR THE BENEFICIAL REUSE OF CONTAMINATED DREDGE MATERIAL

One of the key issues facing the reuse of dredged material is how to remove, decontaminate, or stabilize chemical contamination within the sediment matrix. Several technologies have been developed to accomplish this. The Water Resources Development Act (WRDA) sponsored a demonstration of some of these technologies as part of the Dredged Material Management Plan for the Port of New York and New Jersey (NY/NJ Harbor). Under the Sediment Decontamination Technologies Demonstration (SDTD) program, participants that include federal, state and local governments, several academic institutions, and concerned citizens have been working together to identify, evaluate and demonstrate technologies to treat contaminated dredge material from the Port.

Dredge materials from ports and harbors often contain elevated levels of a variety of contaminants, including dioxin, polychlorinated biphenyls (PCBs), chlorinated pesticides, polycyclic aromatic hydrocarbons (PAHs), and heavy metals. The objective of the SDTD is to treat sediments to render them suitable for ocean disposal, upland disposal, or a variety of beneficial uses. Decontamination and/or stabilization technologies employed under this program demonstrate a variety of processes to reduce, separate, immobilize, or detoxify contaminants. They can be classified into four general functional categories: (1) processes that separate the contaminants from the sediment solids; (2) processes that destroy the contaminants or convert them to less toxic forms; (3) physical separation of course-grained from fine-grained sediments to reduce the volume of contaminants; and (4) physical and chemical stabilization processes that immobilize the contaminants making them resistant to losses by leaching, volatilization and erosion. The SDTD employed both bench-scale and pilot-scale projects in demonstrating these technologies. Several of these are discussed below and summarized in Table 3.

5.1 Thermal Desorption

The process of thermal desorption involves heat to remove the more volatile contaminants from the sediment matrix. Temperatures (around 500 °C) are not high enough to entirely eliminate all organic compounds and most metals (*Hall, 1998*). The process takes place in a rotary kiln. The rotary kiln is merely a tube containing the sediment that is rotated to mix the sediment while the temperature is elevated. The level of decontamination depends on the temperature and amount of time the sediment remains in the kiln. This process was demonstrated and shown to be effective in reducing contaminant levels, however a side product was a waste stream of hazardous material that would require disposal at a hazardous waste treatment facility (*Jones et al., 1999*). The proposed beneficial uses for the end product (decontaminated sediment) were for applications such as construction fill and habitat restoration. Thermal desorpiton production costs have been estimated at between $50 and $70 per cubic yard.

In a similar demonstration, a rotary kiln was used by the Institute of Gas Technology (IGT) to destroy organic contaminants (*Rehmat et al., 1999*). The technology used (Cement-Lock) is similar to that used in the cement industry. One advantage of this technology is that existing cement plants may be able to be used to handle large volumes of dredged material. In the Cement-Lock process, dredged material is reacted in a kiln, proprietary modifiers are added, and the kiln is heated to 1400 °C. This temperature is sufficient to melt the sediment mixture. The high temperature used in the kiln essentially completely destroys all organic compounds and removes much of the metals through volatilization. Remaining metals are locked into the melted matrix. The end result is construction-grade cement. The properties of the cement produced in the Cement-Lock process were found to be acceptable in comparison with industry standards. The pilot-scale treatment plant operates on a capacity of 30,000 cubic yards per year. It was estimated that processing costs are approximately $50 per ton, while the commercial value of the construction-grade cement product is between $50 and $70 per ton. An advantage of thermal desorpiton and Cement-Lock technologies is that they can utilize any type of dredged material.

5.2 Fluidized Bed Treatment

BioSafe Corp. has developed a fluidized bed treatment (FBT) cracking technology that completely destroys organic compounds in dredged material using a high-temperature heating unit (*Jones et al., 1999*). It is not an incineration or oxidation process. It converts all organic materials to carbon monoxide, hydrogen, and methane. The remaining solids are free of organic material and, depending on the metal content, can be disposed of without restriction. The advantage of this technology is that it can operate with a continuous feed of material and can use the material without dewatering. It produces a product free of organic contaminants with 99.9 percent efficiency. Beneficial uses for the treated end product are clean fill, concrete aggregate, cover material, and agricultural material. The disadvantages of this process are that it is extremely energy intensive and costly. Despite promising results in pilot studies, the BioSafe Corp. has discontinued research into FBT technology. Production costs were estimated by BioSafe at between $40 and $120 per cubic yard.

5.3 Plasma Vitrification

Westinghouse Energy Company, demonstrated a plasma vitrification process that destroyed organic contaminants and immobilized metals to form a glass matrix using a high-temperature plasma torch. The plasma torch is an effective method for heating sediments to temperatures that are higher than can be achieved in rotary kilns. Plasma temperatures can reach 3000 °C and at this temperature the sediment is melted using fluxes to produce a glass product. The molten glass can be quenched to produce a glass aggregate or directly fed to glass manufacturing equipment to produce a saleable product (*McLaughlin et al., 1999*). The pilot plant operated at a rate of 100,000 cubic yards per year and it was estimated that a full-scale plant could operate at a rate of 380,000 cubic yards per year. Preliminary costs for sediment processing ranged between $90 and $120 per cubic yard. This glass product can be resold to recover some costs associated with the process.

5.4 Base-Catalyzed Decomposition

The base-catalyzed decomposition (BCD) process was developed by Batelle (*Jones et al., 1999*) and involves a two-stage process for removing halogenated compounds (e.g., dioxins, furans, and PCBs). In the first stage, sediment is mixed with sodium bicarbonate and heated to 340 °C. This vaporizes and partially decomposes the contaminants. The vaporized contaminants are dehalogenated using heat, sodium hydroxide, and a catalyst in the second stage. The volatile and semi-volatile organic compounds present in the contaminated dredged material are also removed by the heat treatment, as are inorganic compounds with high vapor pressure or solubility. The removal/destruction efficiency of the thermal desorption process in handling chlorinated compounds was 99.8 percent in the demonstration project. PAHs could not be removed or decomposed using the BCD process. Metals that remained after treatment were not found to be leachable by standard leachate testing, and the final product was not considered a hazardous waste. Sidestream wastes (e.g., water, volatile and semi-volatile organic compounds, and volatile metals) require a complex material and pollution handling system to minimize environmental emissions. Batelle estimated the cost of dredged material decontamination at a BCD facility treating 150,000 cubic yards per year at $108 per cubic yard.

5.5 Soil Washing

Soil washing technologies have been developed by BioGenesis, Inc. and Roy F. Weston, Inc. The proprietary processes use a blend of biodegradable surfactants (detergents), chelating and oxidizing agents, and high pressure water jets to remove both organic and inorganic contaminants (*Amiran et al., 1999*). This blend of mechanical and chemical processes to clean contaminated sediments showed reduction of the organic compounds by approximately 90 percent and the inorganic compounds by approximately 70 percent. The process produces an end material that is suitable for use as a base for manufactured topsoils (see below). A full scale processing plant is planned that will be able to operate on a scale of 275,000 cubic yards per year. Production costs for soil washing techniques were estimated at between $30 and $50 per cubic yard. A disadvantage of this technique is that in order to become available at a large scale operation (>500,000 cubic yards per year), a very large treatment/handling facility would be required.

In a similar concept, solvent extractions have been used to remove contaminants from dredged material. Organic alcohols have been used to remove the surface coatings of contaminants. Removal efficiency of this method depends on the porosity of the material and the treatment time. The extraction process operates at a temperature of between 37 and 60 °C and uses isopropyl alcohol and isopropyl acetate solvents (*Gasbarro et al., 1998*). This process is not very effective for sediments containing a mix of contaminants, as would be expected from ports and harbor areas, because it does not remove metals, although the use of a chelating agent may help this process.

5.6 Solidification/Stabilization

Sediment solidification/stabilization (S/S) technology is a simple method to treat contaminated sediments by the addition of cement, fly ash, lime and/or chemicals to create soil aggregates. The aim is to mix dredged material with cement and other additives to bind the small particles into larger aggregates with improved physical and chemical properties that qualify the treated sediment for use as aggregate in some types of construction processes. The end product can be used in landfill closure and Brownfield remediation projects. The process has used sediment from both freshwater and marine environments. The S/S technology process has been used following solvent extraction procedures described above. The S/S process has been applied successfully in Japan and the United States (*Jones et al., 1999*). Production costs are estimated at between $30 and $60 per cubic yard.

5.7 Manufactured Soils

One promising use of dredge material is as a raw material base for manufactured topsoil. Both freshwater and marine sediment have been used to produce topsoil and planting mixes for commercial re-sale. Manufactured soils have been created from dredged material in proprietary processes by augmenting sediment with cellulose, biosolids, or a combination of the two. Technology for the development of topsoil products has been funded through the Cooperative Research and Development Agreements (CRDA) program in conjunction with industrial partners. Topsoil manufactured from dredged materials has been used in projects throughout the United States. Some notable projects are recreational fields at Pearl Harbor, Hawaii, and landscaping throughout the city of Toledo, Ohio. Manufactured artificial soils have also been used as cap material at Brownfield sites and Superfund sites.

Scott and Sons Company has developed a process where dredged material is mixed with cellulose waste such as yard waste (e.g., grass clippings), sawdust, and waste paper along with biosolids (e.g., sewage sludge and animal manure) to produce a topsoil product for sale to both municipalities and the public. In a similar process the N-Viro Company produces soils using biosolids, kiln-dust (an alkaline industrial waste), and fertilizer augmentation to produce a potting and topsoil product sold to the public. Both of these products are produced from non-marine dredge material, however, the USACE has tested similar products using soils from New York/New Jersey Harbor (*USACE 1999*). The manufactured soil was shown to be able to grow wetland plants and the USACE also demonstrated that plants grown on this soil helped reduce the contaminant content, particularly the PAH content. The U.S. Navy, in conjunction with the USACE also demonstrated a similar project with marine sediments from Pearl Harbor, Hawaii. In these studies sediment was augmented with shredded classified U.S. Navy papers and local biosolids. Costs associated with manufacturing topsoils from dredged material were around $20 per cubic yard. It should be pointed out that this has only been done on small scale projects and full scale production would require a large area.

5.8 Construction Products

In addition to using dredge material as construction fill as described above, sediment has been used as a raw material for manufacturing construction products such as building blocks, tiles, and bricks. Technologies have been developed to produce these products, although full-scale commercial production is not yet available for all products. Building blocks have been manufactured from dredged material (both freshwater and marine). The proprietary process involves a blend of dredged material and industrial wastes such as ash or glass. Blocks have been used in construction projects such as noise barriers, security walls, and buildings. The manufacturing process involves high compressive forces to form the blocks rather than the heating process commonly used to produce bricks and blocks. Blocks formed in this process meet ASTM standards and can be used for a variety of building projects by unskilled labor. Production costs are estimated at between $20 and $80 per cubic yard to develop construction products from dredged material.

Another construction product made from dredged material is Flowable Fill. This product is made from dredged material, residential waste such as recyclables, and a proprietary binding agent. The product remains in a liquid slurry form similar to cement products, sets up in a short period, and is stable for a long period. The advantage of this product is that it encapsulates any contaminants within the sediment and no leachabililty problems have been observed using this material at Brownfield sites (*USACE, 1999*).

6.0 REVIEW OF REUSE PROJECTS

6.1 Historical Perspective of Reuse Projects

With the realization that in-water disposal options for dredged material are decreasing, more projects are considering the environmental, economic, and aesthetic beneficial use options for dredging projects. Dredge projects are turning to beneficial uses of dredged material both within the United States and abroad. In 1987 the USACE summarized projects that utilized dredge material as a resource in the U.S. and Canada. Some 43 projects were listed for California, and over 1,300 projects were described for the U.S. and Canada together (*USACE, 1987*). Since that time many more projects have been completed throughout the world. The following sections summarize some key programs conducted recently in the U.S. and throughout the world. These projects have been in the forefront of the beneficial use arena and demonstrate new and innovative technologies and workable solutions.

6.2 Projects in the U.S.

The most visible and perhaps the largest beneficial reuse effort has been the series of projects carried out through the Port of New York/New Jersey. Due to restrictions at the local aquatic disposal site and contamination found in the sediments, the port has sought alternative strategies for disposal. These have included the beneficial reuse of material including an assessment of the effectiveness of different technologies for this purpose. Some of these technologies have been described above. Working in conjunction with the EPA, USACE, State and local governments, and citizen groups, the Port has developed a comprehensive treatment train to demonstrate these technologies on a commercial scale.

Dredged material from the Claremont Channel in New Jersey was used in several innovative projects (*O'Donnel and Henningson, 1999*). Sediment was used in major site improvements in the Hugo Neu Schnitzer East (HNSE) ship loading facility that included noise control berms, site re-grading for storm water control, dock rebuilding and rail extensions, and an inter-tidal wetland was created using dredged material from the channel. Sediment from the channel was treated with a PROPAT, a recycled product from automobile shredders, and used as volumetric fill and grading for a new golf course and nearby residential development. Finally, dredged material was mixed with fly ash and a proprietary activator to prepare a low-strength, compacted cementitous grout. This grout was used to seal abandoned Pennsylvania coal mines to reduce acid mine drainage. The estimated cost of the PROPAT demonstration project was $5 million. The estimated cost of using 150,000 cubic yards of material to produce grout to seal mines in Pennsylvania is $6.75 million ($45/cubic yard). Habitat improvement costs associated with the Claremont Channel projects are estimated at $4.5 million.

One of the largest reuse projects on the West Coast is a joint project between the Port of Oakland and the USACE. In order to deepen the Port of Oakland to –42 feet, approximately 4.5 million cubic yards of material that was determined to be NUAD material needed to be placed in an upland disposal facility. A large confined disposal facility was created on the footprint of the Galbraith golf course (*USACE/POAK, 1994; EPA et al., 1998*). The golf course was removed, and slurried dredge material from the port was delivered to the site over a three-year period. Decanted water was discharged to San Francisco Bay under a permit from the RWQCB. Following treatment and drying in the disposal facility, a new golf course will be constructed and maintained. The Port is currently in the process of obtaining permits for both in-bay and upland disposal of up to 22 million cubic yards of material for the -50 foot project.

In a related project, the Sonoma Baylands Tidal Marsh Restoration Project (developed by the California State Coastal Conservancy and the Sonoma Land Trust), restored a bayland to its "historic" conditions using approximately 2 million cubic yards of clean dredged material from the San Francisco Bay area (*ENTRIX et al., 1991; Urso and Mohan, 1996*). Most of the dredged material (approximately 1.7 million cubic yards) came from the Port of Oakland's –42 foot project, and the remainder (approximately 0.25 million cubic yards) came from the Petaluma River. This uncontaminated material was placed in a 322 acre tidal wetland designed to aid two endangered species: the salt marsh harvest mouse, and the California clapper rail.

On the West Coast, the Moss Landing Harbor project is an example of a small to medium sized beneficial reuse project (Figure 5). The Moss Landing Harbor District (MLHD) was unable to dredge their commercial and recreational harbor as a result of elevated pesticides and a lack of a suitable upland site for disposal. The MLHD, working closely with Federal (e.g., EPA, USACE, U.S. Fish and Wildlife Service, National Marine Sanctuary) and State (RWQCB, California Department of Fish and Game, California Coastal Commission) agencies obtained permits to develop an upland drying and processing site. In conjunction with this site, the MLHD utilized cement additives (a waste product from a refractories plant) to provide base material for structural fill in road construction, parking lot, and the development of a new recreational use facility (*HLA, 1999*). Approximately 110,000 cubic yards has been utilized in this manner to date.

6.3 Projects Outside of the U.S.

Most countries outside of the U.S. do not have as stringent regulations requiring upland disposal of dredged material and most beneficial reuse project are completed to fill existing bays or aquatic areas to create additional land. Some of these projects are described below.

The government of Tunis is preparing to fill approximately 900 hectares of the 1600 hectare Lac Sud in a remediation project for planned future residential development (*DEME, 1999*). The city of St. Petersburg, Russia is removing approximately 11 million cubic yards of material that is contaminated with metals and organic pollutants. The material will be separated into sand and fine-grained fractions using a mechanical separator. The relatively clean sand will be reclaimed for construction purposes, while the fine-grained fraction will be disposed in a landfill (*DEME, 1999*).

Shallow areas in the St. Lawrence River at the Port of Sorel that posed a navigational hazard were dredged and found to contain elevated levels of metals (*EC, 1995*). In a project in conjunction with Environment Canada (EC), the Port initiated a demonstration project to remove the sediment, dewater it, and treat it to decrease the amount and toxicity of metals. The project involved a rotary press and additives as described above to dewater and decontaminate the sediment. The dewatering process yielded a dry cake, however production rates were low due to very high fine grain content. During the dewatering process approximately 30 percent of the metals were removed, making the sediment suitable for disposal. The cost of this process was estimated to add approximately 30% to the overall cost of dredging and disposal.

The United Kingdom has initiated a study to evaluate the use of dredged material in the restoration of salt marshes throughout the country (*Landin et al., 1999*). Dredged material from a variety of ports and harbors will be utilized to provide fill and habitat for wetland species.

7.0 FUTURE DIRECTIONS

With the continued need to dredge and the ever-decreasing disposal options available, it is important that the Southern California dredging community develop a comprehensive policy to pursue the beneficial reuse of dredge material. One important aspect of this policy will be to develop a regional rehandling facility for dredged material. The Port of Oakland, with funding from the State Coastal Conservancy, is currently carrying out a feasibility study for a regional rehandling facility for dredged material in the San Francisco Bay Area (*POAK, 1999a,b,c*). Under the feasibility study, the Port of Oakland hired a consultant team to investigate options available to the Bay Area dredging community. Specifically, the feasibility study will address: (1) a review of potential sites for their environmental, engineering, and economic features; (2) identification of potential end-users for dredged material from a rehandling facility; (3) recommended sites for consideration, and; (4) a detailed engineering plan and financial analysis for implementation of a regional rehandling facility for dredged material. The program has been broken down into the following set of tasks:

- Task 1. Identify Four Potential Rehandling Sites for Further Evaluation
- Task 2. Investigation of Demand/Reuse Options for Four Selected Sites
- Task 3. Feasibility Analysis of Selected Sites
- Task 4. Legal Liability Issues and Environmental Site Assessment
- Task 5. Develop Economic Analysis, Capital and Operational Plan
- Task 6. Prepare Preliminary Engineering Design
- Task 7. Develop Permit Acquisition Plan.

A committee of interested agencies, environmental groups, and business and port interests was formed to help direct the dynamic nature of the project. The Dredged Material Rehandling Project (DMRP) committee meets regularly and reviews the work products of the tasks, and provides feedback and report comments. The DMRP votes on aspects of the project and helps direct the tasks future direction. To date, Tasks 1, 2, and 3 have been completed and Task 4 is underway. The project has an overall budget of $750,000 and has cost approximately $500,000 to date, although some of this cost has been used to develop engineering specifications on prospective sites in addition to the stated project tasks (*L. Cardoza, Port of Oakland, personal communication*).

The DMRP program serves as a model that can be carried out in Southern California and lead by the CSTF. One of the key issues that a Southern California effort will face is available space. Un-developed space is more available in the Northern California area than in Southern California, although the best available area would be in the Port of Los Angeles/Port of Long Beach area. These port facilities not only are responsible for the majority of dredged material, they also maintain the best available land options.

One of the most important aspects of a rehandling facility will be access for both delivery and recovery of dredged material. Port facilities with established truck, rail, and water access offer the most options for dredged material delivery and recovery. Airport facilities may also serve to provide land access, and this option has been considered at both Oakland and San Francisco airports in the Bay Area. One of the biggest constraints on developing a reuse facility will be in establishing an end-user base. Considerable reuse of material may be incorporated in the port facilities, especially if the re-handling facility is located within the area; however, a concerted effort needs to be established to educate the potential end-users of the benefits of utilizing dredge material as a resource. With a coordinated effort between dredgers, regulators, environmental groups, and the public, development of a rehandling facility and the establishment of the acceptance of the beneficial reuse of dredged material can be achieved in the Southern California area.

8.0 CONCLUSIONS

The technology exists today to meet the needs of the southern California dredging community in dealing with the most contaminated dredge material, however; before full-scale rehandling and reuse of dredge material is implemented in the southern California area, several issues need to be addressed. First, the southern California dredging community needs to develop a comprehensive management strategy to pursue beneficial reuse as a regional goal. The CSTF has made great strides in this area, but needs to formalize a policy. This will include developing public acceptance of reuse as a beneficial product of necessary dredging activities. Second, a regional reuse/rehandling facility needs to be developed. This includes space for dewatering and handling sediment, as well as space for utilization of reuse technologies applicable for the local area. Reuse technologies that lend themselves best to the southern California are those that produce construction-related materials such as aggregate, cement, and building blocks. Third, a comprehensive study of the end user community for reuse of contaminated dredge material needs to be completed. This will provide information to the dredging community on the amount of dredge material that can feasibly used in reuse projects. Reuse of material by the primary generators (i.e., Ports), is probably the best and easiest reuse of material and avoids the added problems of developing a user base. Finally, a financial plan needs to be developed with all stakeholders involved to determine the best use of limited resources to within the region for the beneficial reuse of contaminated dredge material.

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The Beneficial Reuse of Dredged Material
for Upland Disposal

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TABLES

Table 1. Recommended Tests for Physical and Engineering Properties of Dredged Material to Evaluate Its Suitability of Beneficial Reuse (*Winfield and Lee, 1999*)

Physical Analysis	Source
Grain Size	
Standard Sieve Test	ASTM D422-63; COE V; DOD 2-III, 2-V, 2-VI, CSSS 47.4
Hydrometer Test	ASTM D422-63; CSSS 47.3; COE V
Pipette Test	CSSS 47.2
Particle Shape/Texture Test	ASTM D2488; D4791-95; D3398-93
Water Content/Percent Moisture	ASTM D2216-92; COE I-1, DOD 2-VII
Permeability	ASA 41-3 and 41-4; ASTM D2434-68
Atterberg Limits (Plasticity)	ASTM D4318-9 5; COE III; DOD 2-VIII
Organic Content/Organic Matter	ASTM D2487-93

Engineering Properties	Source
Compaction Tests	
Proctors	COE VI
Standard Compaction Test	ASTM D698-91
Modified Compaction Test	ASTM D1557-91
15 Blow Compaction Test	ASTM D5080.93
California Bearing Ratio	DOD 2-IX
Consolidation Tests	COE VIII; ASTM D2435-90
Shear Strength	
UU (Unconsolidated, Undrained)	COE X-18
CU (Consolidated, Undrained)	COE X-29
CD (Consolidated, Drained)	COE IX-38

Notes:

ASTM = American Society of Testing Materials

ASA = American Society of Agronomy/Soil Science Society of America. Method of Soil Analysis, Part 1, 1965

COE = EM 1110-2-1906 (Headquarters, US Army Corps of Engineers) 1986

CSSS = Canadian Society of Soil Science (Carter 1993)

DOD = U.S. Department of Defense, 1987

Table 2. Aspects of Base and Subbase Materials Used for Structural Elements

Type of Material	Abbreviation	Gravel Factor (G_f)
Aggregate Subbase	AS-Class 1-5	1.0
Aggregate Base	AB-Class 2	1.1
	AB-Class 3	1.1[1]
Asphalt Treated Permeable Base	ATPB	1.4
Cement Treated Base	CTB-Class A	1.7
	CTB-Class B	1.2
Lean Concrete Base	LCB	1.9
Lime Treated Subbase	LTS	0.9 +[UCS/6.9]

1 - Must conform to the quality requirements of AB-Class 2
UCS = Unconfined Compressive Strength in MPa

Table 3. Summary of Innovative Technologies for the Beneficial Reuse of Contaminated Dredge Material

Technology ID	Feature	Pros	Cons	Costs
Contaminant Separation				
Thermal Desorption/ Cement-Lock	Heat (up to 1400^{o} C) to remove contaminants from the sediment matrix, then added to cement mix. The process takes place in a rotary kiln.	Beneficial uses include construction fill and habitat restoration. Existing cement plants may be able to be used to handle large volumes of dredged material. Process can remove all organic compounds and much of the metals.	A side product formed from some of these types of processes is a waste stream of hazardous material that requires disposal at a hazardous waste treatment facility.	Processing cost of $50 per cubic yard Value of construction-grade product $50-$70 per cubic yard Disposal costs of waste stream will depend on the level of contamination
Fluidized Bed Treatment	High temperature heating unit (not an incineration or oxidation process) that converts all organic materials to carbon monoxide, hydrogen, and methane.	99.9% free of organic material and, depending on the metal content, can be disposed of without restriction. It can operate with a continuous feed of material and can use the material without dewatering.	Extremely energy intensive and costly. Process has only been demonstrated in a small pilot scale project	Pilot and full-scale production costs are estimated at between $40 and $120 per cubic yard
Plasma Vitrification	Plasma torch (~5000^{o}C) melts sediment using fluxes to produce a glass product.	Glass product can be resold to recover some of the costs associated with the process.	Does produce a small waste stream of oversized debris and $CaSO_4$ which can be readily landfilled.	Processing cost of $90-120 per cubic yard (depending upon the cost of electricity).
Contaminant Destruction				
Base Catalyzed Decomposition	2-stage process which primarily removes halogenated compounds	99.8% free of chlorinated compounds. Also removes volatile and semi-volatile compounds. Remaining metals are not leachable.	PAHs are not removed.	Production costs are approximately $108 per cubic yard

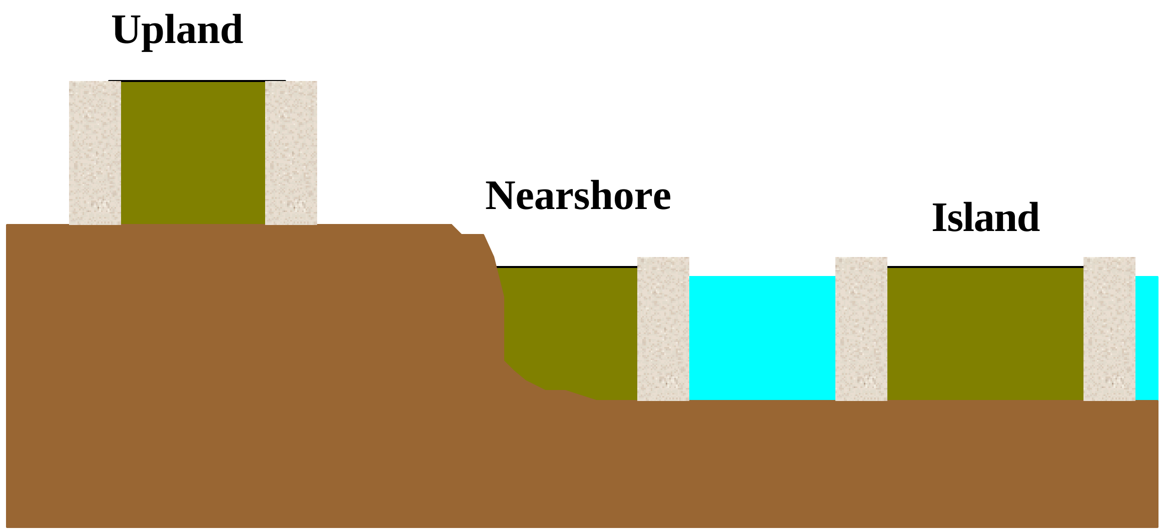
Table 3. (Cont.) Summary of Innovative Technologies for the Beneficial Reuse of Contaminated Dredge Material

Technology ID	Feature	Pros	Cons	Costs
Contaminant Reduction				
Soil Washing	Process blends detergents, chelating and oxidizing agents, and high pressure water jets	90% organic compound reduction & 70% inorganic compound reduction. Process (after blending) yields a product suitable for manufactured topsoils.	Only useful for low to medium contamination levels.	Processing costs estimated at $30-50 per cubic yard
Contaminant Stabilization				
Solidification/Stabilization	Addition of cement, fly ash, lime and/or chemicals to soil aggregates. Can be used in conjunction with other processes.	Bound aggregates can be used for some types of construction processes as well as landfill closure and Brownfield remediation projects. Both freshwater and marine sediments used.	Highly contaminated sediments may need to be pre-cleaned with another process prior to S/S to produce a beneficial end product. In some cases the S/S treatment may change the chemistry of the contaminants and render them more susceptible to leaching.	Production costs vary by sediment/soil type, raw materials costs, and the level and type of contamination. Costs of production were not inclusive of contamination removal which may be necessary prior S/S. Production costs estimated at $30-60 cubic yard.
Manufactured Soils	Dredge material mixed with other proprietary materials to produce a topsoil.	Provides beneficial use for other waste products. Topsoil product can be sold to both municipalities and the public.	Process requires relatively small (<5000 cy) per batch	Production costs estimated at approximately $20 per cubic yard, but does not include contamination reduction costs.
Construction Products	Used as a raw material for manufacturing construction products such as building blocks, tiles, and bricks.	Both freshwater and marine sediments can be used.	Full-scale production is not yet available.	Industry estimates at $20-80 per cubic yard do not include contamination removal costs.

FIGURES

Figure 1. Diagram of (A) Confined Disposal Facility (CDF) configurations, and (B) CDF Operational Flow.

(A) Confined Disposal Facility Configurations



(B) Confined Disposal Facility Operational Flow

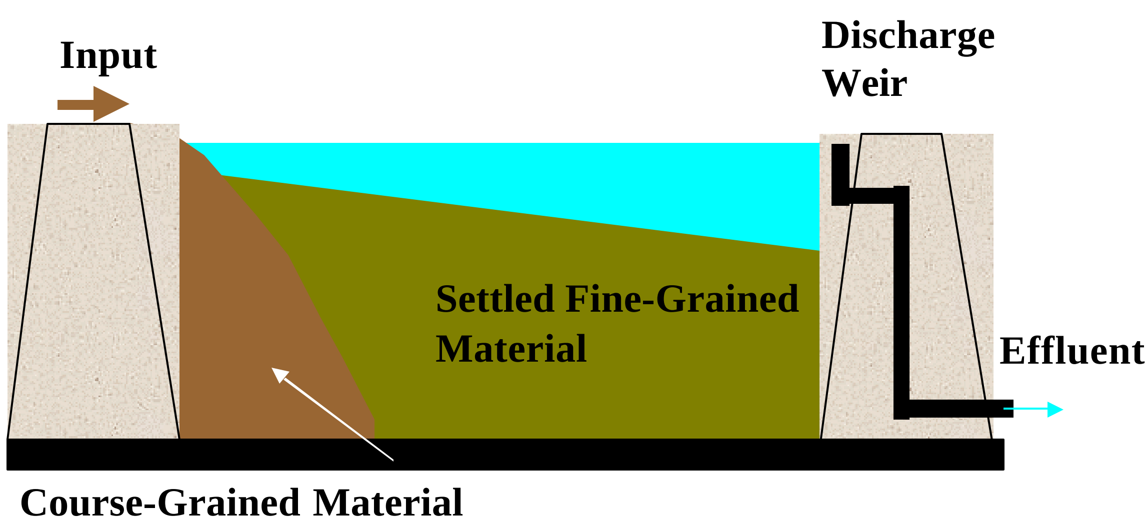


Figure 2. The Pump Barge Liberty Offloading a Sediment Scow at the Sonoma Baylands CDF Site in the Bay Area.

Figure 3. Surface of Drying Dredged Material at the Galbraith CDF in Oakland, California.

Large cracks are indicative of settlement and drying within the CDF.

Figure 4. Discharge Weir Located Downstream of the Overflow Point for the Galbraith CDF facility in Oakland, California.

The weir regulates the flow of decant water from the main ponds and is the point of final discharge from the facility.

Figure 5. Sediment Dewatering and Rehandling Pond at Moss Landing Harbor.

Picture shows sediment slurry being delivered to the pond.