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PART VI: Sediments

Chapter 19

INNOVATIVE SYSTEMS FOR DREDGING, DEWATERING OR FOR *IN-SITU* CAPPING OF CONTAMINATED SEDIMENTS

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1. INTRODUCTION

Dredging has evolved into a highly sophisticated process drawing from some of the latest technology. The methods of navigational dredging range from clamshell buckets to sophisticated hydraulic dredges. More recently, these techniques have evolved into the processes used for environmental dredging applications.

High concentrations of certain contaminants in sediments pose human heath and ecological risks. Dredging of contaminated sediment provides a method of removal of these contaminants of concern (COC). One of the most obvious benefits of environmental dredging is the fact the contaminated sediments are permanently removed from the water body. These sediments are typically disposed of in an upland containment facility or landfill. In some cases disposal of contaminates may not be permitted or the costs to transport them to a permitted facility may be very high.

Alternate uses for the contaminated sediments may be considered and may help to reduce or eliminate risks. The cost of these alternate treatment and use methods must be evaluated against other permissible disposal options.

Of paramount concern when dredging is the ability of the process to remove the COCs to a level that is below the regulated concentration. Although dredging techniques have been demonstrated to reduce sediment contaminant concentrations, it appears that these techniques can result in residual contamination. This residual contamination may be the result of re-suspension of contaminates into the water column or sloughing of adjacent materials into the dredged areas. Concern over these residual concentrations may lead to subsequent passes or other means to minimize risk from the residuals.

The impacts of the cleanup activity to the surrounding area need to be evaluated regarding the impact of the operation or long-term disturbance of an area. A dredging operation will typically require some sort of sediment dewatering process. After removal of the solids, the associated water may have to be treated before it can be discharged back into the waterway. Because of these facts a dredging operation typically requires onshore support facilities. Construction of these facilities will likely impact the area surrounding the dredged area.

2. *IN-SITU* CAPPING

An alternate solution to dredging contaminated sediments is to cap them in place. *In-situ* sediment caps are typically designed, using computer modeling, to take into consideration stabilization and physical isolation of the sediments as well as contaminate transport mechanisms (Palermo et al. 1998). But there remains some uncertainty, due to the limited available information on many of the mechanical processes that can affect the long-term stability of the cap. Concerns exist over the effects of ice heaving, currents, tides, wave action, propeller and thruster wash on the cap. Caps may be limited to areas where concerns over these erosion forces do not exist. Alternatively, these concerns are typically addressed by increasing the cap thickness to the point that it exceeds the thickness of material that may be affected by such forces. Additional research in this area may provide a clearer understanding of these forces on a cap design. Another alternative is to include a component in the cap design that would act to minimize the effect of these erosion forces.

A proper cap design should take into account the indigenous benthic community. To do so means to properly address the potential for biointrusion into the contaminated sediment. This is typically done by increasing the overall cap thickness to the point that it exceeds the depth of penetration of the local benthos. Another approach is to block biointrusion with some other layer in the cap design.

Construction processes have evolved to allow an accurate placement of the cover materials in a traditional sand cap. Although these processes have advanced, an allowance in the cap design is typically made to account for the spatial variability of the cover material placement. Once again this allowance usually entails adding more material to account for the variability of placement. Methods of ensuring uniform placement of materials are needed.

With all of the variability in the conditions which a cap may be in service, comes a degree of uncertainty. This uncertainty is typically compensated for by adding more and more material to the cap design. For this reason cap designs may become impractical in water depths that do not even exceed the total cap thickness. Clearly, the impact to navigability must be assessed when evaluating whether a cap design is practical. From a practical point, if a thin cap can be designed that provides as good or better performance than a traditional sand cap, then the capping alternative may become a practical solution for a wider range of applications.

Despite the variability in cap designs based on the range of considerations herein, *in-situ* capping whether traditional or thin cap design does offer some inherent advantages over dredging. First, the cost to cap is typically only 30 percent of the cost to dredge and dispose (Evison et al. 2004). In addition to the cost advantage, typically a remediation of contaminated sediment can be completed faster by *in-situ* capping than by dredging. This may be of significance to a heavily navigated area or an area where recreational use needs to be restored rapidly. Finally, the impact on surrounding areas may be of importance. In an urban setting the shoreline may not be conducive to the operation of a dewatering facility. Or, the impact of having sustained dredging operations to the area may be financially significant. These impacts are generally less if capping is chosen as the remedial option.

3. REACTIVE MATERIALS

Various reactive materials (e.g., activated carbon, apatite, organoclay, zeolite, zero-valent iron) are used for water, wastewater and groundwater treatment and can be applied to *in-situ* capping. Activated carbon is a widely used adsorptive media for water treatment removal of phenol, halogenated compounds and pesticides. Activated carbon is made by the thermal decomposition of various carboneous materials followed by an activation process. Raw materials include woods, rice hulls and nutshells. The resulting activated carbon is amorphous and contains complex networks of interconnected micropores (Thomas and Crittenden, 1998). Apatite, $Ca_{10}(PO_4)_6(OH,F)_2$, is a commercially available mineral that has been shown to be effective at sequestration of lead. Apatite removes contaminants from water through three mechanisms: ion exchange, isomorphic substitution and precipitation (Gardner and Stern, 2004).

Organoclays are surface-modified clays that have been shown to be effective adsorbents for insoluble and partially insoluble compounds. The production of organoclays replaces the surface cation of bentonite or hectorite clay with an organic molecule. Quaternary amines based upon tallow are the most commonly used organic compound. The resulting organoclay is oleophilic, hydrophobic and permeable. A properly compounded organoclay will exhibit minimal swelling upon organic adsorption and maintain high permeability. Several manufacturing quality control tests have been developed using x-ray diffraction and thermo gravimetric analysis to assure proper compounding. In treatment of produced water from offshore crude oil production organoclays have removed polyaromatic hydrocarbons to non-detect levels (Darlington 2002).

Zeolites are porous crystalline aluminosilicates. Both natural and synthetic zeolites are used commercially for their adsorption, ion exchange, molecular sieve and catalytic properties. Zeolites are used in water treatment for removal of nitrates and metals such as lead, zinc, and copper (Thomas and Crittenden, 1998). Zero-valent iron, Fe(0), is a strong reductant and has been used successfully in permeable reactive barriers for the dechlorination of chlorinated hydrocarbons and the reductive precipitation of chromate (Cr^{+6} as CrO_4^{-2}) (Powell 2002). Reductive precipitation involves the transfer of electrons from Fe(0) to the hexavalent chromium and transforming the chromium to a less soluble form, $Cr(OH)_3$.

3.1 Bulk Deployment

A layer of reactive material can be placed in bulk using a clamshell, pouring from super sacks or pumped through a tremie pipe. At the Anacostia River Demonstration Project in Washington, D.C. apatite material was placed in bulk over sediments using a clamshell. The clamshell was opened just above the surface and the material settled over the sediments. The target thickness was 150 mm. Core samples indicated that the actual thickness was 130 mm ± 45 mm. A sand layer approximately 150 mm thick was placed over the apatite to allow for colonization by benthic organisms. Operator experience and a global positioning system on the crane were critical for controlling the thin lifts. In the Willamette River in Oregon, a

600 mm thick organoclay bulk layer was placed over hydrocarbon non-aqueous phase liquid (NAPL) seeps using 1800 kg super sacs. The super sacs were positioned over the area with a backhoe and then the bottom of the sacs was opened above the surface allowing the organoclay to pour out and settle over sediments (Fig. 1). An articulating concrete mat was placed over the organoclay cap for protection.

Figure 1. Deployment of Organoclay Cap at Willamette River

4. REACTIVE MATERIALS MAT

A system has been devised that encapsulates reactive materials within a geotextile composite that can be easily deployed as an *in-situ* capping material over sediments. Geotextiles are textiles that are manufactured into flexible, porous fabrics with synthetic fibers. Synthetic fibers are resistant to biodegradation. Geotextiles have varying properties based upon the type of polymer, the type of fiber and fabric style. The four main functions of geotextiles are separation, reinforcement, filtration and drainage. Geotextiles have used in civil engineering, and particularly coastal work, for decades. Some early uses of geotextile were seen in the late 1950s behind precast concrete seawalls and under large riprap (Koerner, 1998).

Reactive mats have been constructed by CETCO using two methods. The first method is needlepunching. This method has been used since the late 1980s to manufacture geosynthetic clay liners. In the needlepunching operation a layer of geotextile, either woven or nonwoven, is fed onto the line. A hopper disperses an even layer of the reactive material onto the geotextile. A top nonwoven geotextile is then unrolled on top of the reactive material. The material is then fed through a loom where nonwoven fibers are needlepunched through the reactive material and into the lower geotextile. Typical thickness of the needlepunched mat is 6 mm. The reactive mat is rolled onto a core tube and then wrapped in a polyethylene bag.

The second method is a laminating method (Fig. 2). This method allows a higher mass per unit area than needlepunching and the ability to use abrasive reactive materials that cannot be needlepunched. In the laminating method a nonwoven core is bonded either by needlepunching or adhesive to a geotextile. The bonded material is then fed core side up through the line. Reactive material is fed onto the core from a hopper. The core has an apparent opening size (AOS) that is larger than the maximum particle size of the reactive material. The reactive material is worked into the core openings by suction and/or vibration. A cap geotextile is then bonded to the top of the core by heat or adhesive. Typical thickness of the laminated mat is 11 mm. The reactive mat is rolled onto a core tube and then wrapped in a polyethylene bag.

Certain reactive materials, such as activated carbon, are buoyant. The reactive mat may be engineered with a geotextile with a high specific gravity and/or a fraction of sand mixed with the reactive material to counteract the buoyancy.

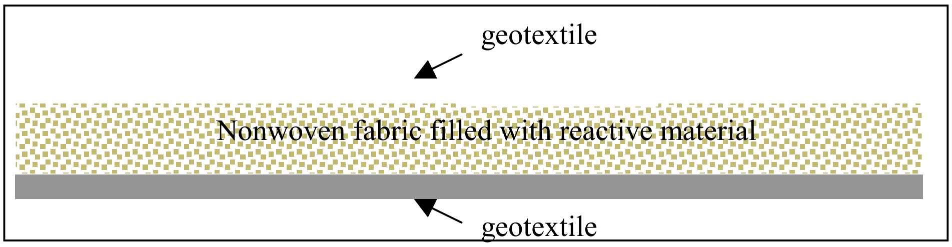

Figure 2. Cross section of laminated reactive core mat

4.1 Benefits

One advantage of a reactive cap over a sand cap is reduced cap thickness. Lab column testing and modeling illustrate that a thin layer of highly adsorptive material such as activated carbon can have over 100 times the adsorption capacity for PCBs as sand or organically-rich soil containing 3.8% carbon fraction (Murphy and Lowry, 2004). Project specific conditions and adsorptive material properties will affect results. However, a 10 mm thick reactive mat can theoretically replace 1 m of sand or soil. This can help maintain navigable depths and flow capacity of waterways.

One factor with using reactive materials is their cost. By constructing a mat encapsulating the reactive materials within geotextiles they can be used in a controlled and potentially cost-effective manner. The reactive mat also combines the benefits of reactive materials and geotextiles.

The U.S. EPA program on Assessment and Remediation of Contaminated Sediments (ARCS) has developed guidance on the design of *in-situ* caps that includes laboratory tests and models of the following key processes; advective/diffusive contaminant flux, bioturbation, consolidation and erosion. The potential functions of geotextiles in *in-situ* cap designs include: 1) providing a bioturbation barrier; 2) preventing mixing of cap materials with underlying sediments; 3) reducing contaminant flux; 4) promoting uniform consolidation; 5) stabilizing the cap; and 6) reducing erosion of the capping materials (Palermo, et al. 1998). Since the reactive mat is constructed with two geotextiles, the composite mat can be designed to perform multiple cap functions.

Hampton et al. (2002) showed that geotextiles can greatly reduce movement of benthic invertebrates in sediments. As previously stated, a geotextile with a proper AOS can contain the cap material and prevent mixing into the underlying sediments. The permittivity of the geotextiles can reduce contaminant flux and/or promote uniform flow during consolidation. The multiaxial tensile strength of the geotextiles can provide stabilization to the cap. At the Anacostia River Demonstration Project the reactive mat was installed over soft sediments with 0.6 kN/m^2 undisturbed shear strength (at 600 mm depth) per field vane shear ASTM D2573 test results. The geotextile, along with appropriate armoring, can also help reduce erosion of the capping material.

4.2 Mat Deployment

Reactive mats may be deployed in a number of ways. The Anacostia River demonstration project was a successful demonstration of a barge-based deployment technique (Fig. 3). In this demonstration, a barge-mounted crane was used to position the rolls and unroll the reactive mat underwater. The mats were first submerged to allow them to absorb water and displace entrained air. Then the rolls were positioned 450 mm above the river bottom and anchored with sand at one end. The crane was able to swing across and unroll the mat. The installation was assisted by a global positioning system and coordinated by a diver in radio communication with the crane operator. A sand layer approximately 150 mm thick was placed over the reactive mat for protection and to allow for colonization by benthic organisms.

Figure 3. Reactive material mat being prepared for deployment on the Anacostia River

Land based deployment techniques may also be used to deploy reactive mats. Rolls may be positioned on shore suspended by a spreader bar system with a clamp connected to the leading edge of the roll. The material is then pulled off the roll using a winch that is either mounted on a barge or on the opposite side of the waterway.

Deployment techniques may also take advantage of temporary buoyancy before the mat absorbs water and displaces air to allow the material to “float” into position and subsequently sink as it takes on water. This technique is planned for capping approximately 4 hectares of hydrocarbon contaminated sediment with an activated carbon reactive mat in a Minnesota bay in late 2005 or early 2006.

5. CONCLUSIONS

The environmental remediation community is seeking innovative methods to remediate contaminated sediments. Reactive materials and geotextiles have been used extensively in civil engineering for water treatment and coastal applications, respectively. The use of reactive materials for *in-situ* capping of contaminated sediments has many potential benefits. A reactive material mat combines the benefits of reactive materials and geotextiles in addressing concerns with *in-situ* capping. Several techniques have been used or planned for deployment of reactive material mats. It is likely that as the reactive material mat technology develops, the methods of deployment will also evolve.

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