Design Consideration Involving Active Sediment Caps

EDWIN BARTH* AND DANNY REIBLE**

*National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 26 West Martin Luther King Drive, Cincinnati, OH 45268 barth.ed@epa.gov

**Department of Civil, Architectural, and Environmental Engineering, University of Texas, Austin, Texas reible@mail.utexas.edu

SUMMARY: When contaminated sediments pose unacceptable risks to human health and the environment, management activities such as removal, treatment, or isolation of contaminated sediments may be required. Various capping designs are being considered for isolating contaminated sediment areas, since activities involving dredging, off-site sediment treatment, as well as limited disposal areas are associated with short-term environmental concerns, longer time implementation, and relatively higher cost. A sand cap design may be adequate for many contaminated sediment applications, however, recent field demonstrations are evaluating if other capping materials may be more suitable for more mobile contaminants in limited contamination areas (small surface areas). The concept of an active cap is to influence ground water interactions with the sediment, as well as sequester any contaminant that interacts with the capping material. The design of an active cap must consider numerous physical, biological, and chemical forces expected to occur in the subsurface environment.

1.0 INTRODUCTION

Sediment management techniques range from monitored natural recovery, isolation by capping, in-situ treatment, and dredging followed by ex-situ treatment and disposal. Natural attenuation is limited in effectiveness if the deposition rate of clean sediment is less than the accumulation rate of contaminated sediment. In-situ treatment may be limited by the capacity to adequately deliver reactive material to the area of concern. Dredging, followed by ex-situ treatment and disposal may be associated with short-term environmental (water, air) concerns, longer time implementation, and limited disposal options. Hybrid remedies including both dredging and capping have been implemented.

Alternative cap designs incorporate concepts or material other than employed with traditional sand caps. The concept of an active cap incorporates purposeful influence of advective transport and/or sequestering or degradation agents for controlling contaminant migration to the overlying water body. An active cap may be more protective, yet at a higher cost than a sand cap, for sediment contamination scenarios that have implemented some form of source control measures (removal, barrier walls).

This paper will briefly discuss technical issues that are associated with the evaluation, design, construction, and monitoring of sediment active capping remedies for protecting public health and the environment.

2.0 TECHNICAL ISSUES ASSOCIATED WITH SEDIMENT CAPPING

2.1 Applications

The conceptual site model identifies the physical, chemical, and biological systems that influence the fate and transport of the contaminants and identifies all exposure pathways. Application scenarios for active caps for the purposes of isolating contaminants of concern may include the presence of mobile organic or inorganic contaminants in "hot" spot areas with high advective rates, or in scenarios involving the potential for direct contact. For example, non-aqueous phase liquids (NAPLs) that are not strongly sorbed to the natural organic material present in the sediment are amenable to active capping. Control of the sources of the contaminants will limit re-contamination of the surficial sediments. Depending upon material cost, a traditional sand cap may be effective for less mobile contaminants that are strongly sorbed to the natural organic compounds present in the sediment.

2.2 Materials

Capping design options range from the use of natural materials (sand, clay), more reactive compounds (modified clays, activated carbon, coke by-products, apatite, biodegradation supplements), and geosynthetic materials, to a hybrid-design incorporating elements of various materials to sequester contaminants and minimize advective transport.

Modified clays, coke breeze (Reible et al., 2006) and activated carbon (Millward et al., 2005) have the ability to sequester certain organic compounds. Bauxite (Gavaskar et al., 2005), apatite (Reible et al., 2006), and zeolites (Jacobs and Foster, 1999) may have the ability to sequester inorganic compounds.

2.3 Design Considerations

Design considerations for an active cap should include consideration of the following elements:

- -performance criteria
- -contaminant transformation
- -sorption/reactivity capacity
- -materials placement

-ground water influence
-contaminant release mechanisms
-physical stability
-monitoring
-performance modeling

Each of these design elements are discussed below:

2.3.1 Performance Criteria

Capping remedies should be evaluated on the basis of whether they meet the site-specific performance criteria established for each contaminated sediment area(s) in a post-capping timeframe. In general, sediment caps are designed for physically isolating and minimizing the loss of dissolved contaminants through the cap materials through transport processes such as advection, diffusion, gas ebullution, and bioturbation. Performance criteria option parameters include: water quality criteria, surficial sediment concentration (above the cap), pore water concentrations (resulting from the contaminant flux though the capping material to meet water quality criteria established for the water body), and benthic tissue concentrations.

2.3.2 Contaminant Transformation

Degradation of contaminants by natural processes under the cap, or within the reactive capping material needs to be considered. Zero-valent iron (ZVI) is a reactive compound that has been used in subsurface environments to react with the contaminants found in ground water (Wilken and McNeil, 2003). Natural processes that could adversely affect water quality (e.g. mercury methylation associated with reduced oxidation/reduction potential and anaerobic conditions in the environment directly underneath a cap that could adversely affect water quality should also be considered.

2.3.3 Sorption/Reaction Capacity

The ability of the active material to sequester or degrade the contaminants must be estimated so that the material can be replenished if breakthrough is anticipated in a post-capping timeframe. The sorption capacity of organoclays, carbon, and coke may be estimated through sorption isotherm studies. Reactivity of reactive compounds may be estimated from laboratory studies using parameters such as the reaction half-life.

2.3.4 Placement

Several options exist for placing capping media in a subsurface application. The properties influencing a material's ability to settle in a water body include mesh or sieve size, density, buoyancy, and porosity. Considerations include minimizing the disturbance of soft sediment to decrease re-suspension or volatilization of the contaminants. Capping material can either be placed by material broadcasting methods (clamshell dredge, conveyors, drop-barges) or placed within geotextile material containing reactive core mats (RCM). Material that is present on the bottom surface such as rocks, debris, and dead trees might require removal before a RCM liner is installed. Another important placement consideration is the ability to minimize the potential short-circuiting of flow through seams between RCM sheets. Considerations for replacement techniques are necessary if sorption capacity of the capping material is limited.

2.3.5 Ground Water Influence

Caps may be designed to have semi-permeable or non-permeable properties to influence the velocity and direction of upwelling ground water. Alternatively, a combination design of these properties, directing upwelling ground water to a more permeable, reaction area is possible (subsurface funnel and gate capping concept).

Semi-permeable caps allow the contamination from upwelling ground water to interact with the sequestering material as the water moves through the material. An example of this is the multiple use of semi-permeable caps over hot spot areas at the McCormick and Baxter, Oregon wood-preserving site. Limited coring has suggested that the contamination underneath organoclay material has not shown break-through.

An example of a non-permeable cap to divert the upwelling ground water away from the contaminated sediments, yet having the capability to sorb contaminants is the AquaBlok^{R} cap placed in the Anacostia River cap demonstration area in Washington, DC. The upwelling ground water velocity prior to capping was approximately 4-6 cm/d, but was reduced to negligible or even negative values after capping with the AquaBlok material (USEPA, 2007).

2.3.6 Contaminant Release Mechanisms

Besides advective transport, several contaminant release mechanisms must be considered in the design of the cap, including release during placement due to sediment re-suspension from displacement forces. Subsequent consolidation of the capping material and pore-water pressure may also result in contaminant release.

Gas ebullution from microbial activity has been observed at several sites (Reible, et al., 2006). The buoyant weight of the cap may aid in gas release from the underlying sediments. Significant gas fluxes may result in uplift and deformation of the cap material. It may be possible to minimize release associated with the gas if the capping material can sequester the contaminants before breakthrough or if the gas can be captured within geotextile material.

2.3.7 Physical Stability

The long-term performance concerns of active sediment caps has not been verified over time nor has performance been evaluated in harsh environmental settings. The thickness of the cap must be maintained to meet advective transport performance and maintain armoring to reduce contaminant release from bioturbation. Colder environments that experience freeze/thaw cycles or ice-scouring are a concern. Larger ground water upwelling velocities, wave action, flooding, and extreme tidal movements may also result in cap heaving.

2.3.8 Monitoring

Periodic measurements of the physical and hydraulic properties of the cap are necessary to ensure the cap is performing as planned. Physical stability of the cap can be monitored with bathymetric techniques. Seepage meters can be temporarily placed to monitor ground water upwelling. Pore water measurements can be obtained to estimate contaminant flux through the cap.

For example, in the Anacostia River, various bathymetric tests, geophysical tests, seepage meter testing, gas monitoring, and sediment profiling imaging techniques indicated that the cap was physically stable in the tidal environment (Barth, et al., 2008). However, inclinometer data suggested some heaving of the cap over time (Reible et al., 2006).

2.3.9 Performance Modeling

In-situ sediment capping models typically vertically oriented, one-dimensional (1-D) models, that include advection, diffusion, and dispersion (Petrovski, et al., 2005). Models used for estimating the mass flux of contaminants are based on dispersion through each cap layer. Realistic cap modeling would include transient and steady-state estimates of the fate and transport of contaminants through each layer of capping material. Bioturbation and material heaving due to gas ebullution and location and environmental conditions should be considered. Several advective transport models have been developed for both above-ground and subsurface capping applications.

The RECOVERY model, developed by the US Army Corps of Engineers, is a sediment-water interaction model which can incorporate the Corp's PSDDF model for consolidation and compression (Ruiz, et al., 2000; Lampert, et al., 2008). The initial consolidation of the covered sediment results in transient dissipation of excess pore pressure, resulting in a large advective flux relative to diffusion forces (Alshawbkeh, et al., 2005).

The emphasis on monitoring should occur when the conceptual model of the site indicates the greatest potential for future contaminant break-through.

3. CONCLUSIONS

Active cap designs may be considered for sediment capping applications because of the potential ability to physically isolate the sediments from the overlying water column, influence ground water flow, and the ability to sequester or transform contaminants. The design of such a capping system is complex because of the numerous physical, chemical, and biological forces associated with the subsurface environment, as well as the interactions of the contaminants with the capping material. Post-capping monitoring techniques, coupled to the site conceptual model, are available to ascertain long-term capping performance.

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