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In Situ Remediation of Contaminated Sediments – Active Capping Technology

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Abstract

Active capping is a relatively new approach for treating contaminated sediments. It involves applying chemically reactive amendments to the sediment surface. The main role of active caps is to stabilize contaminants in contaminated sediments, lower the bioavailable pool of contaminants, and reduce the release of contaminants to the water column.

Metals are common contaminants in many marine and fresh water environments as a result of industrial and military activities. The mobile, soluble forms of metals are generally considered toxic. Induced chemical precipitation of these metals can shift toxic metals from the aqueous phase to a solid, precipitated phase which is often less bioavailable. This approach can be achieved through application of sequestering agents such as rock phosphates, organoclays, zeolites, clay minerals, and biopolymers (e.g., chitosan) in active capping technology. Active capping holds great potential for a more permanent solution that avoids residual risks resulting from contaminant migration through the cap or breaching of the cap. In addition to identifying superior active capping agents, research is needed to optimize application techniques, application rates, and amendment combinations that maximize sequestration of contaminants. A selected set of active capping treatment technologies has been demonstrated at a few sites, including a field demonstration at the Savannah River Site, Aiken, SC. This demonstration has provided useful information on the effects of sequestering agents on metal immobilization, bioavailability, toxicity, and resistance to mechanical disturbance.

Key words: Active caps, metals, sediments, in situ remediation, erosion

Introduction

Conventional remediation/risk management options for contaminated sediments include no action, monitored natural recovery, institutional controls (land use restrictions, etc.), in situ treatment and management, ex situ treatment and management, and passive capping. Traditional efforts to manage contaminated sediments often focus on removal and ex situ management including dredging or dry excavation followed by off-site management (including treatment) of the removed sediments. The limitations of dredging include releases during implementation, risks to workers during construction and transportation, community impacts (accidents, noise, odor, air emissions), disruption of use and enjoyment of the resource, disruption of benthic ecology, impacts on fish and wildlife, impacts of contaminated residuals (inside and outside of the remedial area), and risk of releases at the final disposal location.

In situ management of contaminated sediments is potentially less expensive and risky than ex situ management, but there are relatively few alternatives for in situ treatment and some are still under development. Among the more promising alternatives for in situ treatment are active capping technologies. However, apart from the types of amendments to be used in active capping, little is known regarding amendment application techniques, application rates, and amendment combinations that will maximize sequestration, immobilization of contaminants, and resistance to erosion. A selected set of active capping treatment technologies has been demonstrated in the field as part of the Anacostia Active Capping Demonstration Project (Reible et al., 2006) and at the Savannah River Site (Knox et al., 2009). Knox's field deployment (Knox et al., 2009) showed that active amendments such as apatite or organoclay can effectively immobilize

contaminants but are subject to erosion in dynamic stream environments.

The design of sediment caps must consider a wide variety of factors, including the mobility of the contaminants, burrowing habits of potential receptors, erosive forces acting on the surface of the cap, and geotechnical characteristics of the native sediment (Palermo et al., 1998).

Consideration of the preceding facts suggests that there is a need for capping technologies that can sequester organic and inorganic sediment contaminants and create a reliable, stable, and long-lasting cap in a range of aquatic environments. Current technologies typically produce caps with limited physical stability that are suitable primarily for low-energy, depositional aquatic environments. However, depositional environments can become erosive as a result of unpredictable natural events such as floods and storms as well as anthropogenic actions such as boating and construction activities. Under such conditions, caps can be rapidly compromised resulting in the mobilization of contaminated sediments. In recognition of this limitation, we tested innovative active capping materials offering containment, treatment, and erosion resistance. The primary objective of this study was to evaluate promising sequestering materials for the construction of active caps that stabilize inorganic and organic sediment contaminants and are resistant to physical disturbance.

Materials and Methods

In this study the effects of active caps on metal immobilization and erosion resistance were evaluated in pilot-scale experimental active caps in Steel Creek, at the Savannah River Site near Aiken SC, USA. There were eight plots with four treatments: two controls consisting of uncapped sediments; two caps composed of apatite and sand; two caps composed of a layer of biopolymer/sand slurry over a layer of apatite and sand; and two caps composed of a top layer of biopolymer/sand slurry, a middle layer of apatite and sand, and a bottom layer of organoclay and sand (Figure 1).

The monitoring of active caps in Steel Creek was conducted for twelve months. The effectiveness of the active caps was determined on the basis of contaminant immobilization, amendment impact on benthic organisms (toxicity tests), and cap resistance to erosion. In this paper only the effects of active caps on metal

immobilization and erosion resistance are presented. Metal immobilization was evaluated by analysis of metal concentrations in pore water.

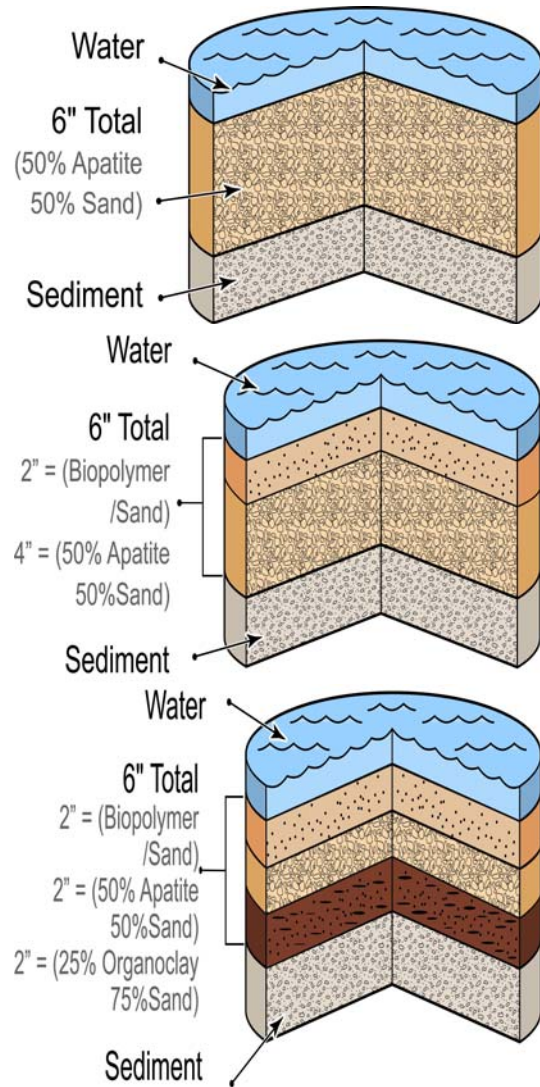


Figure 1. Three types of caps were tested in the field deployment.

Cap erosion was evaluated based on visual observations, sediment core characterization for integrity of the cap layers, and measurement of erosion rates and critical shear stresses by an Adjustable Shear Stress Erosion Transport (ASSET) flume (Roberts et al., 2003). Seven months after cap deployment, sediment cores were collected from the apatite cap plot, the biopolymer/apatite/organoclay cap plot, and the untreated plot. All cores were analyzed by the ASSET flume (Figure 2).



Figure 2. The coring tubes and sediment cores used for evaluation of erosion resistance by an ASSET flume.

Results and Discussion

Metal concentrations in pore water samples collected from untreated sediment outside of each cap and sediment located beneath each cap 12 months after cap placement are presented in Figures 3. For the apatite cap the clearest

reductions of metal concentrations were observed for As, Cd, Cr, Mo, Pb, and Zn. Reduction of metal concentrations in pore water were less clear for the caps composed of biopolymer, apatite, organoclay, and sand, especially twelve months after cap placement (Figure 3).

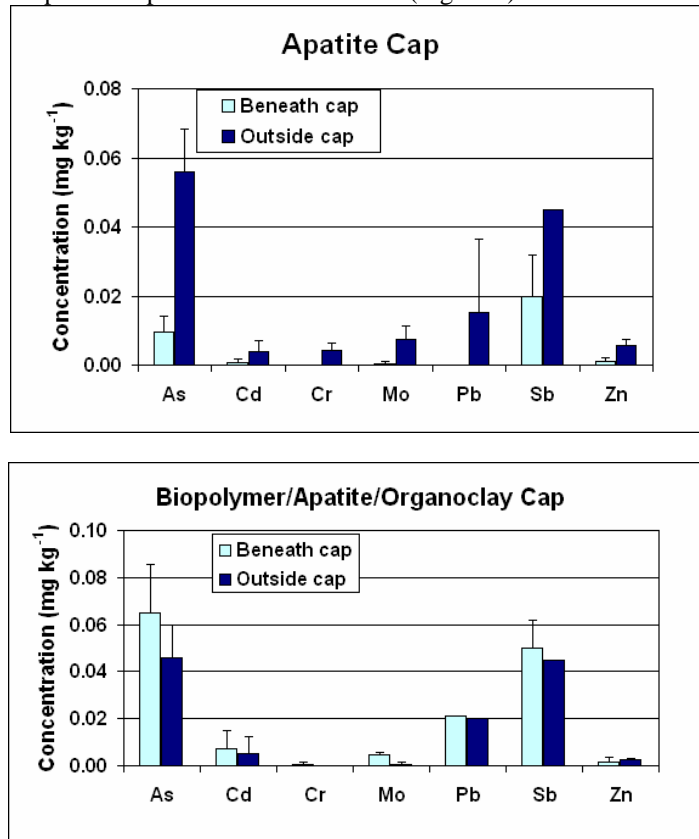


Figure 3. Effect of cap materials on metal concentrations in pore water twelve months after cap placement.

Reduction of metal concentrations in pore water was related to the sequestering agents

and to changes in pore water chemistry resulting from the caps. Parameters modified by cap

placement included oxidation-reduction (redox) potential and pH (Knox et al., 2009). These parameters may have major effects on metal speciation in pore water.

The data from the ASSET analysis is presented as erosion rates and critical shear stresses for the initiation of erosion as a function of depth from the sediment surface (Figure 4). The results indicated that the cap most resistant to erosion was the cap with apatite and biopolymer, which became increasingly harder to erode with depth. These results, using samples collected from the field, were consistent with the laboratory evaluation of biopolymers (Knox et al., 2009). Both studies showed that guar gum cross-linked with xanthan (Kelzan) initially increased cap erosion resistance, but erosion resistance decreased after two months. The application of xanthan/guar gum in the field as

the top layer of active caps is beneficial for a short time for erosion resistance. Another benefit of biopolymer was that it reduced sediment suspension during cap construction and caused the rapid settling of other amendments that were placed below the biopolymer layer. A third benefit of biopolymer addition was an increased pool of carbon in the sediment beneath the cap and lower release of metals and other elements, especially P, in comparison with apatite only. However, more research is needed on the type of biopolymers applied to caps and methods for delivering biopolymers to the cap. A three layer cap composed of biopolymer on the top, apatite in the middle, and organoclay on the bottom does not appear to be ideal for biopolymer interaction with other amendments, which could serve as cross-link reagents.

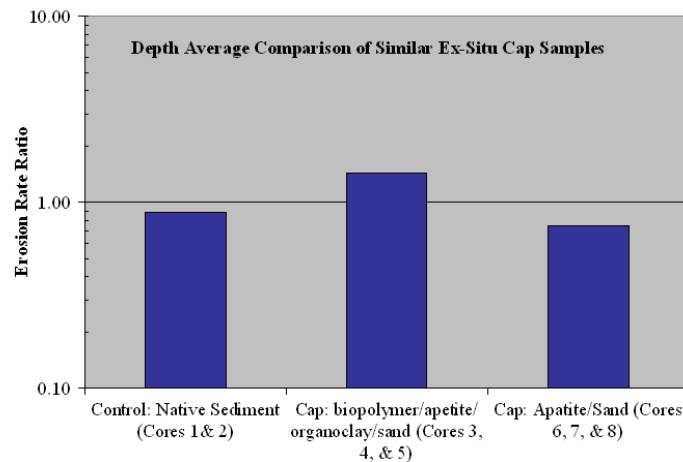


Figure 4. Erosion rate ratio - comparison of material types: native material (control plot – samples 1 and 2), biopolymer/apatite/organoclay material (samples 3, 4, and 5) and apatite/sand material (samples – 6, 7, and 8).

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