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CARVING SAND – PRECISION DREDGING TO MAKE A MOLD FOR A LOW-PERMEABILITY CAP

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ABSTRACT

Coal tar was actively migrating to surface water due to biogenic gas release from sediment on the Penobscot River in Maine. The tar sheens that formed at the river surface over the tar deposit were causing unacceptable levels of human health risk. In order to reduce the risk, we designed a remedy that would allow us to manage the gas while containing the migration of tar from the sediment to the environment. The remedy is an innovative capping system to control gas migration, and hence, tar migration. We used precision dredging techniques to shape the surface of the tar deposit in order to provide a base grade on which we constructed the low-permeability cap. After the dredging was completed, we needed to place the fill material at slopes and thicknesses that were highly controlled. The focused dredging program and innovative cap design minimized project cost while achieving the remedial objective of permanently stopping tar migration to the river surface.

Keywords: Ebullition, underwater grading, NAPL, contaminated sediment.

INTRODUCTION

Sediment contaminated with non-aqueous phase liquid (NAPL) is common at outfalls for historical industrial sites, such as manufactured gas plants, coking facilities, or refineries, for example. NAPLs include both light NAPLs (LNAPLs) such as diesel or lubricating oils, and dense NAPLs (DNAPLs), such as coal tar or creosote. Remediation of sediment containing NAPL poses special problems. To begin with, NAPL commonly is present with a high concentration of entrained gas in sediment, and migration of the gas can facilitate the migration of NAPL from sediment (McLinn and Stolzenburg, 2009a). If gas is released during removal of sediment containing NAPL, the gas may exacerbate spreading of contaminants at the water surface. These complex multi-phase flow phenomena can lead to a high potential for re-release of contaminants during dredging operations.

Treatment for disposal of dredged material containing NAPL can be difficult and expensive. Odor problems associated with volatilization of contaminants that are being removed can be difficult to control. In some cases, volatilization of dredged constituents has been modeled to have the potential to cause human health risks (e.g., Minnesota Department of Public Health, 2003). As a result of these considerations, minimization of dredging volumes at sites containing NAPL in sediment is desirable. In addition, in order to prevent NAPL migration from sediment via dredging, all of the affected sediment must be removed, because a very small volume of NAPL can spread over a comparatively large volume of surface water. During dredging, it is possible that only the weathered surface layer of sediment is removed, exposing fresh residual sediment that may have a higher toxicity and mobility that the overlying weathered sediment. Hence, partial mass removal has the potential to increase the risk, unless special care is take to control remediation in the area where mass was removed. Because of the complexity of the transport mechanisms of NAPL-contaminated sediment, and the inherent risk of re-release associated with its removal, specialized methods are needed to address remediation of these sites.

At the Bangor Landing site, on the Penobscot River, in Bangor, Maine, a ten-acre area of riverbed contained high concentrations of coal tar. At this site, coal tar had been migrating from sediment to the water surface for decades. The total volume of affected sediment (sediment containing visible coal tar) was on the order of 60,000 m^3, and the total volume of sediment with active NAPL migration was approximately 15,000 m^3.

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In order to construct a cap to control NAPL migration from sediment at this site, 5,000 m^3 of sediment was removed, and over 15,000 m^3 of fill needed to be placed. This NAPL-Trapping Cap (patent pending) was designed to redirect gas flow, and hence, to control NAPL migration.

The NAPL Trapping Cap has four major components:

1. Grading layer – a layer consisting of permeable general fill (gravel) placed on top of the dredged surface to serve as a stable surface on which to construct the gas transmission layer.
2. Gas Transmission Layer – a layer consisting of highly permeable (washed gravel) material that facilitated the migration of gas and NAPL within the cap. This layer needed to have precise grades and sufficient thickness so that the overlying gas control layer would be able to direct gas and NAPL to the appropriate locations within the cap.
3. Gas Control Layer – a low-permeability layer consisting of clay (hydrated bentonite [AquaBlok®]). This layer needed to be continuous and have an underside that had an appropriate geometry (inclination and smoothness) for controlling gas flow.
4. Armor Layer – a layer consisting of riprap, designed to protect the rest of the cap from erosion by ice, river currents, and vandalism.

The purpose of this paper is to describe the dredging and underwater grading that were needed to construct an underwater sediment cap to remediate sediment contaminated with coal tar.

Previous Studies

The phenomenon of gas –facilitated migration of NAPL from sediment at a field site was discussed in detail in McLinn & Stolzenburg (2009a). Laboratory studies of the migration of NAPL through sand covers due to gas migration were discussed in McLinn & Stolzenburg (2009b). The difficulties of remediation of sediments contaminated with NAPLs are illustrated by considering the remedies at two major field sites: the former Pine Street Barge Canal site in Burlington, Vermont (Maynard, and others, 2005), and the former McCormick & Baxter Creosoting site in Portland, Oregon (Oregon Department of Environmental Quality, 2008). At both of these sites, complete removal of NAPL-contaminated sediment was determined to be infeasible, and instead, a hybrid remedy consisting of removal and sand capping was put in place. At both of these sites, gas migration facilitated NAPL migration from sediment after dredging and capping was completed.

METHODS

Construction of the NAPL Trapping cap at Bangor involved the use of precision dredging and capping techniques.

Dredging

Dredging was performed using a combination of techniques, depending on the physical location of the material to be dredged and the type of material that was being removed. In deep water, dredging was performed from a barge, and in shallow water, long-stick excavators were used. A 5 m^3 environmental bucket was used when silty to sandy sediment was being dredged, and a 2 m^3 clamshell bucket was used when heterogeneous coarse-grained material was encountered. Dredged material was placed in waterproof hoppers on the barge; the hoppers were offloaded with a crane and transported to a temporary treatment building. The dredged material was mixed with stabilization agents to remove free liquids and render it loadable. The consistency of the dredged material was similar to cake batter after dredging, but after stabilization was similar to a mineral soil. The chemistry of the stabilization agents varied depending on the consistency of the material encountered, but typically was a blend of granulated and powdered lime and cement.

The total period of dredging was 25 days. Cycling time for the barge-mounted dredge was on the order of two minutes per bucket. The dredged surface is shown on Figure 1. It is important to bear in mind that the main objective of the dredging was not mass removal, but rather to provide a stable engineered surface to serve as a mold on which to construct the NAPL migration control system.

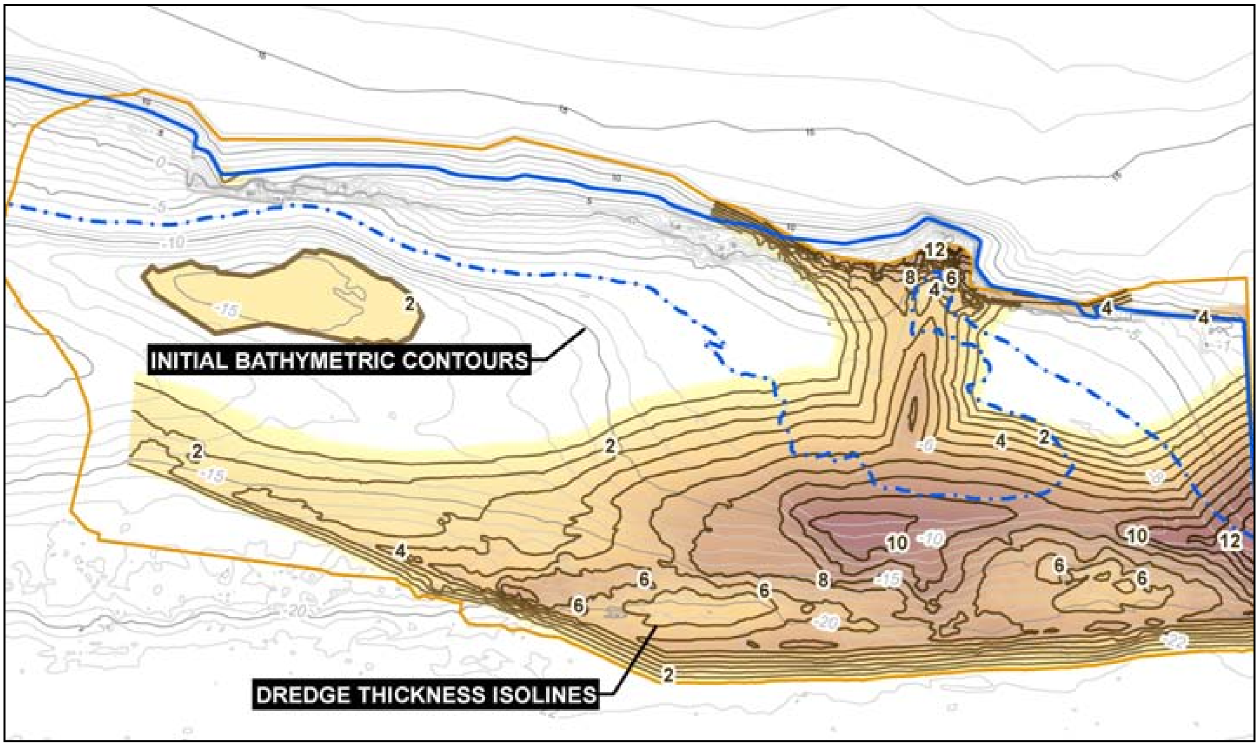

Figure 1. Configuration of dredged surface.

Surveying during dredging

To facilitate communication between surveyors, engineers and construction crew, a grid system covering the construction area was established. The grid system was composed of range lines that extended perpendicular to the shore and divided the cap into nine panels. The range lines were separated by roughly 15 m. Every other range line also corresponded with an H-pile location on the perimeter turbidity curtain.

The location of the dredge bucket and the cut surface were estimated during dredging using a GPS-equipped dredge bucket (Clam Vision®) and depth meters visible to the crane operator. The design plan view, as well as the current and post-dredge bucket locations, were displayed in real time on the crane operator's control panel. Depths were monitored and quality controlled by land-based survey; typically, a survey system (total station) on shore viewed the height and location of a survey rod that was lowered from a skiff to the surface of the remaining river sediment. The dredged surface was not smooth because the clamshell would take bites from the sediment surface. The quality control (QC) requirements for the dredged surface were that the dredged surface elevation would agree with the design surface elevation within 0.15 m.

Two other methods were used to acquire QC survey information during dredging. One method utilized by lowering a calibrated measuring tape attached to an eight-pound mushroom anchor to the river bottom and reading the distance on the measuring tape from the bottom to a survey prism fixed to the gunwale of the boat; while the boat was in the same location, the survey prism location was recorded by the total station. The horizontal data was recorded directly from the survey shot, and the vertical coordinates where calculated by subtracting the sounding tape measurement from the survey shot prism measurement. A second method for depth measurements utilized a boat with a fixed survey prism as described above, and an acoustic depth sounder. In this method, the sounding depth was subtracted from the survey elevation. A majority of dredging progress was surveyed using the fixed survey rod and the sonic depth sounder. Dredged surface elevations for QC in deep water were surveyed predominantly using the weighted tape method because this was found to be most efficient and accurate.

Filling

Fill placement and grading needed to be done with precision to allow us to construct an inclined high-permeability layer that would transport gas, and entrained NAPL, to an accumulation zone on the shoreward side of the cap. The cap is shown in cross section on Figure 2. The upper surface of the Gas Transmission Layer needed to be placed to within ± 0.15 m during grading. The low-permeability gas-control layer (AquaBlok®) was placed on top of the high-permeability gas transmission layer. In addition, the minimum thickness of the AquaBlok® needed to be at least 24 cm. Approximately 15,000 m^3 of fill was placed during construction. Placement of the fill at the appropriate location was relatively straightforward. However, filling to the appropriate grade (and no higher) was extremely difficult when working underwater.

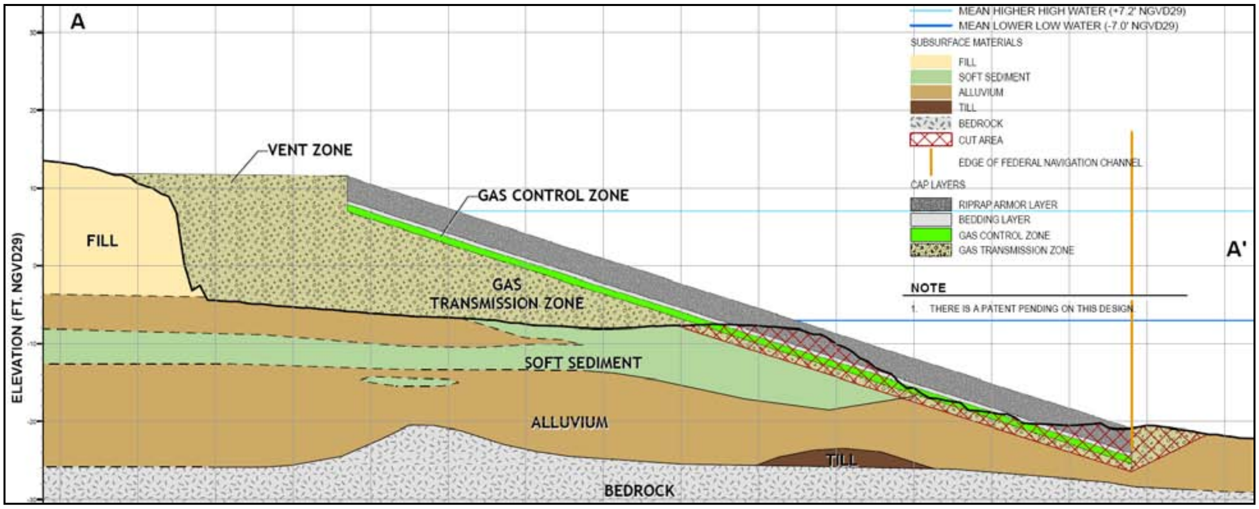

Figure 2. Section view of NAPL-Trapping Cap (patent pending).

Surveying During Filling

All cap layers were subject to QC surveying. The QC surveying involved a total station survey instrument set up on land. Survey measurements were taken every 1.6 m along each half range line to guide construction. Survey measurements were recorded every 8 m for QC documentation. The deep water layers were surveyed by fixing a prism to a skiff and lowering a weighted tape measure into the water. Upon reaching the bottom material, the tape measure was read and the prism location was surveyed. The tape measure length was entered into the total station and the layer depth was recorded. Each layer met the specified minimum thickness, most notably the select fill and AquaBlok®. Select fill thicknesses were acceptable if they were within the design tolerance, and the slope of the surface between QC points was no less than 10:1 and no greater than 3.5:1. AquaBlok® thicknesses were all greater than 24 cm and in many areas were over 30 cm. Scuba divers were utilized several times to confirm underwater cap construction integrity. The divers were able to feel the extent, roughness, and continuity of the various cap layers.

RESULTS AND DISCUSSION

Crushed Stone Gas Transmission Layer Fill

Cap layer construction began with placement of general fill. The general fill was composed of crushed stone passing a 2.5 cm sieve. Cap installation was completed from deepwater to shallow water and continued upslope to elevation 3 m NGVD29.

General fill was placed during initial capping phases with a long-stick excavator and a stone slinger. The long-stick excavator was able to reach approximately 15 m from its point of operation on the bank. General fill placed with the stone slinger was spread from discrete points on the shore. The stone slinger utilized an approximately 5m^3 hopper that fed a high speed conveyor belt. The conveyor belt moved at speeds of several m per second and could spread material up to 40 m from the location of the stone slinger. The direction and angle of the stone slinger conveyor was hydraulically actuated by a radio controlled remote. The operator of the stone slinger generally attempted to spread thin layers (< 5 cm) in the full arc of the conveyor. The stone slinger operated in this way was able to cover a very large geographic extent with thin continuous layers while positioned in one place. Coverage area was greater than 560 m^2 with the stone slinger. Thickness of material placed with the slinger was controlled by how long the slinger conveyor was held on one vector. To physically observe the thickness of material placed, the operator would keep the change in conveyor angle constant and place material in an arc that intersected the above water portion of the intertidal area. General fill for the entire cap was brought to within approximately plus or minus half a foot of design grades prior to placement of any other layers.

Once general fill had been completed to rough grades, the focus shifted to building up the layers of the cap on narrow panels along range lines. Cap construction started at the bulkhead and moved downstream. Placement of the upper layers followed the placement of the lower layers, so that with the exception of the general fill, no layer was completely constructed before the subsequent layer. This construction sequence was as intended by the design to mitigate pressure build up under confining layer of AquaBlok® and to ensure slope stability during construction.

Select fill was placed in panels roughly bounded by the survey control range lines or half-range lines described earlier. The design specified that select fill would be placed in panels approximately 8 m wide and 0.45 to 0.75 m thick. The average thickness of select fill in deep water portions over dredge materials was greater than 0.75 m. Placement started in the protection of the bulkhead and progressed downstream.

During construction of the panels, select fill was stockpiled at the top of the slope with a loader. A long-stick excavator then placed the material within reach of the barge crane. Select fill was placed from the deep water at the navigational channel upslope to approximately the low tide line with the clam shell bucket from the barge. Above the low tide line, select fill was placed with the long reach excavator from shore. Rough grading of select fill was completed with the long reach excavator, and clam shell buckets. Fine grading of select fill was completed by dragging deep water portions with blast mats or steel beams (Figure 3). Fine grading of select fill in intertidal and upland areas of the cap was accomplished with an adjustable-grade, low-ground-pressure dozer. Select fill was surveyed on a 2-m spacing along each half-range line and recorded at 8-m intervals for QC documentation before placement of AquaBlok®. Placement of select fill preceded the placement of AquaBlok® by no more than two full range lines (30 m). Grading of the upper surface of the select fill had to be completed with a high degree of precision because the surface of the select fill was the mold on which the clay layer would be applied. The shape of the clay layer allowed us to control gas migration, and hence NAPL migration, from sediment.

Figure 3. Using a steel beam drag bar to grade the surface of the cap.

Placement of AquaBlok®

AquaBlok® was placed in a manner similar to select fill. At least 25 cm of AquaBlok® was placed over the select fill. AquaBlok® was placed to half range lines, and a half range line buffer was always kept from the edge of select fill, such that select fill placement to range line 6 meant AquaBlok® placement would stop at range line 6.5. The clamshell bucket placed material in the deep water area, and excavators and dozers were used to place material in the intertidal and on-shore areas. AquaBlok® was not placed using the high velocity stone slinger technique since testing showed that the AquaBlok® bentonite coating could separate from the core aggregate during placement with the high-speed conveyor.

When placing AquaBlok® in the intertidal area, the long-stick excavator was first used to locate the western edge of AquaBlok® placed by the barge crane. The edge was then cut to create a uniform surface for the excavator to tie into. Grading stakes were set to assure the proper thickness of AquaBlok®. AquaBlok® was then placed in the intertidal and on-shore area. A butt joint was created joining the deep water AquaBlok® panel and the on-shore AquaBlok® panel.

The major concern for gas control layer was that the layer was continuous, and that it had a sufficiently low permeability to control gas flow. The precise configuration of the upper surface for this gas control layer was not critical in the design of the cap.

Placement of Select Crushed Stone Bedding Layer, Geogrid and Riprap Armor

Fifteen cm of aggregate bedding material, a polyester geogrid (Huesker Fortrac 35 polyester grid), and 0.8 m of rip rap were placed on top of the AquaBlok®. Geogrid was placed using 5-m wide rolls and was placed within the 15 cm of aggregate bedding material. After the 8 cm of bedding layer were placed, the rolls were held up over deep water with the crane and unreeled upslope using boats and manual labor. The geogrid was cut on the barge and then sunk to the bottom. To facilitate sinking of the neutrally buoyant geogrid, a single piece of 5-m long #5 rebar was knitted into the grid. The second 8-cm layer of bedding stone was placed over the geogrid prior to the placement of rip rap. Rip rap was placed in deep water using the clamshell bucket and on dry land using the loader and excavator. The rip rap generally appeared to conform to its specification, however, due to its large grain size, no material testing could be performed. Some loads of rip rap had a noticeable amount of fines, i.e. particles less than 2.5 cm diameter. This will not adversely affect the performance of the armor layer since the smaller stone will sift down between the larger stones and make the whole layer more stable. Due to its large size, the larger pieces of rip rap were placed individually.

Long-term settlement will be monitored using five settlement plates. Each settlement plate was constructed from a 1.4 m by 1.4 m plate of steel with a 1 cm box beam welded vertically in its center. The settlement plates were placed on the top of the bedding layer prior to the placement of the rip rap. Rip rap was placed over the top of the plate with the top of the box beam extending above the rip rap. The elevation of the highest point of the box beam was recorded by the surveyor.

CONCLUSIONS

Carving the fill into shape for construction of the NAPL Trapping Cap was challenging. The accuracy specification of (± 3 cm) was very difficult to meet for the construction of the upper surface of the gas transmission layer in deep water, but a looser specification may not have resulted in a cap that that functioned as intended. The underwater grading methods that we used (drag beam/blast mats and grader box) for shaping the upper surface of the gas transmission layer were adequate but not ideal. The most important way to increase grading efficiency in this environment was to place thin lifts of fill, survey often, and above all, avoid overfilling.

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