REPORT

Final NAPL Controls Report
Pine Street Canal Superfund Site
Burlington, Vermont

Submitted to:
Green Mountain Power

Submitted by:
ARCADIS
Hart Crowser, Inc.

Project 69852, June 20, 2008

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Respectfully submitted,

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List of Acronyms and Units of Measure

ARAR	applicable or relevant and appropriate requirements
DNAPL	dense non-aqueous phase liquid
EPRI	Electric Power Research Institute
ft	feet
ft^2	square feet
GRA	general response action
HDPE	high-density polyethylene
In	inch
kg	kilogram
kg/year	kilograms per year
MGP	manufactured gas plant
NAPL	non-aqueous phase liquid
OC	organoclay
PAH	polycyclic aromatic hydrocarbon
QAC	quaternary ammonium compound
RCM	reactive core mat
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
VTDEC	Vermont Department of Environmental Conservation

1. Introduction

1.1 Purpose and Objective

This final non-aqueous phase liquid (NAPL) controls report was prepared by ARCADIS BBL and Hart Crowser, Inc. in accordance with the NAPL Action Plan (BBL and Hart Crowser 2006a) for the Pine Street Canal Superfund Site in Burlington, Vermont. The Action Plan proposed a path forward to address NAPL seepage into the canal, including NAPL field investigations, which were conducted in three separate events (spring, summer, and winter). In spring and summer 2006, surface and subsurface investigations were conducted to assess NAPL migration to the water column in the canal. The winter field investigation of the bank subsurface was conducted in early 2007. The Final NAPL Investigation Report, which was finalized on February 1, 2008, presents the results of the spring, summer, and winter investigations and confirms the conceptual site model with respect to NAPL migration mechanisms. This Final NAPL Controls Report is a companion to the Final NAPL Investigation Report.

In accordance with the Consent Decree and the Record of Decision (ROD) for the Pine Street Canal Superfund Site, the existing sand cap was designed to physically isolate NAPL from the overlying water and to improve the habitat values of the surficial sediments. In addition, the cap was designed to prevent or minimize the migration of contaminants (by erosion, diffusion, advection, or bioturbation) from the underlying contaminated sediments upward through the cap. The existing sand cap generally meets these objectives, with the exception of a few locations where NAPL is entering the water column. The existing performance standards are included as Appendix D (Section VII, Pages 45-53 of the RD/RA SOW).

The objective of this Final NAPL Controls Report is to identify and evaluate NAPL controls that would prevent or minimize NAPL seepage into the canal and that can be readily and economically implemented as partial replacement for, augmentation of, or addition to the existing sand cap.

1.2 Site Description

The Pine Street Canal Superfund Site is located in Burlington, Vermont near the shore of Lake Champlain (Figure 1-1). The site is situated in an urban residential/industrial area approximately 0.5 mile south of downtown Burlington and is surrounded by manufacturing and commercial facilities, as well as by residential neighborhoods with medium to high population density. The Burlington recreation path and the shore of Lake Champlain lie immediately west of, and adjacent to, the Vermont Railroad tracks, which mark the western boundary of the site. The overall site is approximately 70 acres in area and is substantially undeveloped. The primary physical features of the site are an abandoned barge canal and turning basin, which are hydraulically connected to Lake Champlain through a partially restricted inlet/outlet under the Vermont Railroad trestle bridge. The canal and turning basin were constructed during the industrialization of this area, which began in approximately 1868. In addition to the open-water environment (approximately 5 to 6 acres) formed by the canal and turning basin, the site consists of a 21-acre vegetated wetland area and a 45-acre upland area. A site plan showing study subareas and transect locations is presented on Figure 1-2.

The Burlington Light & Power Manufactured Gas Plant (MGP) operated from around the turn of the 20th century until 1966. The former MGP was located east of the canal on Pine Street (see Figure 1-1). As described in Section 2 of the Action Plan (BBL and Hart Crowser 2006a) and Appendix A of the Work Plan for the site (BBL and Hart Crowser 2006b), analysis suggests that operations at the MGP resulted in coal tar releases in and around the Pine Street Canal.

In September 2004, The Johnson Company of Montpelier, Vermont prepared the Remedial Action Construction Completion Report (The Johnson Company 2004) for the capping of canal sediments. Subsequent to the capping, NAPL was encountered on probes of the cap surface, and sheens were noted in association with methane bubbles (i.e., "ebullition"), most predominantly in the areas between Transects T9 and T12. The presence of NAPL on the cap prompted the need for additional studies, described in the Final NAPL Investigation Report, to determine the source of the NAPL and the mechanism by which NAPL is migrating to the canal, as well as to identify potential measures for NAPL control.

1.3 Summary of NAPL Investigation Findings

The Final NAPL Investigation Report evaluates data collected during the spring, summer, and winter investigations and updates the conceptual site model with respect to NAPL migration mechanisms.

The following conclusions from the Final NAPL Investigation Report provide a basis to evaluate and select NAPL controls at the site and are generally conservative with respect to the extent and mass of NAPL. To evaluate NAPL location and mass with respect to the potential for NAPL seepage into the canal, a grid was projected onto the canal. Each cell in the grid is 25 feet by 25 feet in plan view, which is a reasonable size to create a modular design for NAPL controls. The values depicting location and mass of NAPL are derived using conservative (high-end) assumptions. Since appropriate controls will be designed for any location within a cell that has a high potential for NAPL migration, the NAPL masses are calculated based on the maximum chemistry results within that cell. Therefore, the calculated masses per cell represent a reasonably conservative order-of-magnitude estimate of the maximum NAPL migration that could require controls during the design.

This section discusses relative order-of-magnitude masses of NAPL within different stratigraphic layers at the site. This does not represent a mass balance. Since these masses are order-of-magnitude estimates, the actual NAPL mass or seepage associated with each cell may be lower or higher.

NAPL Seepage into the Canal

In the spring and summer of 2006, NAPL seepage into the canal was observed between Transects T9 and T12, with the majority between Transects T10 and T11. Seepage was mostly associated with gas bubbles and varied in location, timing, and rate. Limited NAPL seeps also occur as globules rising to the canal surface without gas bubbles. We estimate that the rate of NAPL seepage into the canal is on the order of 111,000 grams per year[1] (111 kilograms per year). The estimated maximum rate of NAPL seepage per cell was 32 kg per year, which was estimated on the western side of the canal near Transect T10+75. Based on observed seepage, the overall area of potential seepage is approximately 14,000 square feet (ft^2), or about one-third of an acre.

NAPL Deposition on the Cap Surface

The majority of NAPL deposition, defined as the amount of NAPL that can be quantified using cap swabs, was observed between Transects T10+50 and T11+50 and appears to be correlated with the observed seepage locations. We estimate that the mass of NAPL deposition on the top of the cap is on the order of 2.5 kg in the area of interest. On a cell basis, the estimated maximum mass of NAPL deposition is on the order of 0.5 kg,

[1] The Final NAPL Investigation Report is the source of the estimated NAPL masses and fluxes presented in this report. These values are conservative order-of-magnitude, model-derived estimates, which were developed for the purpose of evaluating NAPL controls for the site. These values do not represent a mass balance for the site.

which was estimated on the western side of the canal near Transects T10+75 and T11. Significant NAPL mass is also present in the upper portion of the sand cap (defined as the top 4 inches), which is discussed below.

NAPL within the Sand Cap

Based on 2006 sampling conducted to characterize the presence of NAPL within the canal sand cap, the area of observed NAPL in the cap is generally similar to and coincident with the area of observed NAPL seepage into the canal. To estimate locations where NAPL is potentially migrating upward through the cap, the mass of NAPL in the upper and lower portions of the sand cap were calculated separately. We estimate that the mass of NAPL in the upper portion (i.e., the top 4 inches) of the sand cap is on the order of 756 kg and the mass of NAPL in the lower portion (i.e., below the top 4 inches) of the sand cap is on the order of 2,400 kg. On a cell basis, the estimated maximum mass of NAPL in the upper portion of the sand cap is on the order of 158 kg (on the western side of the canal near Transect T11+25) and in the lower portion of the sand cap is on the order of 1,450 kg (on the western side of the canal near Transect T11). Approximately 77 percent of the total estimated mass of NAPL within the lower portion of the cap (below the top 4 inches) is found in three 25-ft by 25-ft cells (10.4A, 10.4C, and 11.1A).

Five out of a total of 25 cap coring locations in the canal exhibited increased NAPL concentrations toward the bottom of the cap, indicating that NAPL may be migrating upward through the lower portion of the cap at these locations. Generally, the cap coring locations did not show visible horizontal gradation of NAPL. A visible horizontal gradation of NAPL, indicative of a vertical seepage path, could be observed in the core sample at a few locations. However, based on the volume of NAPL within the pore space of the sand, this mass is interpreted as residual NAPL and is not expected to be mobile.

During the winter investigation an additional nine cap cores (on three transects) were conducted in the west bank cap. The west bank cap coring results indicate that limited, localized, discrete intervals of NAPL are present at the apparent interface between the base of the cap and the underlying soil. However, no continuous pathway of NAPL from the cribbing to the canal was observed.

Thickness of the Sand Cap

Forty-two sand cap thickness measurements were obtained. Of these, 10 measurements were less than 1.5 feet, the cap's minimum design thickness. Most cells with low sand cap thickness also exhibited NAPL seepage and relatively high NAPL concentrations within the cap.

Potentially Mobile Subsurface NAPL

NAPL is potentially mobile in soil and sediment matrices at concentrations above residual saturation. At concentrations at or below residual saturation, NAPL is trapped within soil pores by capillary forces, which are greater than gravity or hydraulic forces, and the NAPL is immobile.

Based on the 2006 subsurface explorations beneath the canal and three-dimensional modeling, the majority of the subsurface NAPL is within the peat layer beneath the canal. The area of interpreted mobile NAPL within the subsurface is larger than the area of observed NAPL seepage. The estimated mass of mobile NAPL in the canal subsurface in the area of interest is on the order of 521,000 kg. Approximately 70 percent of the interpreted mobile NAPL is in the peat layer. On a cell basis, the maximum mass of mobile NAPL in the canal subsurface was 17,200 kg on the western side of the canal near Transect T10+50. The other cells with the highest mass of subsurface mobile NAPL tended to be in the middle of the canal.

Investigation data indicate that there is a significant mass of potentially mobile NAPL present beneath the canal. It generally does not appear to extend into the stratified silt and sand or clayey silt layers underlying the peat. Therefore, the vertical extent of potentially mobile NAPL has been adequately defined at the site.

Although the horizontal extent of potentially mobile NAPL has not been completely defined at the site, the lack of observed NAPL seepage north or south of the spring investigation boundaries indicates that the horizontal extent of potentially mobile NAPL along the canal length has been defined for the purposes of this study.

Based on the winter investigation, the horizontal extent of potentially mobile NAPL along the banks of the canal is less than the extent of mobile NAPL beneath the canal. The calculated mass of potentially mobile NAPL beneath the west and east banks is 11 percent and 6 percent, respectively, of the total mass of potentially mobile NAPL beneath the canal and banks. Furthermore, NAPL concentrations beneath the banks appear to decrease with distance away from the canal. In the vicinity of documented seepage to the canal, the only significant NAPL observed beneath the banks is in the former slip on the east bank, and even here NAPL concentrations are lower than beneath the canal. These results are consistent with historical observation of subsurface NAPL at the site.

Conceptual Site Model

The conceptual site model for NAPL migration, originally presented in the Action Plan, is updated based primarily on four potential NAPL migration mechanisms:

- NAPL migration via vertical hydraulic gradient – Vertical hydraulic gradients in the clayey silt and organic silt/sediment are sufficient for upward NAPL movement toward the base of the sand cap. This mechanism makes it possible for localized pools of NAPL to form at the interface between the organic silt/sediment and the sand cap. Upward NAPL movement through the sand cap via hydraulic gradient is unlikely due to lower hydraulic gradients within the sand cap. Other NAPL migration mechanisms, however, can cause the NAPL to migrate through the sand cap into the canal.

- NAPL migration via horizontal hydraulic gradient – Horizontal hydraulic gradients in both the east and west banks fluctuate seasonally, correlating with surface water levels and groundwater recharge. Gradients capable of mobilizing NAPL towards the canal are likely not present or are only present intermittently.

- NAPL migration via localized bearing-capacity failures – Consolidation settlement may have contributed to NAPL migration through the sand cap in the past, but it is anticipated that under current conditions, consolidation settlement will play a decreasing role in NAPL migration to the canal. NAPL migration to the canal, however, may still occur along localized bearing-capacity failures. Implementation of the selected NAPL controls has the potential to create NAPL migration by this preferential pathway under certain conditions of loading from construction equipment, as well as loading from the capping material type(s) and placement approach.

- NAPL migration via preferential pathways – NAPL wicking along the cribbing and NAPL migration via preferential flow paths (such as hydraulic fractures and high-porosity zones) are potential NAPL migration mechanisms to the canal.

- NAPL migration via gas bubble-induced transport – Gas bubbles are an observed method of NAPL migration to the canal.

The overall conclusion is that NAPL may have migrated from the NAPL-rich peat layer to the organic silt/sediment layer and the base of the sand cap in the past as a result of consolidation and is continuing to migrate due to the effect of vertical hydraulic gradients. From the organic silt/sediment layer, gas bubbles carry the NAPL through the cap and into the canal. The effect is most pronounced where the cap is thinnest. This migration pathway appears to be the most significant of the potential ongoing NAPL migration pathways and is the primary pathway that the NAPL controls must address.

For the west bank and the majority of the east bank in the area of seepage (Transect T9+00 to T12+50), which was the focus of this investigation, there is no indication that there are significant NAPL pools or that NAPL is migrating into the canal from the banks. However, there is potentially mobile NAPL within the former slip along the east bank. The NAPL controls must address the primary and secondary migration mechanisms and the impact of potentially mobile NAPL in the former slip on the cap and its ability to prevent NAPL releases. Two forms of NAPL control are possible at the site:

- Control of NAPL already on the surface of the cap
- Control of NAPL migration into the canal

The Investigation Report concluded that the contiguous area of cap requiring NAPL control is approximately 14,000 ft^2, or one-third of an acre; however, the NAPL controls area has been extended, as requested by the USEPA, to include the entire canal between Transects T9+00 and T12+50 for a total of approximately 26,000 ft^2 or one-half acre. In comparison with the Final NAPL Investigation Report analysis, this expands the area of NAPL controls by approximately an additional 30 ft to the north and south and to include the entire canal from the west bank to the east bank. This area was used to evaluate the NAPL controls alternatives in this Final NAPL Controls Report. The actual extent of NAPL controls may differ based on additional analyses during design.

1.4 Site Constraints

In addition to the findings of the NAPL Investigation and the revised CSM described above, the following site constraints were taken into account in selecting an approach for NAPL control:

- Constructed elements must consist of partial replacement for, augmentation of, or addition to the existing sand cap, per the existing ROD. The existing performance standards are included as Appendix D (Section VII, Pages 45-53 of the RD/RA SOW).

- Constructed elements for cap replacement/augmentation must achieve a weight equal to or less than the weight of the existing sand cap to the extent possible, to avoid remobilization of NAPL due to consolidation.

- Constructed elements for cap replacement/augmentation must include consideration of erosion forces and cap stability.

- The top of the final replaced/augmented cap must include a 6-inch (in)-thick habitat layer of clean sand, in accordance with the existing ROD.

- The existing hydraulic capacity of the canal must be retained, because the canal is used as a City of Burlington stormwater conveyance.

- The wetland/habitat balance specified in the ROD must be maintained.
- Constructed elements must take into account the presence of gas in sediments.
- Constructed elements must take into account potential ice effects in the canal.
- Construction methods must take into account the presence of subsurface structures and debris beneath the canal.

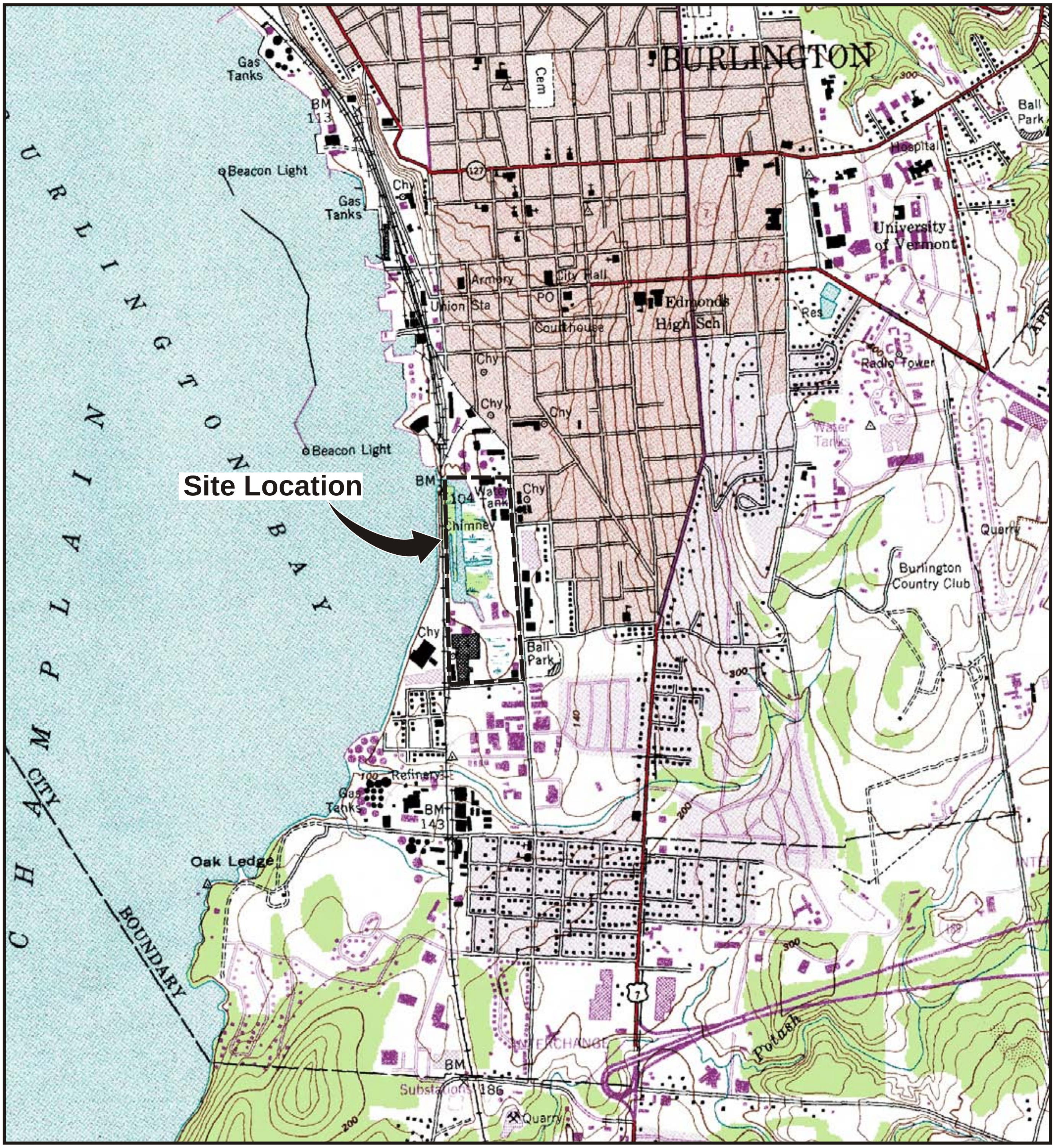
1.5 Report Organization

The remainder of this report is organized as follows:

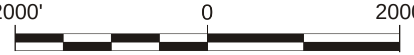
- Section 2 identifies and screens potential NAPL control technologies.
- Section 3 develops and describes the most likely NAPL control concepts.
- Section 4 develops and evaluates three NAPL control alternatives retained from the NAPL control concepts presented in Section 3.
- Section 5 presents our recommendations regarding a preferred approach for NAPL control.

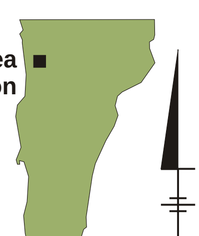
The following appendices are included:

- Appendix A – Review of Engineered Capping at NAPL-Impacted Sediment Sites
- Appendix B – Review of NAPL Barrier Projects at NAPL-Impacted Sites
- Appendix C – Cost Estimates and Assumptions
- Appendix D –Performance Standards (Section VII, Pages 45-53 of the RD/RA SOW)
- Appendix E – Pre-Design Testing of Organoclay NAPL Capacity and Vendor Specifications
- Appendix F – USEPA, VTDEC, and USFWS Comments



REFERENCE: BASE MAP USGS 7.5 MIN. QUAD., BURLINGTON, VERMONT, 1948, PHOTOREVISED 1987.





BURLINGTON, VERMONT

PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

VICINITY MAP

ARCADIS BBL
Infrastructure, environment, facilities

FIGURE
1-1

05/12/07 SYR-D85-DJH
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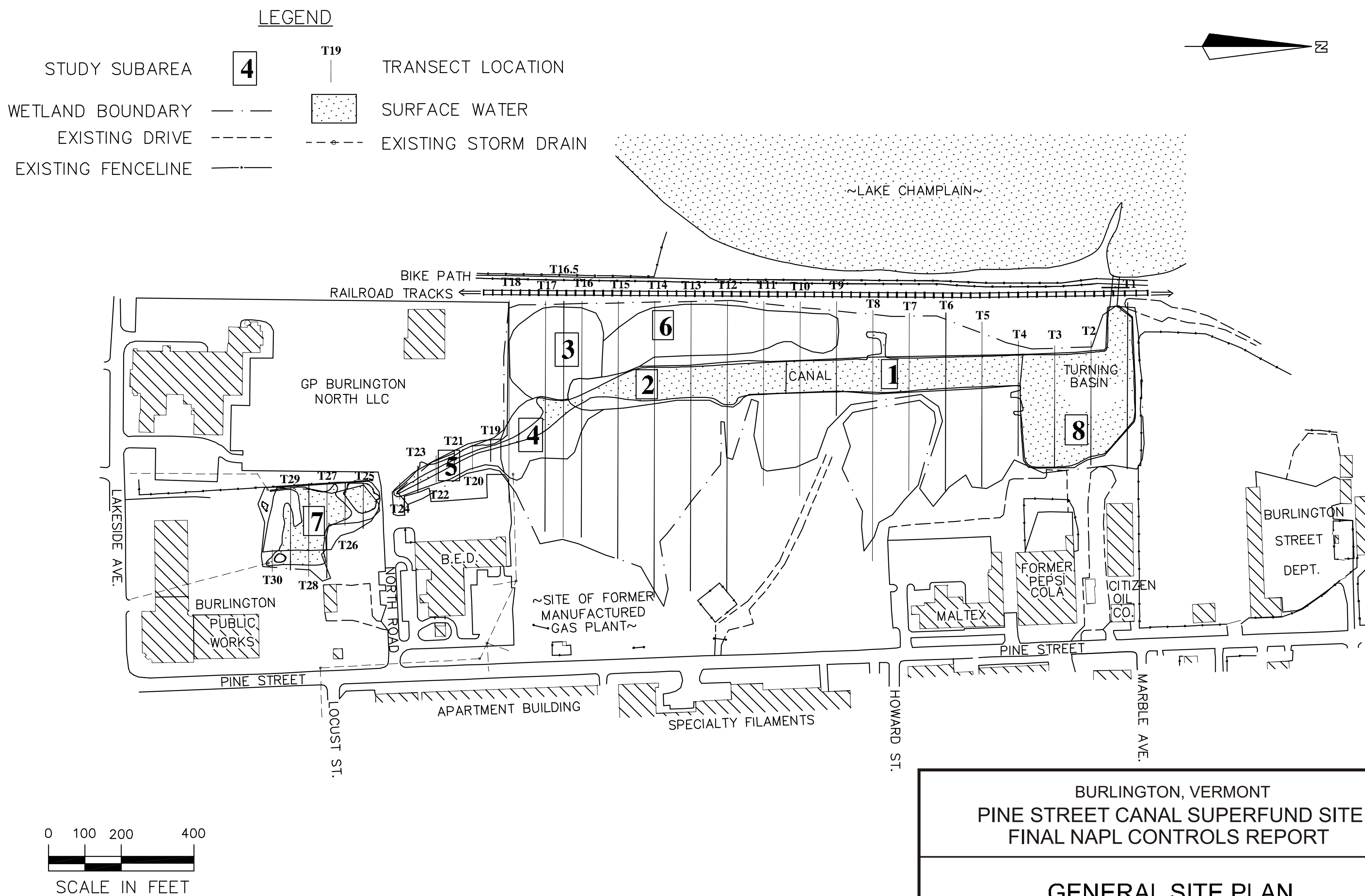

BURLINGTON, VERMONT

PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

GENERAL SITE PLAN

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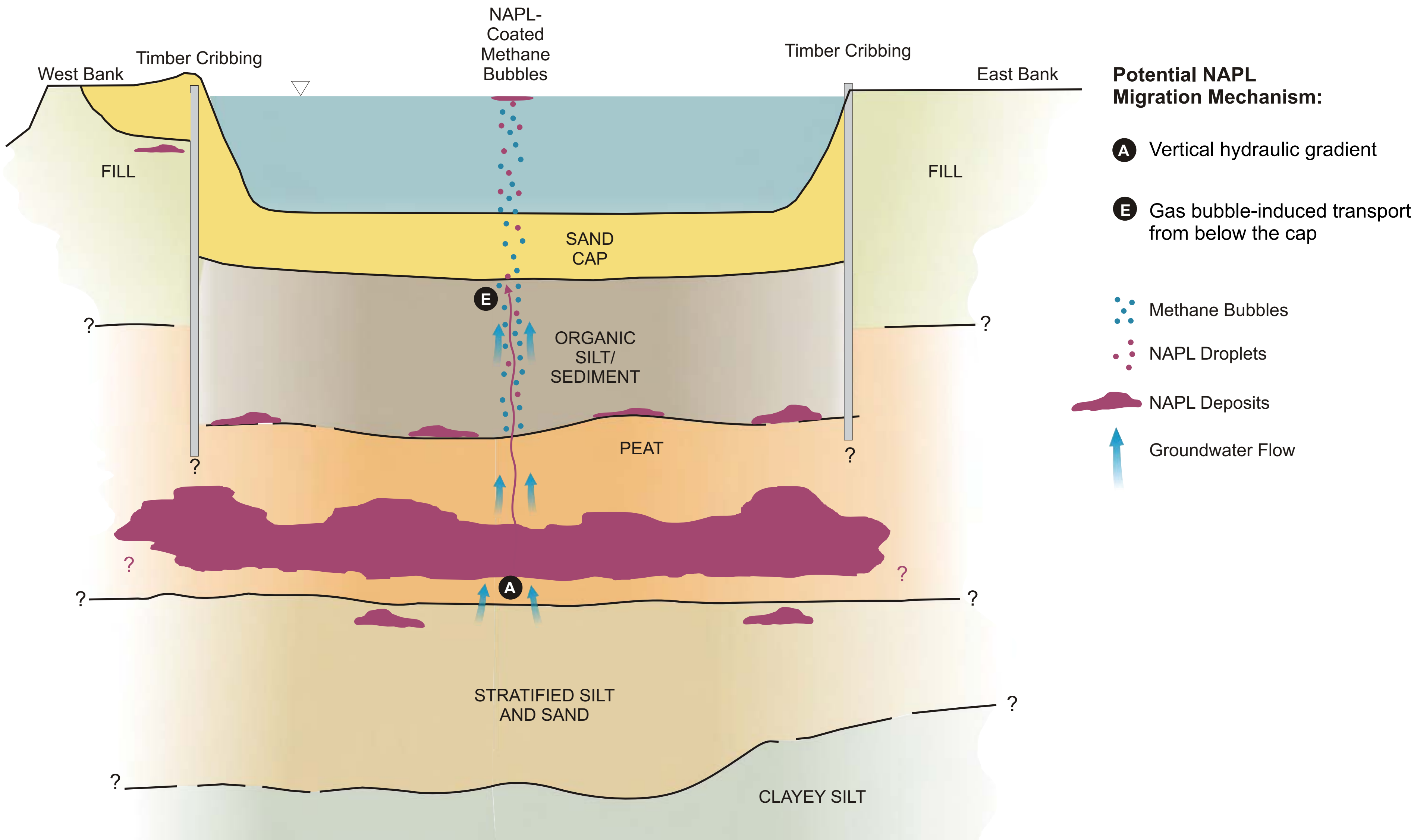
FIGURE
1-2

Note: Map provided by The Johnson Company.



NOTE: NOT TO SCALE

BURLINGTON, VERMONT
PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

REVISED CONCEPTUAL SITE MODEL

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Infrastructure, environment, facilities

FIGURE
1-3

2. Identification and Screening of NAPL Control Technologies

2.1 General

The objective of the selection process presented in this report is to identify and evaluate NAPL control options that would reduce NAPL seepage into the canal and that can be readily and economically implemented as partial replacement for, augmentation of, or addition to the existing sand cap. NAPL controls may include supplemental containment, NAPL removal, NAPL treatment, alone or in combination. The following discussion identifies technologies that are potentially applicable to the project based on the professional experience of ARCADIS BBL and Hart Crowser at other NAPL-impacted sites, as well as on current guidance documents published by the U.S. Environmental Protection Agency (USEPA 2005c, 2000a) and the Electric Power Research Institute (EPRI 1999). The identified technologies are then screened using the criteria of effectiveness, implementability, and relative cost in accordance with USEPA guidance (USEPA 1988). Technologies identified as potentially applicable are intended to be applied either directly to the cap or to the source of NAPL that can potentially migrate to the cap. Additional site constraints that may affect the selection process are summarized in Section 1.4.

2.2 Identification of General Response Actions and Technologies

In the process described above, the first step is to identify applicable general response actions (GRAs). GRAs are generic technology types that can be utilized individually or combined with other GRAs to achieve the project objectives. The GRAs applicable to this project are:

- Containment technologies (described in Section 2.2.1)
- Removal and recovery technologies (described in Section 2.2.2)
- In-situ treatment technologies (described in Section 2.2.3)

Dewatering and off-site disposal of removed sediment are auxiliary GRAs; however, the auxiliary GRAs are not discussed in this report, because they can be developed during the design phase and do not have significant impact on the selection of an overall approach.

2.2.1 Containment Technologies

In-situ containment options include engineered caps and barriers that can effectively sequester, isolate, or otherwise control NAPL mobility and release to the environment. Capping primarily involves chemically and/or physically isolating underlying contaminants from receptors, reducing the long-term risk of exposure to the NAPL. Sediment capping has been applied as a component of site remediation at a significant number of contaminated sediment sites (USEPA 2005c). A sand cap would provide chemical and biological isolation of impacted sediments from the water body. Compared to a sand cap, a reactive cap would provide an additional mechanism to sequester the NAPL. Using barriers in combination with a sand cap and/or reactive cap would provide additional isolation of the most mobile fraction of the NAPL and reduce NAPL loading to the reactive cap.

The containment technology groups considered potentially applicable for the Pine Street Canal Superfund Site are described below and further detailed in Table 2-1. These technologies are:

- Sand cap
- Reactive cap
- Low-permeability cap
- Impermeable Barrier

Sand Caps

Sand is the conventional capping material for providing chemical isolation. However, the sand cap at the site has not been effective at controlling NAPL migration to the water column in the area of interest and particularly lacks the means to control NAPL migration via gas bubble transport.

One observation from the NAPL investigation is that NAPL migration via gas bubble transport is temperature-dependent. A relatively thick sand cap could therefore be used to insulate the organic silt/sediment layer where the bubbles are generated and reduce ebullition and the associated NAPL migration via gas bubble transport. This NAPL control strategy was selected at the Stryker Bay site (See Appendix A). However, a thicker sand cap will weigh more and thus is not feasible at the Pine Street Canal Superfund Site due to the potential for additional consolidation-induced NAPL migration and possible limitations on the hydraulic capacity of the canal.

Reactive Caps

Recently, reactive caps that simultaneously isolate and treat contaminants have been developed (Reible and Constant 2004), including a number of reactive capping technologies for treating or sequestering NAPL. Reactive capping for NAPL control has been applied to only a limited number of sites and is an active area of research at the bench and pilot scales. The use of sorbents, such as bulk organoclay (OC) and OC mats, to sequester NAPL is an area of active research. This research has demonstrated the technical feasibility of using OC and OC mats for controlling even the more complex transport mechanisms (i.e., controls transport via methane bubbles by removing NAPL coating from bubbles) (Reible 2005b).

OC is manufactured by replacing cations in layered clays, such as bentonite, with cationic organic compounds, such as quaternary ammonium compounds (QACs), to create an organic phase along the surface of each layer in the molecular lattice. OC effectively controls NAPL when applied as a bulk cap or as a reactive core mat (RCM), which is a thin layer of OC stitched between two geotextile layers. RCMs are appropriate for a cap of less thickness than a traditional bulk cap and have a significantly lower weight than bulk caps. Additional benefits of RCMs are their ease of installation, stability, and physical isolation. However, this relatively new technology does not have a long-term record of performance at NAPL sites. RCMs may require replacement over time if the mass of NAPL loading exceeds the NAPL retention capacity of the RCM. The CETCO™ (Arlington Heights, Illinois) RCM, which contains OC material, was recently used to control NAPL releases at the McCormick and Baxter Superfund Site in Portland, Oregon.

OC can absorb an amount of NAPL equivalent to more than 50 percent of its weight before reaching saturation (Lo and Yang 2001), although in OC batch tests, NAPL loadings as low as 10 percent produced oil sheens in the overlying water column (Kellems et al. 2002). However, flow-through column tests using residual coal tar following simulated gravity separation in a recovery layer indicated that OC was capable of preventing NAPL "breakthrough" and inhibited the development of sheen on the water surface (Gefell et al. 2006). Thus, if sufficient OC is available for sorption above the portion of the cap that saturates with NAPL, oil sheens will be captured before reaching the water column. Furthermore, OC has been observed to swell and have a reduced permeability when exposed to NAPL (Reible, 2005a) (Appendix E). After the OC has been saturated with NAPL, this reduced permeability may limit seeps through the saturated RCM by promoting lateral migration of NAPL to unsaturated RCM.

Experimental results have shown that an OC cap reduced the gas-associated NAPL flux to effectively zero by stripping the NAPL from gas bubbles while still allowing the gas to flow through the cap at rates that might be observed in nature (i.e., 1 liter per square meter per day) (Khanam 2006). In these experiments, the structural integrity of the OC after adsorbing NAPL was also assessed by laboratory testing of shear strength using an unconsolidated-undrained triaxial compression test. NAPL-saturated OCs had lower load-bearing capacity (110.6 pounds per square inch) compared to water-saturated OCs (214.1 pounds per square inch). However, despite the reduction in shear strength, this study concluded that NAPL-saturated OC should have sufficient load-bearing capacity not to fail under typical environmental capping scenarios (Khanam 2006).

Cellulose, natural peat, and coke breeze are other sorbent types available for sequestering NAPL. For the purpose of this report, these sorbents and OC are categorized as mixed media, meaning that a sorbent and sand or a combination of sorbents would be used for the active cap. For a recent project at a former MGP site in Salem, Massachusetts, an evaluation of active capping technologies incorporated batch testing in the selection of sorbent media. All these sorbent media, as well as OC, performed reasonably well in the testing. On a cost-benefit basis, treated cellulose ranked highest; however, treated cellulose is lightweight and can be difficult to work with in subaqueous conditions. A combination approach using a RCM with OC and separate application of cellulose in a NAPL collection trench has been designed and was constructed at the Salem site in December 2006 to February 2007. Although coke breeze has relatively high organic carbon content (7.2 to 12 percent by weight), it did not prevent NAPL breakthrough or sheen development during flow-through column tests using coal tar, similar to a control column filled with sand (Gefell et al. 2006).

Low-Permeability Caps

A low-permeability cap is potentially effective at controlling NAPL but this technology has seen only limited application. Such approaches may be problematic where methane gases are generated below the cap. The potential uplift and deformation of a low-permeability sediment cap constructed with AquaBlok™ was studied in the Anacostia River reactive capping research project (Mutch et al. 2005). Following initial settlement, the cap began to slowly uplift a total of about 1-inch over a period of 40 days before suddenly uplifting more than 2 ft. Uplift events of similar magnitude occurred intermittently throughout the summer and early fall of 2004. Uplift could potentially cause cracking and jointing of the low-permeability cap, substantially increasing its hydraulic conductivity and, as a consequence, compromising the cap's ability to restrict contaminant flux.

Appendix A describes projects that have included capping to control NAPL. Past successful capping projects offer insights for improving cap design and have identified a wide range of conditions in which capping is applicable. Many accepted scientific and engineering guidance documents address cap design issues, such as mitigating contaminant mobility and providing physical integrity to resist erosion and consolidation of underlying sediment.

Impermeable Barriers

Impermeable barriers are generally physical (e.g., watertight sheet pile) or hydraulic and are designed to isolate the source of NAPL from the water body. Impermeable barriers may be used in combination with the capping technologies described above. A barrier may provide isolation of the most mobile fraction of the NAPL.

Appendix B includes examples of physical and/or hydraulic barrier systems that have been installed to contain NAPL.

2.2.2 Removal and Recovery Technologies

Removal and recovery technologies for NAPL control would address NAPL currently on the surface of the cap and the NAPL source in the peat layer, as well as other zones containing mobile NAPL, either by removing both the NAPL and the associated NAPL-containing soil layer (such as on the cap surface) or by using a high-permeability layer that will allow the NAPL to settle by gravity..

The removal and recovery technology groups considered potentially applicable to the Pine Street Canal Superfund Site are described below and further detailed in Table 2-1. These technologies are:

- Dredging
- Excavation (dry)
- NAPL recovery
- Enhanced extraction

Dredging and excavation are two common methods of physically removing sediments from a water body using either mechanical or hydraulic means. Because of the small area (less than 1 acre) that would be subjected to dredging/excavation at the Pine Street Canal site, micro-dredging may be the best approach for removing the NAPL-containing sand from the top of the cap. Divers or remotely operated vehicles have a maximum precision of plus or minus 1-in of dredge thickness. However, the potential for resuspension and residual contamination presents significant challenges for all dredging projects. Further, it would be necessary to stage, manage, and solidify removed materials at an upland area of considerable size prior to off-site disposal of the material.

NAPL recovery would be accomplished using either (1) a system of NAPL recovery wells or trenches installed along the banks of the canal to collect NAPL and extract it from the subsurface or (2) a NAPL recovery layer installed in the lower portion of the cap to collect NAPL and reduce loading to the upper portion of the cap. NAPL recovery from the banks of the canal would be unlikely to significantly impact the mass of NAPL under the Canal or NAPL seepage into the Canal because the mass of NAPL currently beneath the Canal is greater than that beneath the banks. Appendix A includes an example of a sediment cap containing a highly permeable layer to collect dense NAPL (DNAPL) within a riverbed. Appendix B describes projects that have incorporated a NAPL recovery trench as part of the remedy.

2.2.3 In-Situ Treatment Technologies

The in-situ treatment technology group for NAPL control includes technologies that could potentially address the NAPL source in the peat layer through immobilization, destruction/degradation, or oxidization. Several types of treatment processes have been applied in pilot-scale demonstration projects for sediment remediation; however, these processes have typically been performed ex-situ and have primarily included sediment dredging, pretreatment for dewatering, and other processes to enhance treatability.

The in-situ treatment technologies considered potentially applicable to the Pine Street Canal Superfund Site are described in Table 2-1. These technologies are:

- Solidification/stabilization
- Bioremediation
- In-situ vitrification
- Chemical destruction/oxidation

In general, the high cost of most treatment technologies, particularly thermal and chemical technologies, limits their feasibility (USEPA 2005c). For these reasons, these treatment technologies are not further discussed here; however, they are described in Table 2-1 and screened with other NAPL control technologies in Table 2-2. These in-situ treatment technologies were eliminated since they do not meet the objective and/or have relatively high costs, low effectiveness, and low implementability.

2.3 Technology Screening Criteria

The screening criteria used to evaluate potential NAPL control technologies are effectiveness, implementability, and relative cost (USEPA 1988). Within these categories, specific subcriteria are used to rank technologies on a relative scoring system of high, medium, or low.

2.3.1 Effectiveness

Effectiveness generally refers to a technology's ability to meet the remedial objective in a definable and acceptable time period, as well as to reduce the risk of exposure to human and ecological receptors during construction and implementation. Of these, the sub-criterion of primary significance is the technology's ability to meet the remedial objective within the expected time frame, which is weighted more heavily than other subcriteria in the screening process. The subcriteria for screening the criterion of effectiveness are:

- Meets objectives
    - Control of NAPL seepage through existing sand cap (methane escape is permitted)
    - Creation of a suitable substrate and water conditions for benthic fauna and flora in accordance with the ROD

- Short-term effectiveness
    - Risk of exposure to public or environment in the short term
    - Protection of workers and community during construction
    - Protection of the environment during construction
    - Duration to implement the technology and achieve remedial objectives

- Long-term effectiveness
    - Risk of exposure to public or environment in the long term
    - Risk presented by residuals and contained contaminants
    - Reliability of technical components/controls
    - Degree of NAPL mobility control
    - Long-term isolation of contaminants

2.3.2 Implementability

Implementability generally refers to technical feasibility, administrative feasibility, and the availability of materials, qualified professionals, and services for construction and implementation, including long-term maintenance and monitoring. The subcriteria for screening the criterion of implementability are:

- Technical feasibility
  - Technical feasibility of designing and constructing the technology to meet the remedial objective given the site conditions and other factors

- Administrative feasibility
  - Ease of coordination with local, state, and federal governments in identifying and confirming satisfaction of applicable or relevant and appropriate requirements (ARARs)
  - Acceptance by stakeholders

- Availability
  - Equipment
  - Services
  - Skilled personnel
  - Construction materials

2.3.3 Relative Cost

Relative cost refers to the order-of-magnitude cost of the technology being considered, including capital cost and operation, maintenance, and monitoring costs.

2.4 Screening Results

Results of the screening of NAPL control technologies are summarized in Table 2-2. Based on the screening described above and presented in Table 2-2, the technologies listed below have been retained for further evaluation:

- Low-permeability cap (using an impermeable membrane)
- Reactive cap (using OC/RCM/mixed media)
- Impermeable NAPL barrier (e.g., sheet pile wall)
- Vertical permeable NAPL barrier
- Horizontal permeable NAPL barrier
- Micro-dredging (removal of all or a portion of the existing cap)

These technologies have been combined into the NAPL control concepts presented in Section 3. Note that NAPL recovery (pumping), bioremediation, and enhanced extraction were also retained for consideration, as requested by the USEPA, because they have the potential to reduce the mass of NAPL available to seep through the cap. However, they each have a low effectiveness and do not meet the objective of controlling NAPL seeps through the existing sand cap. Therefore, these technologies were not incorporated into the NAPL Control concepts. These three technologies would also potentially increase NAPL mobility or gas production.

In their request to retain DNAPL recovery, the USEPA indicated that DNAPL recovery via pumping from recovery wells is being conducted successfully at the Libby Groundwater Site in Libby, Montana and the Wyckoff/Eagle Harbor Superfund Site in Bainbridge Island, Washington (USEPA 2005b and 2007). Both of these sites are former wood treating plants, and the primary contaminants are creosote (PAHs) and pentachlorophenol.

At the Libby Montana site, the groundwater component of the remedy consists of an extraction and biological treatment system. The source area extraction and treatment system was constructed in 1989 and consists of extraction wells and a groundwater treatment system. The objective of the system is to remove NAPL from the upper aquifer to improve the performance of the downgradient in situ groundwater remediation. The Third Five-Year Review determined the system is operating as designed and the dissolved contaminant plume associated with the site has stabilized and has decreased slightly in total area (USEPA 2005b). The Review also stated that the overall effectiveness of the source area extraction and treatment system had improved since the second Five-Year Review (USEPA 2005b). Between 1989 and 2005, 19,000 gallons of oily wood treating fluid have been recovered from the subsurface, and the system has an average groundwater extraction rate of 6 gallons per minute (gpm) (USEPA 2005b). For comparison purposes, the 19,000 gallons of recovered NAPL that was recovered over 16 years is equivalent to approximately 14 percent of the mass of potentially mobile NAPL estimated to be in the Pine Street Canal Superfund Site canal subsurface (521,000 kg or approximately 135,500 gallons).

At the Wyckoff/Eagle Harbor site, the extraction system consists of nine active wells that operate continuously at a groundwater extraction rate of approximately 40 to 56 gpm (USEPA 2007). The objective of the extraction system, in combination with the sheet pile containment wall, is to prevent NAPL and contaminated groundwater in the upper aquifer from leaving the Former Process Area (USEPA 2005a and 2007). However, because NAPL migrated offsite prior to the installation of the sheet pile wall, NAPL continues to seep from the shoreline areas outside the sheet pile wall (USEPA 2007). The Second Five Year Review determined the groundwater treatment plant and extraction system were functioning as intended and that hydraulic containment had been maintained over the Five-Year Review period (USEPA 2007). Approximately 2 million gallons per month of contaminated groundwater are extracted and treated, and 125 gallons of DNAPL per month are recovered (USEPA 2007). NAPL removal decreased approximately 50 percent since the First Five-Year Review was completed in 2002, and LNAPL is no longer being removed (USEPA 2007). During 1993 to 2007, the extraction system recovered approximately 100,000 gallons of NAPL, and the treatment plant treated over 475 million gallons of extracted contaminated groundwater (USEPA 2007). However, it has been estimated that one million gallons of DNAPL remain in the subsurface. Therefore, over 14 years, only approximately 10 percent of the mass of NAPL has been recovered. The Report also noted the groundwater treatment plant and extraction system continue to require extensive preventative and corrective maintenance.

Both of the latest five-year reviews for these sites determined the systems had stabilized groundwater contamination and the overall effectiveness of the systems had improved since the previous review. These systems are intended to reduce migration of groundwater/NAPL contamination and appear to be meeting that objective. The objective of these recovery systems, containing the groundwater/NAPL plume, is not applicable to the Pine Street Canal Superfund Site NAPL controls. The DNAPL recovery systems at these sites are operated continuously and recover a significant volume of water that must be treated. This type of DNAPL recovery system is not applicable for NAPL controls at the Pine Street Canal Superfund Site because it does not meet the objective of controlling NAPL seepage through the sand cap into the Canal. Also, the mass of NAPL currently beneath the Canal is greater than that beneath the banks, so recovery wells on the banks would not be likely to significantly impact the mass of NAPL under the Canal or NAPL seepage into the Canal. In addition, based on the volume of NAPL beneath the canal, and the performance of the NAPL recovery systems at the sites discussed above, a significant period of time would have to elapse before all of the potentially mobile NAPL near the canal would be reduced to residual saturation.

In lieu of NAPL recovery as a means to prevent NAPL from reaching the upper portion of the cap, a horizontal permeable NAPL barrier can be included in the lower portion of the cap. Due to its high permeability, such a barrier would have minimal hydraulic gradient within it, allowing the NAPL to settle to the base of the barrier layer due to the NAPL-water density contrast. If NAPL below the cap moves upward due to the stronger hydraulic gradients below the cap, it will accumulate in the base of the horizontal barrier layer, where it can be monitored and removed as appropriate using a system of slotted pipes connected to sumps.

TABLE 2-1
NAPL CONTROL TECHNOLOGIES

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

General Response Action	Technology Group	Process Option	Description
Containment	Sand Cap	Sand and Silt Mixture with Geotextile	Sand or silty sand is used to cap sediments. A geotextile separates the cap from the underlying sediment.
	Reactive Cap	Organoclay Reactive Core Mat (RCM)	RCM is a relatively thin layer of organoclay that is placed between two geosynthetic fabrics and stitched together by the manufacturer, CETCO™. RCMs are placed as caps over NAPL seepage to sequester the NAPL and prevent it from entering the water column.
		Reactive Cap (Bulk Organoclay or Mixed Media)	Organoclay is a sorptive medium that can be placed as a bulk cap over NAPL seepage to sequester the NAPL and prevent it from entering the water column. Mixed media caps involve a mixture of sand or sand and silt with sorptive media at a proportion determined based on bench-scale testing. Other sorptive media include coke breeze, modified cellulose, and natural peat.
	Low-Permeability Cap	AquaBlok™	AquaBlok™ is bentonite-coated gravel or other material (e.g., perlite) that is comparatively lightweight. The AquaBlok™ would be placed as a uniform layer to provide a low-permeability cap over NAPL seepage to cut off the NAPL and prevent it from entering the water column.
		Impermeable Liner	A high-density polyethylene (HDPE) or geosynthetic clay liner (GCL) is placed to provide an impermeable liner over NAPL seepage to cut off the NAPL and prevent it from entering the water column.
	Impermeable Barrier	Sealed Interlock Sheet Pile Wall	A sealed interlock sheet pile wall is driven into the subsurface to provide a physical barrier (i.e., cutoff) to NAPL transport. Barrier may also reduce NAPL transport due control of groundwater gradient. The interlock is sealed by a contact sealant added by the manufacturer or grouting performed following installation.
		Conventional Sheetpile Wall	A conventional sheetpile wall provides a physical barrier, but does not include sealing along interlocks.
		Slurry Trench	A trench is excavated and backfilled with bentonite slurry to provide a low-permeability barrier (i.e., cutoff) to NAPL transport. Barrier may also reduce NAPL transport due control of groundwater gradient.
		In-situ Soil Mixing	Augers mix cement into the soil and create a low-permeability barrier (i.e., cutoff) to NAPL transport. Barrier may also reduce NAPL transport due control of groundwater gradient.

TABLE 2-1
NAPL CONTROL TECHNOLOGIES

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

General Response Action	Technology Group	Process Option	Description
Removal	Dredging	Mechanical	A bucket dredge operated from a barge or shoreline crane removes sediment and places it on a barge or the shoreline.
		Hydraulic	Removes sediment using hydraulic suction. The sediment is then pumped through a pipeline.
		Combination	Removes sediment with hydraulic suction and the mechanical force of a rotating cutterhead to loosen sediments. The sediment is then pumped through a pipeline.
		Micro-dredging	Divers or remotely operated vehicles remove small, precise volumes of sediment.
	Excavation (Dry)	Backhoe	The excavated area must first be dewatered. A backhoe is then used to remove sediments. This may include an extended reach excavator, depending on access.
		Clamshell	The excavated area must first be dewatered. A crane-mounted bucket (clamshell) is then used to remove sediments.
Recovery	NAPL Recovery	Product Recovery (Pumping)	A system of wells is constructed to intercept and collect NAPL. Collected NAPL is recovered from the wells using pumps.
		Recovery Trench	A trench is constructed to intercept and collect NAPL. Collected NAPL is recovered from the trench using drains, sumps, and/or pumps.
		Recovery Layer	A high permeability (gravel) layer is constructed as part of a cap to intercept and collect NAPL. Collected NAPL is recovered through drains, sumps, and/or pumps.
	Enhanced Extraction	Steam-Enhanced	Steam is injected into the subsurface to strip volatiles and improve recovery of NAPL.
		Hot Water-Enhanced	Hot water is injected into the subsurface to strip volatiles and improve recovery of NAPL.
		Electrical Resistance Heating	Electrical resistance heating increases the subsurface temperature to enhance recovery of volatiles and NAPL.
		In-situ Chemical Flushing	Chemicals such as surfactants, cosolvents, or alkaline reagents are injected into the subsurface to increase NAPL recovery.
Treatment	In-situ Treatment	Solidification/ Stabilization	Cementing or stabilizing agents are mixed with contaminated sediments to bind the NAPL with the sediment and reduce the mobility of the NAPL.
		Bioremediation	Enhancement of natural biodegradation of NAPL by biostimulation (addition of nutrients) or bioaugmentation (addition of microorganisms).
		In-situ Vitrification	Partially dewatered contaminated sediments are heated to a molten state with electrical current, destroying the NAPL.
		Chemical Destruction/Oxidation	Chemicals (oxidants) are injected into the subsurface to oxidize the NAPL.

TABLE 2-2
SCREENING OF NAPL CONTROL TECHNOLOGIES

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

General Response Action	Technology Group	Process Option	Effectiveness	Implementability	Relative Cost	Results of Screening
Containment	Sand Cap	Sand and Silt Mixture with Geotextile	Does not meet objective based on existing cap performance. Short-term effectiveness is medium due to disturbance of existing cap. Long-term effectiveness is low.	Materials are available. Readily implemented in water. Long-term operation and maintenance would be required.	Low	Eliminated; does not meet objective.
	Reactive Cap	Bulk Reactive Cap	Meets objective: effectively controls NAPL seepage. Short-term effectiveness is medium due to disturbance of contaminants during removal of existing cap. No long-term performance data, but appears effective at one full-scale site (McCormick & Baxter, Portland) and in bench- and pilot-scale testing.	Materials are readily available from at least three vendors. Readily implemented in water. Bench-scale testing required to complete design. Long-term operation and maintenance would be required.	Medium to High	Retained; however, does not meet objective.
		Organoclay Reactive Core Mat (RCM)	Meets objective: effectively controls NAPL seepage. Short-term effectiveness is high due to relatively less disturbance of contaminants during removal of existing cap. No long-term performance data, but appears effective at one full-scale site (McCormick and Baxter, Portland) and in bench- and pilot-scale testing. Long-term effectiveness depends upon passive NAPL collection systems.	Materials are supplied by a limited number of vendors and lead time for delivery may be a factor. Readily implemented in water. Bench-scale testing required to complete design. Long-term operation and maintenance would be required.	Medium	Retained
	Low-Permeability Cap	AquaBlok	Does not meet objective: not impermeable to NAPL seepage. Short-term effectiveness is medium due to disturbance of existing cap. Long-term effectiveness is low because AquaBlok provides only a low-permeability cover as opposed to a seal.	Material is available from one vendor. Readily implemented in water.	Medium	Eliminated; does not meet objective.
		Impermeable Liner	Meets objective: effectively controls NAPL seepage. Short-term effectiveness is high due to relatively less disturbance of existing cap by placing liner directly on cap surface; though some disturbance may occur in diver support to temporarily weigh down the liner, some exposure may occur during excavations (if needed) for passive NAPL and/or methane collection installations below the liner. Long-term effectiveness depends upon passive NAPL collection and gas collection systems.	Materials are available. Construction and seaming of liner below water would be difficult.	Low	Retained
	Impermeable Barrier	Sealed Interlock Sheet Pile Wall	Meets objective by providing a sealed hydraulic barrier and a control on NAPL seepage. Short-term effectiveness is high due to minimal disturbance of existing cap if installed using hydraulic pressure equipment. Long-term effectiveness is high when combined with corrosion protection and construction QA/QC during interlock sealing.	Materials are available but price may be affected by global steel demands. Sheeting systems that provide sealed interlocks are trademarked and only three vendors are known, one of which is located in Europe. Required specialized installation equipment is less available than standard impact or vibratory installation equipment and standard equipment cannot be used.	High	Retained
		Conventional Sheet Pile Wall	Meets objective by providing a hydraulic barrier and a control on NAPL seepage, though permeable interlocks allow some movement of groundwater and possibly NAPL over time. Short-term effectiveness is high due to minimal disturbance of existing cap if installed using hydraulic pressure equipment. Long-term effectiveness is high when combined with corrosion protection.	Materials are available but price may be affected by global steel demands. Required specialized installation equipment is less available than standard impact or vibratory installation equipment and standard equipment cannot be used.	High	Retained
		Slurry Trench	Meets objective by providing low-permeability clay as a hydraulic cutoff and control on NAPL seepage, but is less effective than sheet pile technologies. Short-term effectiveness is low due to excavation and handling of NAPL-impacted soils and potential for release of NAPL-impacted slurry during construction. Long-term effectiveness is low.	Materials are available; however, process would require disposal of a significant volume of material compared to other technologies. Implementability is low due to peat layer.	High	Eliminated due to high cost and moderate to low effectiveness and implementability.
		In-Situ Soil Mixing	Meets objective when combined with appropriate construction QA/QC to ensure overlap of stabilized zones, though QA/QC would be difficult for Pine Street site conditions. Short-term effectiveness is medium to low due to high potential for movement of NAPL-impacted soils to the surface as drill spoil requiring handling for disposal. Long-term effectiveness is medium.	Materials are available. Moderate implementability using tracked equipment and temporary mat roads.	Medium	Eliminated due to moderate to low effectiveness and implementability.

TABLE 2-2
SCREENING OF NAPL CONTROL TECHNOLOGIES

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

General Response Action	Technology Group	Process Option	Effectiveness	Implementability	Relative Cost	Results of Screening
Removal	Dredging	Mechanical, Hydraulic, or Combination	Does not meet objective: cannot effectively remove the upper NAPL-impacted portion of the cap so that cap modifications can be completed. Short-term effectiveness is low due to disturbance of contaminants during removal of existing cap and sediments. Long-term effectiveness is medium due to removal of some source material.	Materials and construction methods are available; however, this process would require disposal of a significant volume of material.	Medium	Eliminated; does not meet objective.
		Micro-dredging	Meets the objective when used in combination with cap modifications because it removes the upper NAPL-impacted portion of the cap so that cap modifications can be completed. Short-term effectiveness is high due to minimal disturbance of cap or sediments and removal of NAPL-impacted portion of cap in preparation for cap modifications. Long-term effectiveness depends on the cap modifications used in combination with this process.	Would require minimal disturbance of canal and would create minimal amounts of waste material when compared to conventional sediment removal methods.	High	Retained
	Excavation (Dry)	Backhoe or Clamshell	Meets the objective when used in combination with cap modifications because it removes the upper NAPL-impacted portion of the cap so that cap modifications can be completed. Short-term effectiveness is low due to disturbance of contaminants during removal of existing cap and sediments. Even though water is removed, exposure to excavated materials is similar to dredging technology group. Long-term effectiveness is medium due to removal of some source material.	Materials and construction methods are available; however, this process would require dewatering of the canal.	Medium	Eliminated; low implementability.
Recovery	NAPL Recovery	Product Recovery (Pumping)	Does not meet objective due to inability to recovery NAPL in peat by pumping. Short-term effectiveness is low. Long-term effectiveness is low due to lack of success in DNAPL applications.	Materials and construction methods are available. Past site-specific experience has included attempts to dewater the peat layer for civil construction and apparently failed due to plugging of well screens; therefore, extraction of more viscous NAPL distributed within the layer and partially bound to organic matter would not be effective. Further, a shallow pump and treat system was proposed as a component of the remedy in an earlier study and was eliminated. Long-term operation and maintenance would be required.	Medium	Retained; however, does not meet objective.
		NAPL Recovery Trench	May meet objective when combined with modifications to existing cap. Short-term effectiveness is medium. Long-term effectiveness is medium due to removal of some source material.	Materials and construction methods are available. Long-term operation and maintenance would be required.	Medium	Retained
		NAPL Recovery Layer	May meet objective when combined with modifications to existing cap. Short-term effectiveness is medium. Long-term effectiveness is medium due to removal of some source material.	Materials and construction methods are available. Long-term operation and maintenance would be required.	Medium	Retained
	Enhanced Extraction	Steam-Enhanced, Hot Water-Enhanced, Electrical Resistance Heating, or In-Situ Chemical Flushing	Does not meet objective. Short-term effectiveness is medium. Long-term effectiveness is low due to time required to remove source material, lack of control of all migration mechanisms, and mixed levels of success in previous applications.	Materials are available. Construction of an enhanced extraction system would be complex.	High	Retained; however, does not meet objective.

TABLE 2-2
SCREENING OF NAPL CONTROL TECHNOLOGIES

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

General Response Action	Technology Group	Process Option	Effectiveness	Implementability	Relative Cost	Results of Screening
Treatment	In-Situ Treatment	Solidification/Stabilization	May meet objective when combined with modifications to existing cap. Short-term effectiveness is low due to the significant disturbance of NAPL and air quality from the stabilization amendments. Long-term effectiveness is medium because of mixed results at NAPL-impacted sediments at other sites.	Technical feasibility is medium due to the availability of materials and experienced professionals who have conducted stabilization in difficult site conditions. Depending on end use of stabilized area, stakeholder acceptance for application of this technology may be difficult. Construction materials readily available.	High	Eliminated due to high cost and moderate to low effectiveness and implementabilty.
		Bioremediation	Does not meet objective. Short-term effectiveness is low. Long-term effectiveness is low due to lack of success in previous DNAPL applications and potential for increased gas production.	The technology has not been proven to be successful for DNAPL. NAPL toxicity to biological organisms further limits technical feasibility.	Medium	Retained; however, does not meet objective.
		In-Situ Vitrification	Does not meet the objective of controlling NAPL seepage through cap because the quantity of stabilization necessary to mitigate NAPL seeps in both existing cap and peat layer source is impractical. Short-term effectiveness is low due to increased exposure to and mobility of contaminants during vitrification process. Exposure to air emissions poses significant risk unless expensive engineering controls are incorporated. Long-term effectiveness is medium because contaminants are immobilized; however, the technology has not been proven for sediment. Also, the high moisture and organic content in the peat would likely result in incomplete vitrification and risk of NAPL transport.	The technology has not been proven for sediment remediation.	High	Eliminated; does not meet objective.
		Chemical Destruction/Oxidation	May meet objective when combined with modifications to existing cap. Short-term effectiveness is medium. Long-term effectiveness is low due to time required to remove source material, lack of control of all migration mechanisms, and mixed levels of success in previous applications.	Would be difficult to inject sufficient chemicals to reduce the mass of NAPL without increasing mobility of NAPL. Implementation and construction would be moderately complex.	Medium	Eliminated due to high cost and moderate to low effectiveness and implementabilty.

Notes:
1. Objective is to control NAPL seepage through existing sand cap.
2. Other technologies may be necessary to support selected technologies (e.g., removal of existing cap containing NAPL seeps).

3. Identification of NAPL Control Concepts

3.1 General

The selected technologies identified in Section 2 have been combined and developed into five concepts which either reduce NAPL seepage by modifying the existing sand cap (the Concept A series) or reduce NAPL seepage with a permeable or impermeable NAPL barrier (the Concept B series). The five concepts are:

- Concept A1: Reactive Core Mat
- Concept A2: Reactive Cap
- Concept A3: Impermeable Cap
- Concept B1: Permeable NAPL Barrier
- Concept B2: Impermeable NAPL Barrier

The five concepts are illustrated in conceptual diagrams presented on Figures 3-1 through 3-5.

In the following discussion, previous applications of these NAPL control concepts in site remediation are summarized in terms of specific details relevant to the Pine Street Canal Superfund Site. Two of the sites used as examples — the McCormick and Baxter Superfund Site in Portland, Oregon and the Thea Foss Waterway site, part of the larger Commencement Bay Nearshore/Tideflats Superfund Site in Tacoma, Washington — are discussed at greater length in the Action Plan (BBL and Hart Crowser 2006a) and summarized in Appendix A.

3.2 Concept A1: Reactive Core Mat

Concept A1 combines the CETCO™ reactive core mat for NAPL control with micro-dredging to remove the surface of the existing cap within the NAPL seepage area. This NAPL control concept is illustrated on Figure 3-1.

3.2.1 Description of Concept

The design objective for this concept is to control active seeps in the canal through the installation of RCM. Elements of this concept include:

- Placing one or more layers of RCM containing OC
- Placing an overlying habitat layer of sand
- Dredging existing NAPL-impacted sand cap material as needed for construction of the RCM and habitat layer
- Dewatering and off-site disposal of the NAPL-impacted dredged sand cap material

The RCM developed by CETCO™ is a relatively new product that uses OC within a geotextile envelope to provide capacity for NAPL sorption in a thin, rolled product that is readily transported and deployable. To account for the RCM layer and the thickness of the overlying habitat layer, the removal depth of the existing sand cap (on the order of 6 inches to 1 foot) would be relatively thin in comparison to other capping concepts described here. If this concept is selected, the ability to remove a thin layer from the existing cap surface using dredging or dry excavation techniques must be considered during design; that is, the minimum removal and replacement thickness may be governed by the capabilities of the dredging/excavation equipment. The thin layer of removal and replacement are achievable based on the RCM specifications (i.e., approximately ¼-in thick for the McCormick and Baxter project discussed in Section 3.2.2 and Appendix A). According to CETCO™, the weight of OC in this thickness was 0.8 pound/ft^2 for the McCormick and Baxter project, although this may be increased up to about 1 pound/ft^2 for additional adsorption capacity.

The theoretical life of the OC RCM is dependent on the NAPL-absorption capacity of the OC, the NAPL loading, and the quantity of OC in the RCM. The specifications for the CETCO™ OC RCM indicate an oil adsorption capacity of 50 percent by weight minimum and 0.8 pound/ft^2 OC for a ¼-inch thick OC RCM. Pre-Design testing of the NAPL-absorption capacity of the OC has been completed. The results of the testing are presented in Appendix E. Based on this batch testing and the vendor claimed oil adsorption capacity, a NAPL-removal capacity of 50 percent to 60 percent by weight for organoclay is conservative.

An estimate of the theoretical life[2] of a single layer of the RCM is approximately 3.5 years, based on the maximum NAPL seepage within a cell (32 kg/year), cell surface area (625 ft^2), OC content of the RCM (0.8 pound/ft^2), and average OC/NAPL 100 percent capture capacity[3] (50 percent by weight). Using the average NAPL loading per cell (7 kg/yr), the theoretical life of a single layer of RCM is approximately 16 years, and the theoretical life of two layers of RCM is 32 years. Based on this analysis, multiple layers of RCM would be needed to yield a reasonable design life. Alternatively, a source control option such as Concept B1 (permeable NAPL barrier) or Concept B2 (impermeable NAPL cutoff wall) could be combined with the RCM option to provide a longer design life. The reactive cap would need to be replaced at a frequency equal to the design life or more frequently to prevent NAPL releases to the canal. Since the NAPL flux is distributed over the entire cell surface area, this analysis does not take into account the potential for localized seepage points.

Alternatively, a passive NAPL collection layer below the RCM may be required to provide a cost-effective design life for the RCM. The requirement to control the NAPL migration mechanism from groundwater gradients transporting NAPL to below the RCM could be addressed by constructing a horizontal NAPL collection layer beneath the RCM to reduce the loading rate of NAPL to the RCM.

Compared to the coverage conceptually depicted on Figure 3-1, additional RCM may be required to cover the sand cap that was placed on the west bank and cribbing wall, and the RCM would likely be placed over the entire width of the canal. If applicable, the design would consider the constraints of placing and anchoring the RCM in this configuration, as well as stabilizing the habitat layer.

3.2.2 Previous Applications

Two sites where RCM caps were deployed, the McCormick and Baxter site (a former creosote facility) in Portland, Oregon and a former MGP site in Salem, Massachusetts, are briefly discussed below. Appendix A provides information on these and other capping sites.

At the McCormick and Baxter site, RCMs containing OC were placed over one seep in the sand-only portion of the cap in August 2005. The RCM had an approximately ¼-in-thick OC layer stitched between two synthetic blankets. The RCM contained approximately 0.8 pound of OC per ft^2 and came in 1,500-ft^2 rolls (15 ft by 100 ft). The RCMs, which were placed by hand in shallow water, became water-saturated within minutes and were easily placed. In areas where two RCMs were placed, a 6-in-thick layer of sand was applied between the RCMs, and the second RCM was placed in the same manner as the first. Fifty-pound sandbags were laid at all four

[2] The theoretical life is the estimated duration of time that the cap would effectively control NAPL.
[3] The 100 percent capture capacity is a function of the thickness of the OC layer (Kellems et al. 2002).

corners of the RCMs. A 900-ft^2 area overlying the RCMs was then capped with an average 1 ft of sand, 4 inches of gravel, and 1 ft of 12-in minus armoring rock. Additional column tests are being conducted to evaluate the effectiveness of the RCMs. After the RCMs have been in place for one year, they would be removed and analyzed to determine the quantity of sorbed NAPL on the mats.

The Salem MGP site contains two distinct NAPL types in beach and intertidal sediment. NAPL seeps and sheens have been observed, and the NAPL seepage rate was sufficiently voluminous to monitor at one location. In areas of highest observed NAPL seepage, three layers of CETCO™ OC RCM are used, and other areas have one layer. An underlying gravel-filled geoweb has been incorporated into the design to retain hardened coal tar particulates and other miscellaneous fill materials on the beach and prevent further migration with waves and currents. The geoweb also allows NAPL migration pathways to connect to the RCM. The RCM is also placed below Tensar™ marine mattresses to provide the necessary armoring, and also allows access to the RCM to monitor for visible signs of breakthrough, and to replace the RCM if needed.

In addition to capping projects like these, ARCADIS BBL has used RCMs in vertical, passive permeable NAPL barriers. For example, at an active wood-treating site in Kentucky, ARCADIS BBL designed and installed a NAPL barrier with an RCM on the downgradient wall of the barrier to serve as a polishing agent to sequester NAPL sheens and droplets (if any) that may not separate effectively by gravity alone.

3.3 Concept A2: Reactive Cap

Concept A2 involves removing some volume of the sand cap and replacing the removed area of the cap with a bulk OC or mixed media reactive cap. In contrast to Concept A1, in which only the upper portion of the cap is removed, most of the sand cap profile would be removed and replaced in Concept A2. This NAPL control concept is illustrated on Figure 3-2.

3.3.1 Description of Concept

The design objective for this concept is to control active seeps in the canal through the installation of a reactive cap. Elements of this concept include:

- Placing a 1.5-ft-thick reactive cap consisting of OC or other oil-sorbent media
- Placing an overlying 6-in-thick habitat layer of sand
- Dredging the existing sand cap material as needed for construction of the reactive cap
- Dewatering and off-site disposal of the NAPL-impacted dredged sand cap material

The reactive capping media could include OC, cellulose, natural peat, coke breeze, or sand in designed proportions; the mix would be determined during design based on bench-scale treatability testing. The objective would be to achieve a cost-effective mixture. For example, OC is expensive but has significant adsorption capacity. The unit cost of OC is approximately $1.20 to $1.50 per pound or $2400 to $3000 per ton. Mixing OC with sand may improve cost-effectiveness, but the use of sand, or potentially of any of the other, non-OC reactive media, may reduce the NAPL sequestering capacity of the cap and shorten the design life. The reactive cap would need to be replaced at a frequency equal to the design life or more frequently to prevent NAPL releases to the canal.

An additional consideration is the potential thickness and weight of a bulk reactive cap as compared to the existing cap. Managing the weight of the cap is a straightforward way to reduce the risk of additional consolidation of the underlying soil and the associated potential to mobilize NAPL. Using sand in the reactive cap would not only reduce the sorption capacity, but would also increase the overall mass of the cap relative to the bulk reactive media. However, sand cannot be ruled out. For example, cellulose and natural peat are lightweight media; using them would necessitate the use of sand as well, because the weight and friction of sand would stabilize those media. Laboratory treatability testing during the pre-design phase would establish the media mixture and proportions for optimum cost-effectiveness.

Finally, placement of a reactive cap in proximity to the existing crib wall may not be as depicted on Figure 3-2. In this area, removing the sand cap may destabilize the wall before the reactive cap can be placed, and removal of cap material on west bank might trigger additional seeps. This is a consideration that can be addressed by combining the solution with other technologies (e.g., reactive core mat) or by incorporating engineering controls during design (e.g., including a shallow sheet pile wall or using temporary shoring).

An estimate of the theoretical life of a 1.5 foot thick pure bulk OC cap is approximately 365 years based on the maximum NAPL loading within a cell (32 kg/year), cell surface area (625 ft^2), OC bulk density (55 pounds per cubic foot), and average OC/NAPL 100 percent capture capacity (50 percent by weight). Since the NAPL flux is distributed over the entire cell surface area, this analysis does not take into account the potential for localized seepage points. Theoretically, this concept offers a longer life than Concept A1 (reactive core mat) due to the greater mass of OC in the bulk cap compared with the RCM cap.

3.3.2 Previous Applications

To date, a bulk OC cap has been placed only at the McCormick and Baxter site in Portland, Oregon. The poorly graded, fine- to medium-grained, clean to slightly silty sands at that site contain contaminants as deep as 35 ft below the sediment surface, with NAPL present in the upper 7 ft of sediment. A cap consisting of a minimum 2 ft of sand and 1 ft of armoring was installed across 22.5 acres of sediment. An additional layer of OC was placed in three specific areas to prevent NAPL seeps from breaking through the cap, and a sheet pile wall was installed around the upland portion of the site to contain the NAPL. The similarities between the native sediment and the cap’s composition made differential consolidation between the two negligible. Physical stability considerations included slopes, currents, waves (including wind- or vessel-induced), and seismicity. The bulk OC cap consisted of a 1-ft layer of granular OC, a 1-ft layer of sand, 4 inches of filter rock, a woven geotech fabric layer, and articulated concrete block armoring to prevent scour from wave action.

Bench-scale sorption capacity testing of the other oil-sorbent media discussed in Section 3.3.1 was conducted for the Salem MGP project; this project is described further in Appendix A.

3.4 Concept A3: Impermeable Cap

Concept A3 involves constructing an impermeable cap with minimal excavation of the existing cap. The impermeable cap would contain NAPL that is migrating through the existing sand cap by forming an impermeable barrier above the sand cap. This NAPL control concept is illustrated on Figure 3-3.

3.4.1 Description of Concept

The design objective for this concept is to control active seeps in the canal through the installation of an impermeable cap. Elements of this concept include:

- Placing an impermeable cap, such as a high-density polyethylene (HDPE) membrane
- Installing a passive methane collection system
- Placing an overlying habitat layer of sand
- Dredging existing NAPL-impacted sand cap material as needed for construction of the impermeable cap and habitat layer
- Dewatering and off-site disposal of NAPL-impacted dredged sand cap material

A significant obstacle with this concept is controlling the gas bubble-induced transport of NAPL from below the cap to the perimeter of the cap and subsequent expression of NAPL around the perimeter. Inherent in this concept is a requirement to collect and convey methane bubbles from below the cap along the perimeter. Before this concept could be selected, the technical feasibility of installing the gas collection system would need to be evaluated.

Similar to Concept A1, a passive NAPL collection layer may also be required in Concept A3 to provide for removal of pooled NAPL below the cap. The requirement to control the NAPL migration mechanism from groundwater gradients transporting NAPL to below the existing cap could be addressed by creating a permeable barrier in the existing cap possibly with sumps to facilitate collection of mobile NAPL for periodic removal after a period of accumulation below the cap.

The effect of an impermeable cap upon hydraulic gradients in the peat beyond the Canal would need to be evaluated, as increases in that gradient may occur at the ends of the cap, promoting NAPL migration.

3.4.2 Previous Applications

An impermeable cap was installed at the Thea Foss Waterway (Commencement Bay Nearshore/Tideflats Superfund Site) in Tacoma, Washington, capping NAPL seeps with a 60-ft by 75-ft (4,500 ft^2) HDPE membrane and sand. A passive methane collection system was not incorporated into the cap. A habitat layer was placed atop the impermeable cap, which was designed to contain NAPL extending as deep as 15 ft to 50 ft below the mudline. A sheet pile wall was installed across the waterway to keep sediments on the south side of the site from eroding into the north side.

Cap installation was completed in the fall of 2003. Sediment samples collected from the capped areas in August 2004 showed evidence of polycyclic aromatic hydrocarbons (PAHs) and sheen, the sources of which are currently being evaluated. It is postulated that the impermeable HDPE membrane could potentially lead to gas buildup in the capped system, thereby causing inefficiencies in its ability to retain PAHs/NAPL. No long-term performance data are available for the NAPL control system at this site. Appendix A provides further information on the Thea Foss Waterway site.

Other examples of the use of impermeable membranes in sediment caps include a dredging operation on a river in Massachusetts and a coal tar site adjacent to the Hudson River in New York. At the Massachusetts site, an unexpected pool of mobile coal tar DNAPL was encountered below the mudline during a dredging operation to remove sediments with other environmental impacts. The completed remedy included a gravel NAPL-separation layer with a screened DNAPL monitoring/collection sump below a low-permeability membrane within the riverbed. At the New York site, NAPL was encountered up to 30 ft below the mudline in exploratory borings. NAPL-impacted sediments were partially dredged in the dry inside a dewatered sheet pile cell, after which a NAPL barrier was installed. The NAPL barrier consisted of an impermeable membrane keyed to permanent sealed sheeting (cut off at the final mudline), which hydraulically isolated and stabilized the remaining NAPL. The impermeable membrane was then backfilled under 8 to 10 ft of clean sand.

3.5 Concept B1: Vertical Permeable NAPL Barrier

Concept B1 involves constructing a vertically oriented permeable NAPL barrier along the canal. A permeable NAPL barrier could be necessary if mobile NAPL is considered a potentially significant ongoing source that requires further controls to supplement the capping repair/augmentation approach. This NAPL control concept is illustrated on Figure 3-4. The permeable NAPL barrier may be necessary for only one bank of the canal, although the figure depicts installation on both sides of the canal. Additional evaluation of NAPL mobility would be required to determine the exact layout and limits of a NAPL barrier, if selected. In particular, the vertical rate of NAPL migration would need to be assessed relative to the horizontal rate of NAPL migration towards the permeable barrier.

3.5.1 Description of Concept

The design objectives for this concept are to reduce mobile NAPL adjacent to and beneath the canal, prevent additional mobile NAPL, if any, from migrating into the area beneath the canal, and reduce the NAPL subsurface volume through the installation and operation of a permeable NAPL barrier. Elements of the vertical barrier concept include:

- Excavating a 20- to 30-ft-deep, 1- to 3-ft wide trench
- Installing a membrane at the base of the trench or in the sump area, if practicable
- Backfilling the trench with lightweight, coarse media rather than gravel
- Sumps along the trench into which NAPL would flow and collect
- Installing wells within the sumps to allow monitoring and removal of passively collected NAPL without pumping groundwater
- Dewatering and off-site disposal of NAPL-impacted soils excavated from the trench
- Periodic off-site disposal of NAPL

The vertical permeable NAPL barrier would extend to the bottom of the peat layer, likely keying into the underlying stratified silt and sand, using an impermeable basal membrane. NAPL that enters the high-permeability barrier zone would separate from groundwater by gravity. If practical, the bottom of the barrier would be sloped along its length to one or more sumps. Mobile NAPL, if any, would collect in sumps along the barrier, and accumulated NAPL could be extracted from the sumps using a bailer, vacuum truck, or other process.

The vertical permeable NAPL barrier would extend along the bank of the canal, either in the area of the seeps or along the entire length of the impacted section of the canal. A sheet pile cutoff wall could be installed in conjunction with this alternative, but likely only to a depth approximately coincident with the existing timber cribbing wall. The need for a sheet pile wall depends on construction of the reinforcement and backfilling behind the existing timber cribbing. If the trench cannot be excavated while maintaining stability of the canal walls, the position of the permeable barrier may need to be offset from the canal, and an additional cutoff control may be needed to deal with the residual NAPL; Figure 3-4 illustrates NAPL in proximity to the vertical permeable barrier. If the location of the permeable barrier would not require offset, then the wall potentially can be constructed in proximity to the timber crib wall with the aid of temporary shoring or other method to stabilize the timber crib wall during construction.

Achieving the depth necessary for a vertical permeable NAPL barrier constructed through the peat layer may require the use of specialized excavation techniques or a temporary braced excavation. Among the subsurface conditions that may complicate trench excavation are the presence of roots, stumps, and other organic matter; groundwater seepage into excavations; and ground loss from excavation sidewalls. Available excavation techniques vary in their ability to mitigate some of these factors. A trench may be installed using a continuous trenching machine (for relatively shallow trench depths) or biopolymer slurry to support the excavation walls (for relatively deep trench depths). In the biopolymer slurry case, temporary wells would be installed in the trench after excavation and prior to backfilling. After coarse, lightweight media or gravel was placed in the trench, the temporary wells would be pumped while breaker enzymes were added and the slurry was re-circulated over the top of the gravel. The actual barrier material would be determined during Pre-Design Investigation. This would cause the slurry to degrade without the need for disposal. After a few days of recirculation, the viscosity of the biopolymer would be reduced and the trench would be ready for a final cap. Root removal from excavation sidewalls and membrane placement are technical challenges that would be considered in the pre-design phase if this concept is selected.

3.5.2 Previous Applications

NAPL recovery trenches or permeable barriers have been used for recovery and control of DNAPL at MGP and wood-treating sites. Appendix B summarizes sites where NAPL trenches have been used as a remedial alternative.

NAPL recovery trenches were designed to be installed with a slurry wall at the former Northern Indiana Public Service Company MGP in Fort Wayne, Indiana (Zimmerman et al. 2001). The site had discrete pockets of coal tar at depths up to 35 ft. As designed, the NAPL recovery system consisted of six trenches, with a total length of approximately 585 ft and a depth of approximately 30 ft, and groundwater extraction wells. The recovery system was designed to lower the groundwater table by 10 ft, creating a hydraulic gradient away from the river toward the site and mobilizing the coal tar for recovery.

At a wood-treating site in Illinois, creosote DNAPL was encountered beneath a creek bed at a depth of up to 35 ft in fractured clay. The stream channel was permanently rerouted from the creosote-impacted area into a clean area. Two 35-ft deep, permeable NAPL barriers were installed using a continuous trenching machine. The two overlapping NAPL barriers are 910 ft long (combined) and backfilled with pea gravel. Construction was completed in 2004. NAPL is collected using perforated collection piping connected to sumps; over 8,000 gallons of NAPL have been collected from one trench without any groundwater extraction.

At a wood-treating site in Kentucky, creosote DNAPL was encountered in a thin gravel layer near ground surface. The downgradient, NAPL impacted drainage ditch was dredged and a permeable NAPL barrier was installed to protect the remediated ditch from the one-site NAPL source. Two 7-ft deep, permeable NAPL barriers were installed. The two overlapping NAPL barriers are approximately 400 ft long (combined), and backfilled with coke nut, with an RCM on the downgradient side of the NAPL barrier. Construction was completed in 2004. Since construction, no sheens or NAPL have been observed downgradient of the NAPL barrier.

At former MGP site in New York State, MGP LNAPL and DNAPL was encountered in a sandy fill layer and a sand and gravel aquifer adjacent to a river where NAPL has also been observed in sediments. The first phase of the site remedy was the installation of a permeable NAPL barrier in 2006 to intercept mobile NAPL and mitigate further NAPL loading to the sediment. A 750 ft long, 60 ft deep, 30-in wide permeable NAPL barrier was installed with LNAPL-skimming baffle, and NAPL monitoring/collection wells, and DNAPL monitoring/collection sumps.

Appendix B describes projects that have incorporated a vertical permeable NAPL barrier as part of the remedy.

3.5.3 Variation on Concept B1: Horizontal Permeable NAPL Barrier

A variation on the vertical permeable NAPL barrier concept is a horizontal permeable NAPL barrier, which would be located in the canal under a sand or RCM cap. This concept was retained from the screening of NAPL control concepts. The horizontal permeable NAPL barrier is intended to reduce the NAPL loading on the new/modified cap. The vertical hydraulic gradient within the horizontal permeable NAPL barrier would be minimal, allowing DNAPL to separate from groundwater via gravity, reducing NAPL loading of the cap and NAPL flux to the canal.

This concept would require micro-dredging of the existing sand cap to remove NAPL impacted material and to offset the weight and volume of the horizontal barrier. The horizontal barrier layer would then be constructed of 6-in to 24-in of relatively light-weight, coarse material. The actual barrier material would be determined during the Pre-Design Investigation. This barrier of high-permeability and lightweight material is intended to mitigate the transport of NAPL to the cap via vertical hydraulic gradients by reducing the vertical hydraulic gradient. The barrier would also be designed with slopes, slotted pipes, and sumps to facilitate removal of NAPL, if any, that accumulates in the barrier layer.

Appendix A includes an example of a sediment cap containing a horizontal permeable NAPL barrier. During a dredging operation on a river in Massachusetts, ARCADIS BBL encountered an unexpected pool of mobile coal tar NAPL below the mudline. The completed remedy included a gravel NAPL-separation layer with a screened NAPL monitoring/collection sump below a low-permeability membrane within the riverbed.

3.6 Concept B2: Impermeable NAPL Barrier

Concept B2 involves constructing an impermeable NAPL barrier along the bank of the canal. The impermeable barrier (cutoff wall) would provide a hydraulic barrier for groundwater flow related to the hydraulic gradient NAPL migration mechanism. If the primary groundwater flow contributing to vertical gradients that influence NAPL migration beneath the cap is within the stratified silt and sand layer above the clay, then placing a cutoff wall into the clay may be very effective at controlling this NAPL transport mechanism. In addition, a cutoff wall could be necessary if the amount of mobile NAPL under the bank renders a capping remedy alone not cost-effective. This NAPL control concept is illustrated on Figure 3-5.

3.6.1 Description of Concept

The design objective for this concept is to reduce the migration of mobile NAPL into the area beneath the canal through the installation of a cutoff wall.

Sheet pile walls consist of formed steel sheets that are driven into the earth to provide a structural wall. A permanent sheet pile wall approximately 300 ft in length would be installed along the perimeter of the active

NAPL seepage. The wall would be driven to the silty clay layer (to a depth to be determined during pre-design) as shown on Figure 3-5. Under typical construction conditions, an H-beam and concrete lagging system could be used to retain the clean soils in place behind the wall; however, due to the presence of impacted sediment and potential NAPL, the use of Z-type sealed steel, interlocking sheet pile would be necessary. Corrosion-protected steel sheet pile would be required. The sheet pile wall would not be vibratory driven, to avoid numerous problems related to NAPL migration and/or subsurface settlement and deflection of the existing timber crib wall. Rather, the sheet pile wall would be installed using hydraulic pressing. The density and consistency of subsurface soils appear to be amenable to this installation technique.

A cutoff wall could also be constructed in a variety of other ways; alternatives include trenching and backfilling with soil/bentonite slurry (i.e., a slurry trench) with or without an impermeable membrane such as HDPE, deep soil mixing, or possibly some grouting methods. The cutoff wall would be keyed into the uniform clay layer underlying the site materials. However, because trenching in the soft sediment found at the site would be difficult, and because of the depth of the clay layer, steel sheet piling may be the most feasible construction material. Deep soil mixing has been used effectively to stabilize soil for geotechnical purposes, but may not be effective in the peat layer, risking both residual NAPL and upward transport of NAPL as part of the auger mixing process.

3.6.2 Previous Applications

Hydraulic cutoff walls have been used at various sites. At the Solvents Recovery Service of New England, Inc. site in Southington, Connecticut, a sheet pile barrier was constructed in glacial outwash and till to contain impacted groundwater and multi-component NAPL. Non-grouted, interlocking sheet piling was installed, with upgradient groundwater extraction wells for gradient control. The barrier system has been working effectively since 1995.

A slurry wall was designed for the former Northern Indiana Public Service Company MGP in Fort Wayne, Indiana (Zimmerman et al. 2001). To prevent NAPL seepage into an adjacent river, the design called for a 540-ft-long, 35-ft-deep, 3-ft-wide, 4 percent bentonite/soil slurry wall constructed along the river and the northern site boundary. Bench-scale testing of permeability and compatibility with site DNAPL was conducted to select the slurry wall composition. The maximum permeability of the wall was 10^{-7} centimeters per second. The design called for constructing the slurry wall by backfilling trenches and jet grouting to avoid damaging utilities.

At a site in New Jersey, a 2,500-ft long, 30-ft deep NAPL barrier consisting of an HDPE membrane in a soil/bentonite slurry trench was installed in 2004 to surround and hydraulically isolate impacted groundwater and multi-component NAPL. Sealed asphalt was installed as a surface cap to limit infiltration into the barrier area. Hydraulic monitoring has demonstrated a 90 percent reduction in the hydraulic gradient (and, therefore, dissolved-phase mass flux) within the site.

At an MGP site adjacent to the Mohawk River in New York State, DNAPL was observed up to 40 ft below the sediment/water interface and approximately 400 ft away (across the river from the site). Hydraulic gradient analysis and modeling showed that the DNAPL was too dense to migrate upward into the river, but LNAPL seeps were also observed seasonally along the river bank. A NAPL barrier, consisting of 1,150 linear ft of steel sheet piling, was installed to a depth of up to 70 ft to surround and hydraulically isolate LNAPL and DNAPL within the site. The remedy also includes a low permeability surface cap to reduce recharge, and passive NAPL monitoring/collection wells. Construction was completed in 2006, and the site is being converted to a riverfront park.

Other projects encompassing hydraulic cutoff walls are discussed in Appendix B.

3.6.3 Variation on Concept B2

A variation on the NAPL cutoff wall concept includes an in-filled containment area using a sheet pile wall that totally surrounds the NAPL seepage area. Although considered during the identification of NAPL control concepts, this variation was ruled out due to limitations associated with its technical feasibility (involves numerous technical hurdles relative to other concepts), administrative feasibility (has relatively low stakeholder acceptance and includes loss of wetlands), and relative cost. This alternative would conceptually be accomplished by constructing a partial cofferdam structure connected to the bank, then infilling to the same grade as the adjacent bank with clean material and a surface layer of vegetated topsoil, effectively creating an extension of the bank out into the canal. The cutoff walls would prevent further migration of NAPL from the banks into the canal and cap, while the backfill would act as a barrier to upward NAPL migration in the area of the observed seeps and provide long-term isolation of NAPL in the seep areas. This alternative would include an open area within the canal to provide a bypass for stormwater conveyance, which is one of the current uses of the canal.

Some of the limitations of this variation on Concept B2 are as follows:

- The significant weight of the backfill compared to the existing cap would initiate further consolidation, potentially mobilizing additional NAPL mass in the cap surrounding the contained area, which may create NAPL seeps or increase the likelihood that future NAPL seeps are observed surrounding the contained area.

- Consolidation of layers below the backfill would create lateral pressures and downdrag on sheet piling that may deflect the sheet pile walls beyond design tolerances.

- Stakeholder acceptance of a concept that cuts off a portion of the canal would be low, which could put the schedule for project implementation at risk.

- Loss of wetlands would require some form of mitigation.

- NAPL transport along the sheet pile wall from the peat and onto the adjacent cap may occur (i.e., NAPL transport unrelated to consolidation or the increased stress distribution described in the first bullet above), which would likely require this concept to be combined with a reactive cap and/or passive NAPL collection around the perimeter of the sheet pile wall.

- The relative cost of materials and construction for this variation is high compared to preferred capping technologies.

3.7 Screening Results

Potential NAPL control alternatives were assembled from the five NAPL control concepts described in this section. As shown in Table 3-1, the NAPL control alternatives consist of either a cap or a combination of cap and barrier concepts. In Table 3-1, retained capping concepts (shown in columns) are aligned with various barrier concepts (in rows). The NAPL control alternatives created through these combinations are then screened in Table 3-1 based on the criteria of meeting the objective of controlling NAPL seepage (each of the retained concepts meet objective for creation of suitable substrate and water conditions), effectiveness, implementability, and relative cost. Each alternative was ranked low, medium, or high for each of the screening criteria.

As described in Section 2.3, effectiveness includes three subcriteria: meets objective, short-term effectiveness, and long-term effectiveness. The short-term effectiveness of each alternative was evaluated based primarily on the potential for NAPL mobilization or release during construction, which may be an issue for each of the NAPL control alternatives. Micro-dredging of the cap may mobilize NAPL as there is NAPL present in the cap material to be dredged. Placement of an RCM would cause minimal disturbance and would be unlikely to mobilize NAPL. Placement of a bulk reactive cap would potentially cause significant disturbance due to the weight of the cap. Construction of permeable barriers would also potentially mobilize NAPL. A vertical barrier would have a much greater impact on subsurface NAPL due to use of the heavy equipment on the banks and the depth of the required excavation. This is a significant issue, and it will be addressed further during design of the selected alternative.

The impermeable cap concept was screened out due to low effectiveness and low to medium ability to meet objectives. The bulk reactive cap was screened out due to medium cost (up to $3000 per ton for OC material) and low implementability. It would be nearly impossible to construct a bulk OC cap equal to or less than the weight of the original sand cap. A modified cap that would weigh more than the existing cap is not feasible at the Pine Street Canal Superfund Site due to the potential for additional consolidation-induced NAPL migration and possible limitations on the hydraulic capacity of the canal. The impermeable barrier concept was eliminated due to low effectiveness, low implementability, and medium costs. The RCM is the only capping concept which was retained. The RCM is combined with both of the retained barrier concepts (vertical and horizontal permeable barrier) and no barrier resulting in Alternatives 1 to 3.

Based on this screening, three alternatives have been selected for further evaluation:

- Alternative 1: Reactive Core Mat (Concept A1)
- Alternative 2: Reactive Core Mat (Concept A1) with a Horizontal Permeable NAPL Barrier (Variation on Concept B1),
- Alternative 3: Reactive Core Mat (Concept A1) with a Horizontal and Vertical Permeable NAPL Barrier (Variation on and original Concept B1).

These three alternatives are further described and evaluated in Section 4.

TABLE 3-1
ASSEMBLY AND SCREENING OF NAPL CONTROL ALTERNATIVES

NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

Barriers	Caps			
	None	**Organoclay Reactive Core Mats (RCM)**	**Bulk Reactive Cap**	**Impermeable Cap**
None	*Objective: Low* • Does not meet objective of controlling NAPL seepage *Effectiveness: Low* • Short-term effectiveness is low because it does not address current NAPL seeps • Long-term effectiveness is low because it does not control NAPL • Without meeting objectives, NAPL seepage and associated impacts could increase *Cost: Low* • Relative cost is low compared to other alternatives *Implementation: Low* • Easily implemented because requires no construction • Regulatory feasibility is low	*Objective: High* • Meets objective of controlling NAPL seepage *Effectiveness: Medium* • Short-term effectiveness is medium because micro-dredging of the top layer of NAPL-impacted sand-cap (approximately 6 inches) must occur before placement of the RCM. RCM placement causes minimal disturbance. • Long-term effectiveness is medium because RCM would control NAPL seepage but NAPL is still potentially mobile below the cap • No long-term performance data are available, but RCMs appear to be effective at one full-scale site (McCormick & Baxter, Portland) and in bench- and pilot-scale testing *Cost: Low* • RCM material costs and construction costs are relatively low *Implementation: Medium* • Micro-dredging is complex; RCM cap installation has been accomplished in water for at least two sites; long-term maintenance is anticipated to be relatively more involved and costly to replace RCM unless RCM thickness is designed for long-term NAPL seepage rates (McCormick & Baxter, Portland)	*Objective: High* • Meets objective of controlling NAPL seepage *Effectiveness: Medium* • Short-term effectiveness is low to medium because micro-dredging of the sand cap must occur before placement of the bulk reactive cap, and NAPL may be mobilized during placement of a bulk reactive cap. • Long-term effectiveness is medium because cap would control NAPL seepage, but net weight of bulk material and any remaining sand cap compared to original sand cap may compress peat layer and increase NAPL mobility beyond cap unless mitigated in design • No long-term performance data are available, but cap appears to be effective at one full-scale site (McCormick & Baxter, Portland) and in bench- and pilot-scale testing *Cost: Medium* • Bulk reactive cap materials range from low to high in cost, relative construction costs are medium *Implementation: Low* • Implementation is not overly complex, though more micro-dredging and more cap placement are required compared to RCM; long-term maintenance is anticipated to be relatively more involved and costly (McCormick & Baxter, Portland)	*Objective: Low to Medium* • Meets objective of effectively controlling NAPL seepage but gas buildup may result in cap breakthrough around the cap perimeter or increased NAPL mobility *Effectiveness: Low* • Short-term effectiveness is medium because micro-dredging of the top layer of NAPL-impacted sand cap must occur before placement of the impermeable cap • Long term effectiveness is low because not effective for long-term NAPL control without collection of NAPL and/or gases • Uncertain about long-term effects of gas bubble-related transport of NAPL *Cost: Medium* • Costs of impermeable liner materials such as high-density polyethylene (HDPE) are low but placement and construction costs would be high *Implementation: Medium* • Collection of gas bubbles at perimeter would make installation and seaming of liner difficult; long-term maintenance is anticipated to be relatively more involved and costly

TABLE 3-1
ASSEMBLY AND SCREENING OF NAPL CONTROL ALTERNATIVES

NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

Barriers	Caps			
	None	**Organoclay Reactive Core Mats (RCM)**	**Bulk Reactive Cap**	**Impermeable Cap**
Impermeable	*Objective: Low* • Does not meet objective of controlling NAPL seepage *Effectiveness: Low* • Short-term effectiveness is low because it does not address current NAPL seeps in canal and has potential to remobilize NAPL due to heavy equipment and vibrations in close proximity to the cribbing • Long-term effectiveness is low because it does not control NAPL seeps in canal, and NAPL is likely to establish pathway along impermeable barrier or around it • Without meeting objectives, NAPL seepage and associated impacts could increase; ability of mobile NAPL transported by groundwater gradients and other pathways to bypass impermeable barrier is unknown *Cost: Medium* • Impermeable barrier materials are potentially high in cost but no associated capping costs *Implementation: Low* • Implementation is complex due to the depth required for the impermeable barrier and difficult site access for equipment required for pile installation	*Objective: High* • Meets objective of controlling NAPL seepage *Effectiveness: Medium* • Short-term effectiveness is medium because RCM placement causes minimal disturbance but micro-dredging of the top layer of NAPL-impacted sand-cap (approximately 6 inches) must occur before placement of the RCM and construction of an impermeable vertical barrier may result in short-term increase of NAPL mobility unless specialized hydraulic “push” pile installation equipment is used • Long-term effectiveness is medium because RCM and impermeable barrier would control NAPL seepage but the NAPL mass continues to act as a source for the potential pathways • No long-term performance data are available, but RCM appears to be effective at one full-scale site (McCormick & Baxter, Portland) and in bench- and pilot-scale testing; ability of mobile NAPL transported by groundwater gradients and other pathways to bypass impermeable barrier is unknown *Cost: High* • RCM material and construction costs are relatively low, but when combined with construction and material costs for impermeable barrier the total cost is high *Implementation: Low* • Implementation is complex due to the depth required for the impermeable barrier and difficult site access for equipment; cap increases complexity, requiring additional equipment and installation of a rolled mat over soft sediment (McCormick & Baxter, Portland)	*Objective: High* • Meets objective of controlling NAPL seepage *Effectiveness: Low to Medium* • Short-term effectiveness is low to medium because micro-dredging of the top layer of NAPL-impacted sand cap must occur before placement of the bulk reactive cap, construction of impermeable barrier may cause short-term increase on NAPL mobility, and NAPL may be mobilized during placement of a bulk reactive cap. • Long-term effectiveness is low because cap and impermeable barrier would control NAPL seepage but the NAPL mass continues to act as a source for the potential pathways; bulk cap may compress peat layer and increase NAPL mobility • No long-term performance data are available, but cap appears to be effective at one full-scale site (McCormick & Baxter, Portland) and in bench- and pilot-scale testing; ability of mobile NAPL transported by groundwater gradients and other pathways to bypass impermeable barrier is unknown *Cost: High* • Bulk cap materials range from low to high in cost but when combined with construction and material costs for impermeable barrier the total cost is high *Implementation: Low* • Implementation is complex due to the depth required for the impermeable barrier and difficult site access for equipment; long-term maintenance is anticipated to be relatively more involved and costly (McCormick & Baxter, Portland)	*Objective: Low to Medium* • Meets objective of effectively controlling NAPL seepage but gas buildup may result in cap breakthrough around the cap perimeter or increased NAPL mobility; impermeable encapsulation increases risk of NAPL build-up and future seeps *Effectiveness: Low to Medium* • Short-term effectiveness is medium because micro-dredging of the top layer of NAPL-impacted sand cap must occur before placement of the impermeable cap and construction of impermeable barrier may cause short-term increase on NAPL mobility • Long-term effectiveness is low because approach is not effective for long-term NAPL control without collection of NAPL and/or gases • Uncertain about long-term effects of gas bubble-related transport of NAPL; the ability of mobile NAPL transported by groundwater gradients and other pathways to bypass impermeable barrier is unknown *Cost: High* • Costs of impermeable liner materials such as HDPE are low but placement and construction costs would be high and impermeable barrier costs are high *Implementation: Low* • Installation and seaming of liner would be difficult; long-term maintenance is anticipated to be relatively more involved and costly

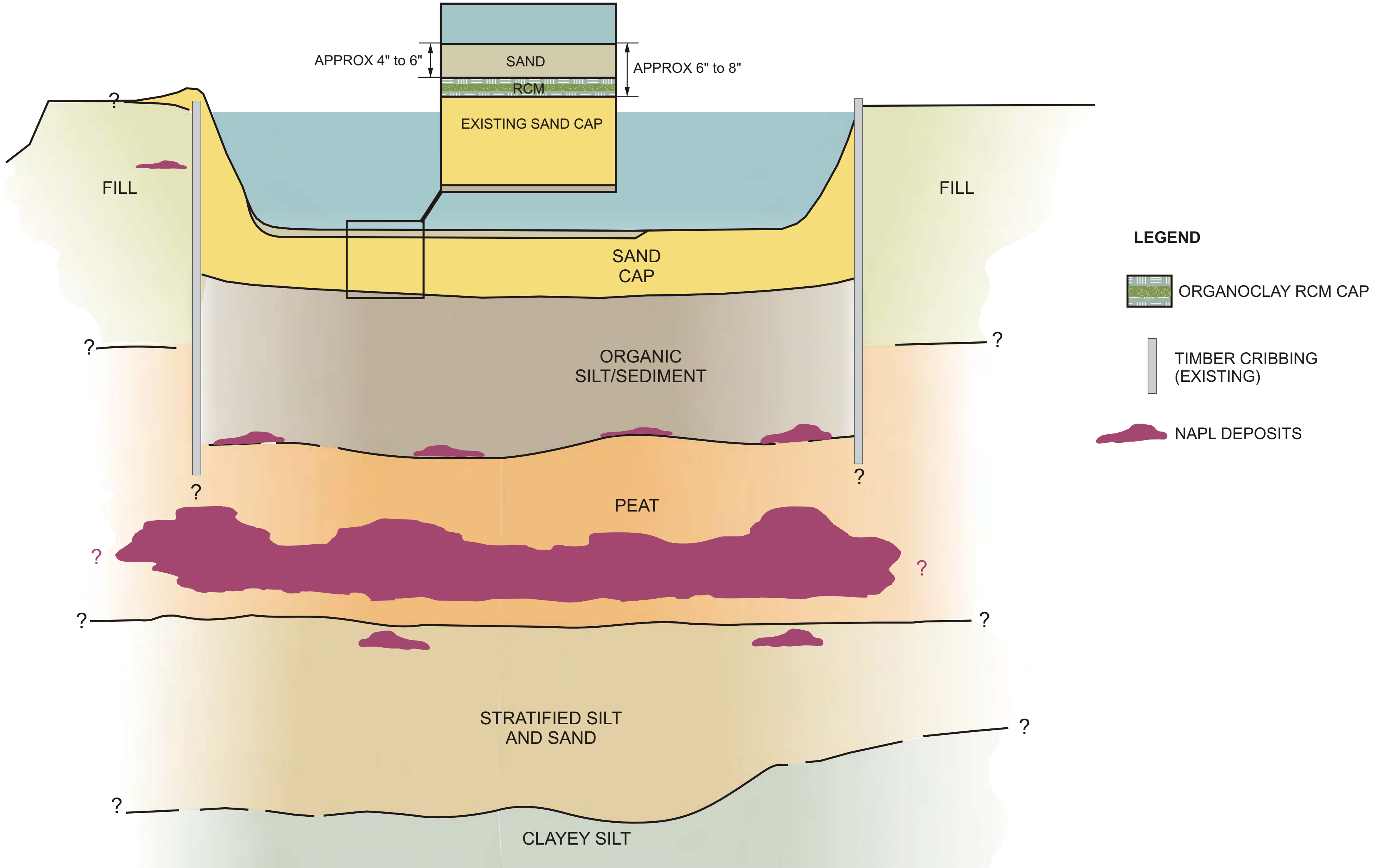
TABLE 3-1
ASSEMBLY AND SCREENING OF NAPL CONTROL ALTERNATIVES

NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

Barriers	**Caps**			
	None	**Organoclay Reactive Core Mats (RCM)**	**Bulk Reactive Cap**	**Impermeable Cap**
Permeable	*Objective: Low* • Does not meet objective of controlling NAPL seepage *Effectiveness: Low* • Short-term effectiveness is low because it does not address current NAPL seeps in canal. A vertical barrier on the banks would potentially remobilize NAPL due to heavy equipment and vibrations on the banks. • Long-term effectiveness is low because it does not control NAPL seeps in canal • Without meeting objectives, NAPL seepage and associated impacts could increase *Cost: Medium* • Construction of permeable barrier is high in cost due to difficult site conditions for excavations and the required depth of installation *Implementation: Low* • Implementation is complex due to the required excavation depth and limited feasible construction methods for the permeable barrier, use of cofferdam/dewatering, and site access for equipment.	*Objective: High* • Meets objective of controlling NAPL seepage *Effectiveness: Medium to High* • Short-term effectiveness is medium because RCM placement causes minimal disturbance, but micro-dredging of the top layer of NAPL-impacted sand-cap (approximately 6 inches) must occur before placement of the RCM and construction of permeable vertical barrier may increase NAPL mobility • Long-term effectiveness is high because RCM and permeable barrier would control NAPL seepage; design could include passive removal of mobile NAPL mass from peat layer within sumps • No long-term performance data are available, but RCM appears to be effective at one full-scale site (McCormick & Baxter, Portland) and in bench- and pilot-scale testing; vertical permeable barriers have proven effective at other NAPL sites *Cost: Medium to High* • RCM material and construction costs are relatively low and construction and material costs for permeable barrier are high *Implementation: Low to medium* • Implementation is complex (depending on barrier configuration) due to the required excavation depth and limited feasible construction methods for the permeable barrier; long-term maintenance is anticipated to be relatively more involved and costly (replacement of RCM upon saturation) (McCormick & Baxter, Portland)	*Objective: High* • Meets objective of controlling NAPL seepage *Effectiveness: Low to Medium* • Short-term effectiveness is low to medium because micro-dredging of the top layer of NAPL-impacted sand cap must occur before placement of the bulk reactive cap, and construction of permeable vertical barrier may have short-term increase on NAPL mobility, and NAPL may be mobilized during placement of a bulk reactive cap. • Long-term effectiveness is medium because cap and impermeable barrier would control NAPL seepage, but bulk cap may compress peat layer and increase NAPL mobility; design could include passive removal of mobile NAPL mass from peat layer within sumps • No long-term performance data are available, but bulk reactive cap appears to be effective at one full-scale site (McCormick & Baxter, Portland) and in bench- and pilot-scale testing; vertical permeable barriers have proven effective at other NAPL sites *Cost: High* • Bulk cap material and construction ranges from medium to high in cost; construction and material and construction costs for permeable barrier are high *Implementation: Low* • Implementation is complex due to the required excavation depth and limited feasible construction methods for the permeable barrier (McCormick & Baxter, Portland)	*Objective: Medium* • Meets objective of effectively controlling NAPL seepage, but gas buildup may result in cap breakthrough around the cap perimeter on the sides not bounded by barriers *Effectiveness: Low to Medium* • Short-term effectiveness is low to medium because micro-dredging of the top layer of NAPL-impacted sand cap must occur before placement of the impermeable cap, and construction of permeable vertical barrier may have short-term increase on NAPL mobility and would involve handling of NAPL-impacted excavation materials • Long-term effectiveness is low because not effective for long-term NAPL control without collection of NAPL and/or gases in cap; design could include passive removal of mobile NAPL mass from peat layer within sumps • Uncertain about long-term effects of gas bubble-related transport of NAPL *Cost: High* • Costs of impermeable liner materials such as HDPE are low but installation and construction costs would be high and permeable barrier construction costs would be high *Implementation: Low* • Installation and seaming of liner would be difficult; long-term maintenance is anticipated to be relatively more involved and costly

Notes:
Green – preferred alternatives
White – screened out alternatives
Alternatives were screened based on:

- Effectiveness
- Implementability
- Relative Cost



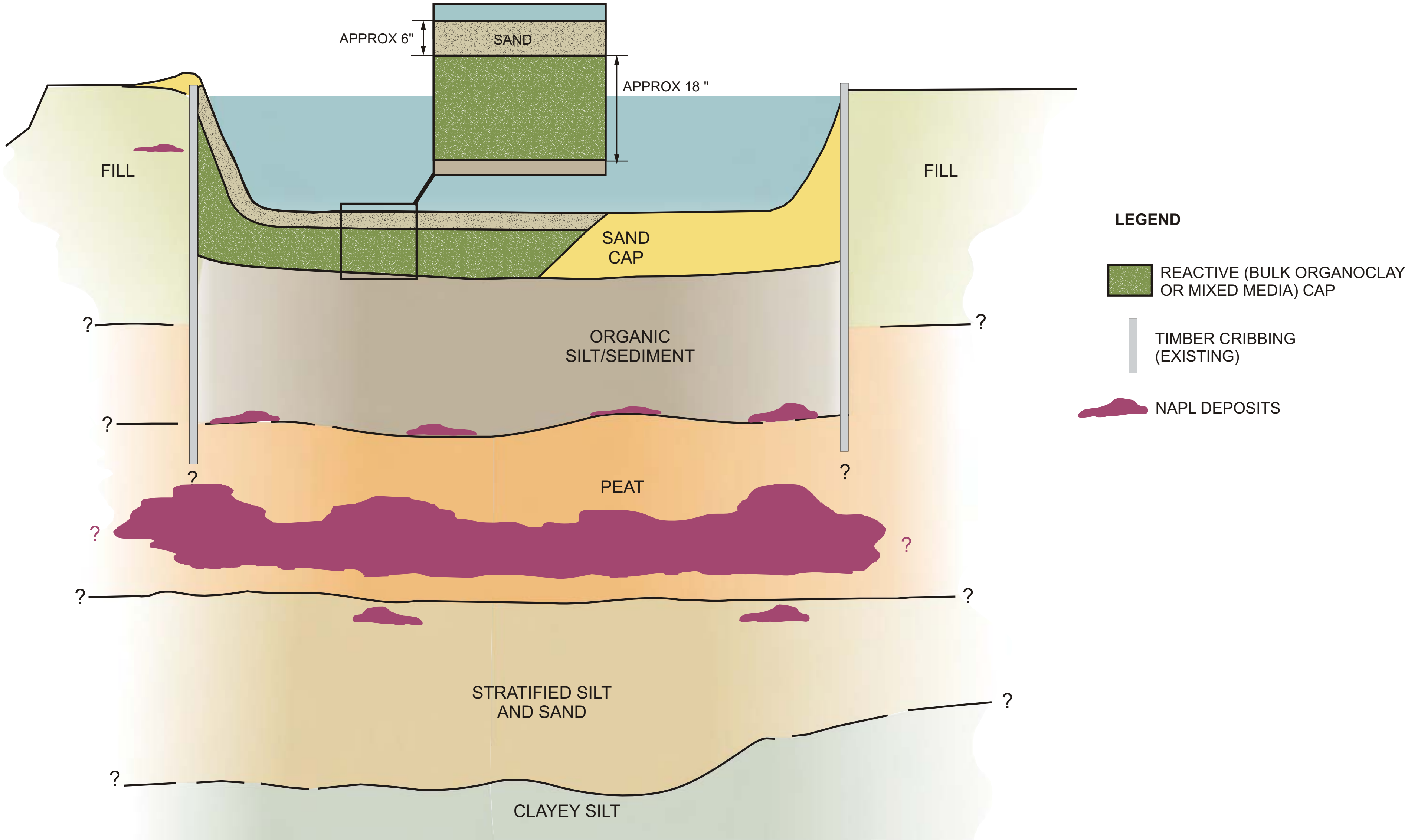
NOTE: NOT TO SCALE

BURLINGTON, VERMONT
PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

CONCEPT A1: REACTIVE CORE MAT

ARCADIS BBL
Infrastructure, environment, facilities

FIGURE
3-1



NOTE: NOT TO SCALE

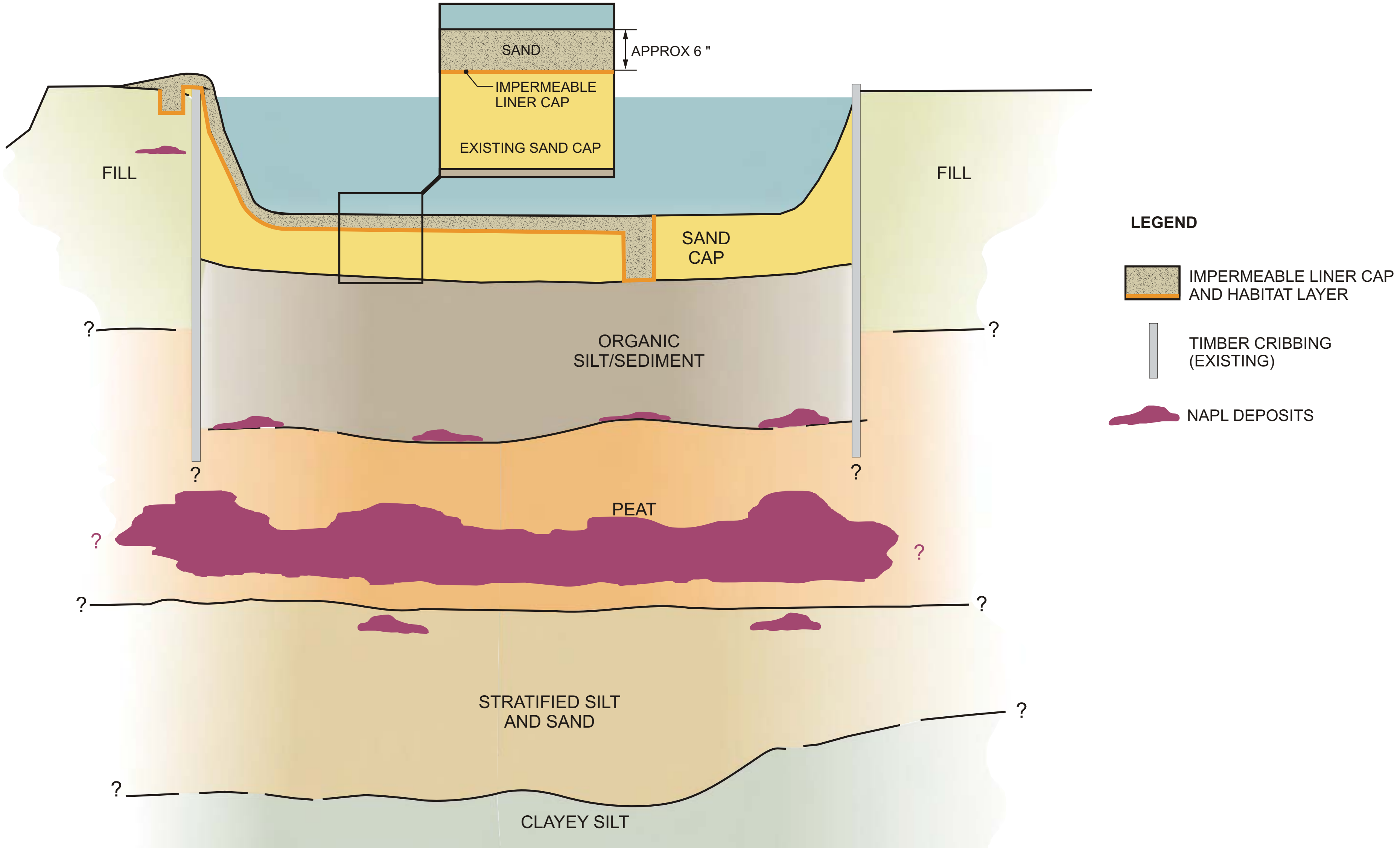
BURLINGTON, VERMONT

PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

CONCEPT A2: REACTIVE CAP

ARCADIS BBL
Infrastructure, environment, facilities

FIGURE 3-2



NOTE: NOT TO SCALE

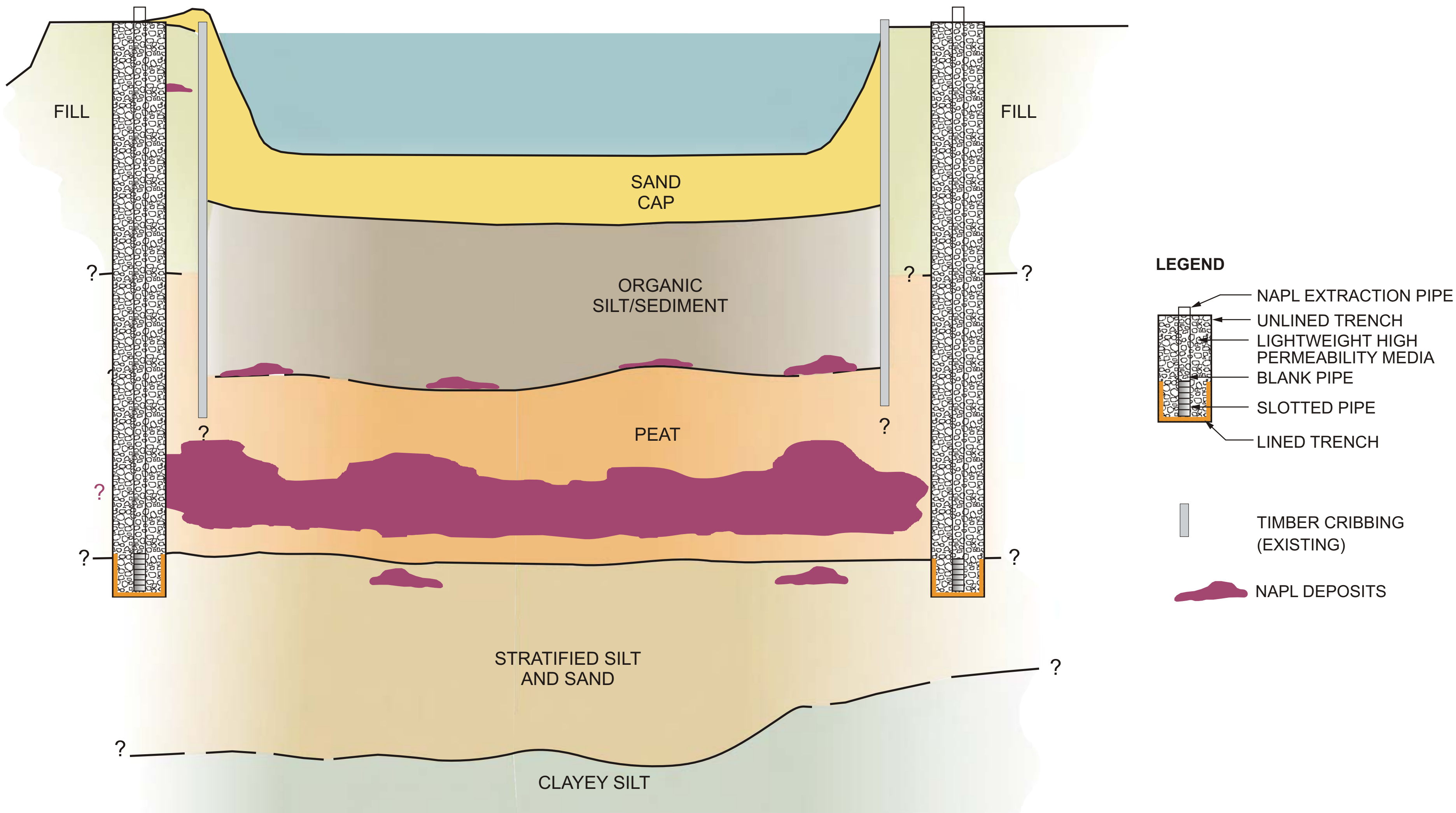
BURLINGTON, VERMONT

PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

CONCEPT A3: IMPERMEABLE CAP

ARCADIS BBL
Infrastructure, environment, facilities

FIGURE
3-3



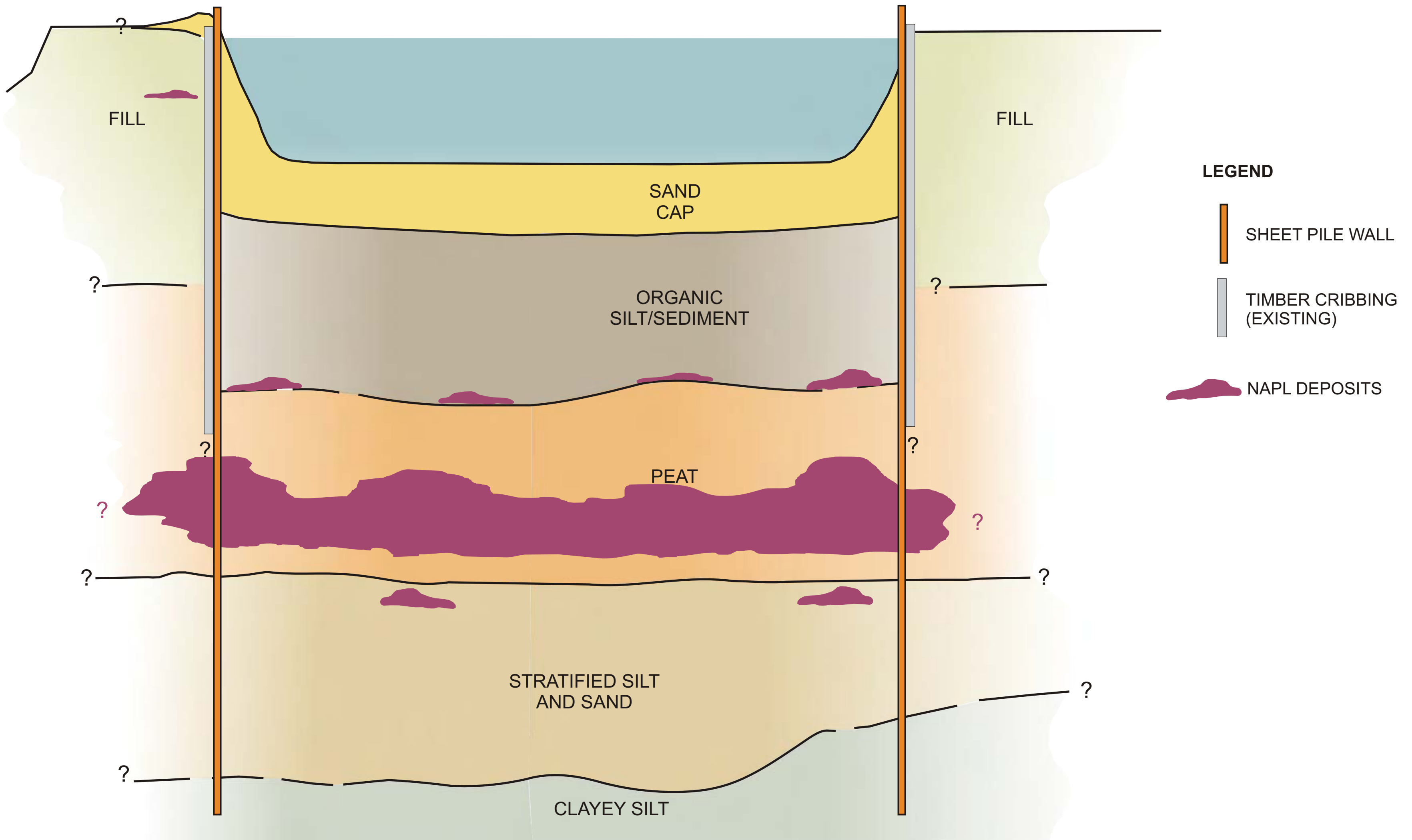
NOTE: NOT TO SCALE

BURLINGTON, VERMONT
PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

CONCEPT B1:
PERMEABLE NAPL BARRIER

ARCADIS BBL
Infrastructure, environment, facilities

FIGURE
3-4



NOTE: NOT TO SCALE

BURLINGTON, VERMONT
PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

CONCEPT B2: IMPERMEABLE NAPL BARRIER

ARCADIS BBL
Infrastructure, environment, facilities

FIGURE
3-5

4. Development and Evaluation of Alternatives

This section further describes the three alternatives retained following the screening of alternatives presented in Table 3-1.

4.1 Alternative 1: Reactive Core Mat

Alternative 1 would meet the objectives for cap repair and NAPL control and would be expected to reduce future migration of NAPL to the water column. This alternative would mitigate the current conditions, but must support a design life that would provide long-term sequestering of NAPL. One approach has been regular replacement of the RCM at sites amenable to that activity; however, RCM replacement would be complex and costly at the Pine Street Canal Superfund Site, so the design approach would likely involve selecting an appropriate number of mats based on estimated NAPL loading rates and selection of a feasible design life.

4.1.1 Description of Alternative 1

Alternative 1 consists of constructing an RCM cap for areas of the canal with the highest seepage rates and greatest mass of NAPL in the surface of the existing cap. Micro-dredging would be performed prior to placement of the RCM to remove the surface of the existing NAPL-contaminated sand cap to a depth of at least 6 inches to offset the weight of the 6-in layer of sand required above the RCM. Figure 4-1 depicts the layout of the RCM alternative in plan view; Figure 4-2 shows a conceptual design of the RCM placement in section view. Estimated unit costs for the construction components of Alternative 1 are summarized in Table C-1. Table C-2 provides a cost estimate for Alternative 1.

4.1.2 Development of Alternative 1

To further detail the retained concepts from Section 3 and develop a complete alternative, the following assumptions have been made:

- Approximately 26,000 ft^2 of the canal (T9+00 to T12+50) would be capped with RCM. Based on a multi-faceted analysis, the Investigation Report concluded that the contiguous area of cap requiring NAPL control is approximately 14,000 ft^2, or one third of an acre; however, the NAPL controls area has been extended, as requested by the USEPA, to include the entire canal between Transects T9+00 and T12+50 for a total of approximately 26,000 ft^2 or one half acre. In comparison with the Final NAPL Investigation Report analysis, this expands the area of NAPL controls by approximately an additional 30 ft in each direction to the north and south and to include the entire canal from the west bank to the east bank.

- Each layer of RCM would consist of an approximately ¼-in-thick OC layer sandwiched between two synthetic blankets and stitched together. The RCM would contain approximately 0.8 pound of OC per ft^2, although this may be increased to about 1 pound per ft^2 for additional adsorption capacity.

- Two to three layers of RCM would be used to increase the life of the RCM cap.

- The RCM is supplied in 1,500-ft^2 rolls (15 ft by 100 ft). Mats are available in shorter lengths (15 ft by 50 ft) but at an increased cost because of the additional labor required to vary from the standard length. It is assumed that a minimum of 12-in of overlap between mats would be required. Actual overlap, number of mats, number of RCM layers, and installation method would be established at a later date.

- A layer of approximately 6 inches of sand suitable for habitat restoration would be placed over the RCM to provide habitat. To create access to the underlying RCM, it would be necessary to remove the sand layer with each replacement event or to design the cap in moveable segments, possibly using geosynthetic materials and other expensive, customized features.

- Assuming the placement of six mats (90 total feet from east to west) as shown on Figure 4-1, 10 extra ft of mat would be available to extend over the bank by 5 ft each on the east and west sides and to drape over the cribbing. Similar to the in-water mat, this upland mat would be covered with approximately 6 inches of sand to secure the edges. The means of anchoring the mat behind the timber cribbing would be determined during the design phase.

4.1.3 Construction Considerations for Alternative 1

Approximately 6 inches of the existing sand cap would be removed to facilitate placement of the RCM and habitat layer. The removal would be performed by micro-dredging. Micro-dredging could be completed by divers in the water, from a barge, or from specialized equipment such as a "swamp buggy" with pontoons. The removed material would be dewatered and taken off site for disposal. A post-dredging multi-beam survey would be completed to ensure that the material has been adequately removed.

The RCM layer(s) could be placed from a barge. RCMs initially float, and then sink upon saturation with water (Olsta and Hornaday, 2007). Sand bags can be used to sink the RCM through the water column to the bottom of the canal. Once the last RCM layer is placed, the sand habitat layer would be placed from a barge (using a clamshell bucket or washed from the barge), via a tremie method, or by similar means in thin layers to prevent excessive buildup of pore pressure in sediments below the cap. A post-capping multi-beam survey would be completed to ensure that the material has been properly placed.

Any construction work not completed from the water (i.e., from a barge) would have to be completed from the canal banks or using specialized equipment. Work from the canal banks would likely require the use of temporary stabilization methods, such as swamp mats. Performing in-water work such as dredging and capping would require water quality control measures and water quality monitoring.

USFWS and USEPA requested the top 6 inches of the sand cap be augmented with 5 percent total organic carbon (TOC) to facilitate benthic recolonization. Sand caps provide a clean substrate for quick recolonization by benthic organisms (USEPA, 2005c). Recolonization often follows this progression: initial colonization by small benthic filter feeders, followed by small burrowing organisms, followed by large organisms (Clarke et al., 2001). Compliance monitoring at the site indicates the cap at the site was recolonized by benthic organism within 1 year after completion of construction and that the number of organisms and the number of species has generally increased with each year (Johnson Company, 2005). This occurred without any TOC amendment or requirement for the cap. Quick recolonization of sand caps (that did not have TOC requirements) has also been observed at other sediment remediation sites (Gutknecht and Warner, 1999; USACE, 1997; USEPA, 2004; Exponent, 2004).

To evaluate the cost and technical feasibility of augmenting the sand cap to achieve a 5 percent TOC, two materials were considered: peat moss and bark mulch. To achieve 5 percent TOC (by weight), the sand cap would need to be approximately 50 percent by volume peat moss and 50 percent by volume sand or 30 percent by volume bark mulch and 70 percent by volume sand, based on the TOC content and density of peat moss, bark mulch and sand. The unit cost of peat moss is approximately $65/cy, and the TOC content is approximately 90 percent by weight. The unit cost of bark mulch is approximately $20/cy and the TOC content was assumed to be approximately 90 percent by weight. The additional cost of these items would be calculated from a combination of their unit cost, the volume of material required, and the additional cost to mix the organic material with the sand prior to capping. There would also be a decreased volume of sand required, assuming the cap thickness would remain the same (6 inches). Overall, the additional cost for adding TOC to the sand cap would not be a significant increase. Experience at another site indicates that the additional cost may be on the order of approximately $5/cy. Although the additional cost is not large, augmenting the sand cap with these materials may be problematic for several reasons: the sand cap would be only 50 percent to 70 percent sand, these materials are less dense than water and may not sink after placement, and these materials may sorb NAPL or dissolved constituents. Based on site monitoring and data from other sediment remediation sites, rapid benthic recolonization of the 6-inch habitat layer is expected to occur with or without a TOC requirement. Therefore, it is recommended that the 6-inch habitat layer consist of clean sand, similar to the existing sand cap.

4.1.4 RCM Replacement

The design life of the RCM layers is the estimated amount of time prior to NAPL breakthrough. The expected design life of Alternative 1 depends on the number of RCM layers, the capacity of the RCM to retain NAPL, and the actual loading rate of NAPL. Each of these elements would be confirmed during design of the NAPL controls.

Based on the theoretical design life of an OC RCM and the average seepage rate of approximately 7 kg/yr, two layers of mat would last approximately 32 years. Thus, areas of the canal with a seepage rate of less than or equal to 7 kg/yr would have two layers of RCM and would not require replacement within the 30-year period. The area requiring replacement within 30 years is estimated to be approximately one third the NAPL controls area (8,750 ft^2 of the canal), based on observed NAPL seepage rates of greater than 7 kg/yr. As described in Section 3.2.1, the estimated theoretical life of a single layer of the RCM is approximately 3.5 years for the cell with the maximum seepage rate. Therefore, the theoretical life of three layers of RCM for the remaining 8,750 ft^2 is estimated to be approximately 10 years.

The actual RCM design life would be determined during design. The intent of the design life would be to limit replacement of RCM and provide a long-term solution. However, some areas would receive higher NAPL loading compared to other areas and would need to be replaced more frequently. In reality, these areas of preferential NAPL loading would be expected to occur in specific areas rather than 25 ft. x 25 ft grids. Further, some areas may not need to be replaced as often as predicted by the design life. The replacement of RCM would be established based on the monitoring plan, and would be based on monitoring results rather than a theoretical design life. RCM replacements would be complicated by the presence of the habitat layer, which would require removal prior to accessing the RCM. Diver-based micro-dredging would be used to avoid excessively damaging RCM around the specific area(s) designated for replacement. The RCM replacement method would also need to prevent re-mobilization of sequestered NAPL, localized bearing capacity failures, or consolidation.

4.1.5 Long-Term Operation, Maintenance, and Monitoring for Alternative 1

Following construction, the cap would be monitored on a schedule to be determined and would also be inspected after significant natural events, such as a large-magnitude earthquake or a major flood. The monitoring program would be developed to include specific objectives, a plan for assessing those objectives, and the methods to be used in implementing the plan. The objectives of the monitoring plan are anticipated to include:

- Assurance that the integrity of the cap is maintained
  - Inspect for erosion or other physical disturbance of cap
  - Inspect cap edges and armoring interfaces for integrity
  - Inspect damage due to trees or other nearshore impacts
- Assurance that the cap is effective at isolating the contaminants
  - Perform periodic passive sheen sampling. Check for evidence of recolonization of the cap surface and resulting bioturbation
  - Observe the cap surface, canal surface water, etc.

The components of the monitoring plan would be based on the physical, chemical, and biological parameters of concern. These parameters would be identified in advance of verification sampling to develop a tiered approach to monitoring activities. It is anticipated that each monitoring event would include visual observations of the canal water surface, sand cap surface, and quantitative sheen/breakthrough sampling (passive sampling).

Each sheen monitoring (passive sampling) event would require two site visits: one visit to deploy the sheen monitoring devices and a second visit to remove the sheen monitoring devices for laboratory analysis. Sheen monitoring would be conducted in the area of NAPL controls as well as upstream of this area (background/control). Specific locations and monitoring procedures will be determined during design. Passive sampling generally involves deploying a passive sampling device into surface water, recovering the device after a determined period, and sending it to an analytical laboratory. A semipermeable membrane device (SPMD) has been used at several sites for passive monitoring of aquatic dissolved contaminants including organochlorine pesticides, polychlorinated biphenyls (PCBs), and PAHs (Alvarez 2004; Lott, C. and A. Newman 2008; USGS 1999). SPMDs are generally made of flat polyethylene tubing that contains lipids ("lipid bags"), high molecular weight silicon fluids, or adsorbents.

The operation, maintenance, and monitoring plan for the selected alternative will be written during design. Note that destructive sampling of the RCM cap would not be conducted, as this would potentially result in NAPL seepage.

Amended performance standards for the RCM would address cap thickness, NAPL isolation, and benthic recolonization. The existing performance standards are included as Appendix D (Section VII, Pages 45-53 of the RD/RA SOW).

4.1.6 Preliminary Cost Estimate for Alternative 1

The preliminary capital cost estimate for Alternative 1, which includes design and construction costs, is $1.8 million. The 30-year net present value cost, including operation, maintenance and monitoring is estimated at approximately $3.1 million.

Table C-1 lists unit costs used in preparing this preliminary estimate. Unit costs are based on previous experience with dredging and capping projects and the RS Means Heavy Construction Cost Data manual (RS Means 2003). Table C-2 provides a preliminary estimate of the capital costs for Alternative 1. This estimate is intended to be within -30 percent to +50 percent of actual costs; further cost evaluation would be necessary during the design phase. Appendix C provides details on the cost analysis and assumptions for the cost estimate. Table 4-1 summarizes the cost estimates for the three alternatives.

4.2 Alternative 2: Reactive Core Mat with Horizontal Permeable NAPL Barrier

In Alternative 2, a RCM is combined with a horizontal permeable NAPL barrier. The horizontal permeable NAPL barrier would be placed below the RCM cap.

4.2.1 Description of Alternative 2

Alternative 2 combines a RCM with a horizontal permeable NAPL barrier. RCM placement would be as described in Section 4.1. A horizontal permeable NAPL barrier would be placed below the RCM cap. The vertical hydraulic gradient within the horizontal permeable NAPL barrier would be minimal, allowing DNAPL to separate from groundwater via gravity, substantially reducing mass loading of the RCM cap and increasing the life of the RCM cap. The barrier would be designed with slopes, slotted pipes and sumps to facilitate passive removal of NAPL, if any, that accumulates in the barrier layer. The horizontal permeable NAPL barrier is further discussed in Sections 4.2.2 to 4.2.7.

Figure 4-3 displays the layout of Alternative 2 in plan view. Figure 4-4 shows the conceptual design in section view. Unit costs for the construction elements of Alternative 2 are summarized in Table C-1. Table C-3 provides a cost estimate for Alternative 2.

4.2.2 Development of Alternative 2

To further detail the retained concepts from Section 3 and develop a complete alternative, the following assumptions were made with regard to the horizontal permeable NAPL barrier.

- After micro-dredging, a horizontal NAPL barrier layer consisting of coarse, lightweight material would be placed below the RCM layer described in Section 4.1 to reduce the upward flow of NAPL, if any, and to mitigate the migration of NAPL from the existing sand cap. The coarse, lightweight material used to construct the high-permeability under-cap barrier could be made of pumice, expanded perlite, expanded shale, recycled glass processed to aggregate, coke nut, a low-density coarse coke material, or polypropylene tower packing media. The specific media to be used in the barrier will be determined based on pre-design bench-scale testing results. A layer of 0.25-in-aperture biaxial geogrid or equivalent permeable separation geosynthetic would be placed below the high-permeability layer to provide stability to the cap and permeable barrier. The under-cap permeable barrier will range from 1 to 2 ft in thickness. A detail of the under-cap permeable barrier is provided on Figure 4-4.

- The edges of the under-cap permeable barrier would be located at approximately Transect T12+50 on the south side and at approximately Transect T09+00 on the north side of the canal, in the areas with the highest rates of observed NAPL seepage.

- Slotted collection pipes would likely be included (pending Remedial Design evaluations) to promote passive NAPL removal, although piping should generally be minimized because of the unavoidable differential consolidation that would occur near them over time. Piping may be placed in an arrangement similar to what has been assumed on Figure 4-3 for the purpose of comparing alternatives, i.e., collection piping spaced on approximate 50-ft centers, extending west to east across the canal. This arrangement allows for access to collection pipe cleanouts, which need to be accessible along the canal banks. The collection layer would potentially have a triangular shape, sloping down from the edges of the layer to the collection pipes.

4.2.3 Construction Considerations for Alternative 2

Approximately 1 to 2 ft of the existing sand cap would be removed by micro-dredging (described in Section 4.1.3) to facilitate placement of the horizontal permeable barrier, RCM, and habitat layer. Micro-dredging would be followed by construction of the permeable barrier, then placement of the RCM and habitat layers as described in Section 4.1.3.

Any construction work not completed in the water (i.e., from a barge) would have to be completed from the canal banks or using specialized equipment such as "swamp buggies" with pontoons. Work from the canal banks would require the use of temporary stabilization methods, such as mats. Performing in-water work such as dredging and capping would require water quality control measures and water quality monitoring.

4.2.4 Evaluation of the Horizontal Permeable Barrier

The estimates of NAPL seepage and the mass of potentially mobile NAPL presented in the Final NAPL Investigation Report were used to evaluate the performance of the horizontal barrier and its potential effect on the life of the RCM cap. This performance evaluation was conducted for the purpose of comparing the Alternatives presented in this report.

In the Final NAPL Investigation Report, NAPL seepage into the canal was estimated to be 111 kg/yr (29 gal/yr) (ARCADIS, 2008a). The total NAPL within the sand cap was estimated to be approximately 3,160 kg (ARCADIS, 2008a). This NAPL has accumulated in the sand cap over approximately 3 years, beginning with the completion of construction in spring 2003 and ending with the Spring Investigation in 2006. Thus, the flux of NAPL to the sand cap in this period is estimated to be 1,050 kg/yr. The total flux of NAPL from the subsurface is the sum of the NAPL that seeps into the canal and the mass that has accumulated in the sand cap. Thus, the total NAPL flux to the cap is estimated to be approximately 1,150 kg/yr. For the purpose of this report, the RCM life for Alternative 1 was estimated based only on the seepage into the canal because not all of the NAPL that enters the sand cap would migrate upward through the RCM, which may result in an overestimate of the RCM life for Alternative 1.

Assuming that a horizontal barrier will recover approximately 95 percent of the NAPL that enters the barrier, the horizontal barrier would recover approximately 1,093 kg/yr (284 gal/yr). Over 30 years, this would be approximately 32,800 kg or approximately 6 percent of the total mass of NAPL in the canal. Although the upward NAPL flux related to ebullition is likely to continue, the 95 percent assumed NAPL recovery efficiency is considered a conservatively low estimate of the expected NAPL recovery for the horizontal barrier. By decreasing the NAPL loading to the RCM, the horizontal barrier would significantly increase the life of the RCM cap in comparison with Alternative 1.

4.2.5 RCM Replacement

As described in Section 4.1.4, the RCM life for Alternative 1 is estimated to be approximately 10 years. Based on analysis in Section 4.2.4, the horizontal barrier would reduce the NAPL flux to the RCM to approximately 95 percent that of Alternative 1. Thus, the NAPL flux to the RCM in Alternative 2 would be approximately 5 percent of the NAPL flux to the RCM in Alternative 1, and the horizontal barrier would extend the life of the RCM by approximately 20 times in comparison with Alternative 1. Therefore, the theoretical life of the RCM for Alternative 2 is greater than 100 years, and the RCM would not require replacement within the 30-year design life.

4.2.6 Long-Term Operation, Maintenance, and Monitoring for Alternative 2

A long-term NAPL monitoring schedule would be developed based on the rate of NAPL accumulation in the collection piping. Cleanout of the horizontal NAPL barrier layer's piping may also be required as a regular maintenance activity. Cleanout rods with sorptive material could be used to "swab" the horizontal slotted piping from the west bank. Additionally, monitoring, and maintenance of the RCM would also be necessary for this alternative, as described in Section 4.1.4. For Alternative 2, in addition to the monitoring required for the RCM, each monitoring event would include inspection of the horizontal barrier system to determine if maintenance is required, gauging of the horizontal barrier NAPL collection system to determine the amount of accumulated NAPL, and NAPL removal if necessary.

The operation, maintenance, and monitoring plan for the selected alternative will be written during design.

Amended performance standards for the RCM would address cap thickness, NAPL isolation, and benthic recolonization. The performance standard for the horizontal barrier would be NAPL capture. The existing performance standards are included as Appendix D (Section VII, Pages 45-53 of the RD/RA SOW).

4.2.7 Preliminary Cost Estimate for Alternative 2

The preliminary capital cost estimate for Alternative 2, which includes design and construction costs, is $2.6 million. This estimate includes Alternative 1's cost of $1.8 million plus the cost of a horizontal permeable barrier below the cap. The 30-year net present value cost, including operation, maintenance, and monitoring is estimated at approximately $3.5 million. The capital cost and the 30-year net present value cost for Alternative 2 is greater than the costs for Alternative 1.

Table C-1 lists unit costs used in preparing this preliminary estimate. Unit costs are based on previous experience with dredging and capping projects and the RS Means Heavy Construction Cost Data manual (RS Means 2003). Table C-3 provides a preliminary estimate of the capital costs for Alternative 2. This estimate is intended to be within -30 percent to +50 percent of actual costs; further cost evaluation would be necessary during the design phase. Appendix C provides details on the cost analysis and assumptions for the cost estimate. Table 4-1 summarizes the cost estimates for the three alternatives.

4.3 Alternative 3: Reactive Core Mat with Horizontal and Vertical Permeable NAPL Barrier

In Alternative 3, a RCM is combined with horizontal and vertical permeable NAPL barrier. Both of the permeable barrier configurations would be designed to facilitate passive removal of NAPL mass collected in sumps. As described in Section 4.2, the horizontal permeable barrier would decrease the vertical hydraulic gradient and provide a collection area below the cap that is expected to reduce mass loading of the RCM and increase design life. The vertical permeable barrier would provide control of NAPL migration from the peat layer on the east bank in the vicinity of the former slip.

4.3.1 Description of Alternative 3

Alternative 3 combines RCM with horizontal and vertical permeable NAPL barrier. RCM placement would be as described in Section 4.1. Horizontal permeable NAPL barrier placement would be as described in Section 4.2.

The vertical permeable NAPL barrier would be placed along the east bank of the canal in the vicinity of the former slip to mitigate the horizontal transport of mobile NAPL to the area under the canal from the adjacent areas by hydraulic gradient reduction and gravity separation of NAPL. The mobile NAPL would settle by gravity upon encountering the high-permeability barrier, while groundwater flow would have an unobstructed pathway. The barrier would fully penetrate the zones of greatest NAPL saturation in the canal, i.e., the organic silt/sediment and peat layers. The vertical permeable barrier would be placed along the east bank of the canal in a north-south orientation. A passive NAPL collection system would be installed at the bottom of the trench, and the trench would be monitored for NAPL accumulation, and, if necessary, used to facilitate the removal of accumulated NAPL.

The Final NAPL Investigation Report concluded that, in the vicinity of documented seepage to the canal, the only significant NAPL observed beneath the banks is in the area of the former slip on the east bank; even there, NAPL concentrations are lower than beneath the canal (ARCADIS, 2008a). Alternative 3 would include a 100 foot long vertical barrier in the vicinity of the former slip from Transect T11+50 to T12+50 on the east bank. This configuration is supported by historical and recent data. Extensive historical data indicate the extent of NAPL on the east bank is not continuous and is generally limited to the former slip (Transect T11+75 to T12+25) and only the former slip area is connected to subsurface NAPL extending farther away from the canal (ARCADIS, 2008a). The northern extent of NAPL is fairly well delineated. There is a TARGOST™ location at Transect T11+75 that has potentially mobile NAPL and three TARGOST™ locations without potentially mobile NAPL starting at Transect T11+00 (ARCADIS 2008a). This is consistent with historical data (ARCADIS, 2008a). The TARGOST™ data in the vicinity of the former slip show decreasing NAPL at the edges of the slip (less NAPL at Transects T12+25 and T11+75 than at T11+95) (ARCADIS, 2008a). Limited TARGOST™ data are available south of the former slip. An area with NAPL is evident outside of our investigation area (south of T13+00); however, this is not adjacent to the area of the canal with observed seepage, and historical data suggest this NAPL is not connected to the NAPL in the former slip (ARCADIS, 2008a). If selected, the extent of the vertical barrier may be refined during design based on additional TARGOST™ borings. The vertical permeable NAPL barrier is further discussed in Section 4.3.4.

Figure 4-5 displays the layout of Alternative 3 in plan view. Figure 4-6 shows the conceptual design in section view. Unit costs for the construction elements of Alternative 3 are summarized in Table C-1. Table C-4 provides a cost estimate for Alternative 3.

4.3.2 Development of Alternative 3

To further detail the retained concepts from Section 3 and develop a complete alternative, the following assumptions made with regard to the vertical permeable NAPL barrier are summarized below.

- Alternative 3 would include a 100 foot long vertical barrier in the vicinity of the former slip from Transect T11+50 to T12+50 on the east bank.

- The barrier would extend on the order of 20 to 25 ft below grade through the peat and into the stratified silt and sand. The barrier, or trench, must extend completely through the peat layer.

- To prevent seepage of the collected NAPL into the stratified silt and sand, the bottom of the trench would be lined with an impermeable material. This would be accomplished using an HDPE membrane placed in the bottom of the trench, which would also seal off the peat/silty sand interface, thus preventing NAPL losses into the stratified silt and sand. Alternatively, the bottom of the trench could be sealed using bentonite or grout slurry. This approach would involve filling the bottom section of the trench, which is keyed into the stratified silt and sand, using a tremie placement method. The bentonite or grout would seal the peat/silty sand interface as well.

- NAPL accumulated at the bottom of the trench would be collected with a slotted pipe extending the length of the trench. The bottom of the trench would be constructed with a designed slope toward NAPL collection sumps.

- The collection sumps would consist of a pipe with a bottom cap, which would be attached to the slotted NAPL collection pipe. The sump would extend below the slotted NAPL collection pipe. A riser pipe, extending to the ground surface, would be attached to the top of the collection sump. The riser pipe would facilitate measurement of NAPL accumulation and, if necessary, removal of the accumulated NAPL in the collection sump. A cleanout for the slotted NAPL collection pipe would be placed at the head of the permeable NAPL barrier; the cleanout would consist of a riser pipe attached to the slotted NAPL collection pipe.

- The trench would be backfilled with a lightweight medium having similar or lower density than site materials to reduce additional settling. We do not expect that site materials would support the weight of traditional gravel backfill without large strains occurring both laterally into the peat and vertically under the weight of the gravel. Therefore, potential backfill media include expanded perlite, expanded shale, recycled glass processed to aggregate, or coke nut. The specific media to be used in the barrier will be determined based on Pre-Design bench-scale testing results. To provide additional support to the trench sidewalls, the trench would be lined with a 1-in-aperture or greater biaxial geogrid prior to backfilling.

4.3.3 Construction Considerations for Alternative 3

If Alternative 3 is selected, additional data may be collected during Pre-Design, including additional TARGOST™ borings on the east bank and NAPL bail-down testing. This additional data would be used during design of this Alternative.

Micro-dredging would be followed by construction of the horizontal permeable barrier, then placement of the RCM and habitat layers as described in Sections 4.1.3 and 4.2.3.

There are three methods which could potentially be used to construct the vertical permeable NAPL barrier. These construction alternatives were evaluated: (1) use of a continuous trenching machine, (2) excavation utilizing biopolymer slurry, and (3) conventional excavation techniques utilizing sheet pile walls and bracing to hold the excavation open. A continuous trenching machine, or “one-pass”[4] technique, could not install an impermeable seal along the bottom of the trench; however, the biopolymer slurry construction method does allow the installation of a HDPE membrane or other type of impermeable seal along the bottom of the trench.

[4]Trade name for DeWind One-Pass Trenching LLC of Zeeland, Michigan.

Additionally, since biopolymer slurry excavation does not require the use of costly sheet pile walls and bracing to keep the trench open, biopolymer slurry excavation is the most feasible.
Work on the east bank would require clearing of vegetation and the use of temporary stabilization methods, such as mats, for equipment access. Erosion control and water quality control measures would be required during construction. Site restoration of the banks and adjacent areas would be completed following construction. Site constraints, including the instability of the canal banks, the depth of the potentially mobile NAPL, the presence of low-strength and highly compressible subsurface soils, and the potential for remobilization of NAPL during construction, would significantly decrease the ease of implementability of a vertical permeable barrier.

4.3.4 Evaluation of the Vertical Permeable Barrier

The estimates of NAPL seepage and the mass of potentially mobile NAPL presented in the Investigation Report were used to evaluate the potential performance of a vertical barrier and its effect on the life of the RCM cap. This performance evaluation was conducted for the purpose of comparing alternatives presented in this report.

Based on 3-D modeling of the available TARGOST™ data, the estimated mass of potentially mobile NAPL beneath the east bank (Transect T9+00 to T12+62.5) is approximately 36,000 kg (ARCADIS, 2008a). However, this includes an anomalous, modeled NAPL area (approximately 7,000 kg) near Transect T10+75. That modeled NAPL area is an artifact of the modeling, and is based on TARGOST™ borings in the canal rather than those along the east bank. The canal borings are not shown on Investigation Report Figure 4-10. This anomalous NAPL area is not consistent with the TARGOST™ results from east bank borings TG127, TG128, and TG130, and is not considered to represent conditions along the east bank. Therefore, a better estimate of the mass of potentially mobile NAPL on the east bank, in the absence of this anomalous modeled NAPL area, is approximately 29,000 kg.

The total estimated mass of potentially mobile NAPL within the area of the potential vertical barrier (T11+50 to T12+50) is approximately 20,500 kg, which is approximately 70 percent of the mass of potentially mobile NAPL on the east bank (29,000 kg) (ARCADIS, 2008a). The potentially mobile NAPL mass of 20,500 kg in the area of the potential vertical barrier is only 4 percent of the total estimated mass of potentially mobile NAPL beneath the canal (521,000 kg) in the area of the potential NAPL controls (T9+00 to T12+50).

As described in Section 4.7.2 of the Investigation Report, the horizontal gradients in the peat layer on the east bank of the canal ranged between -0.184 ft/ft and 0.029 ft/ft, averaging -0.015 during the period of record (ARCADIS, 2008a). During the wet season, groundwater recharge resulting from rainfall infiltration creates consistently positive horizontal hydraulic gradients from the banks to the canal. In the dry season, this pattern is reversed as the horizontal hydraulic gradient in the east bank becomes negative, indicating that the gradient is from the canal into the east bank. The average gradient was negative over the duration of the monitoring period, indicating that the average gradient in the east bank was from the canal to the east bank. In spite of this conclusion derived from the available data set, it is inferred that the long-term average gradient is from the east bank towards the canal. These hydraulic gradient data were collected at Transect T11+00, which is approximately 100 feet north of the center of the former slip.

A conservative calculation of the velocity of potentially mobile NAPL in the east bank peat is approximately 0.02 ft/yr to 0.1 ft/yr, based on the maximum horizontal hydraulic gradient *toward the canal* from the east bank, and the mean and maximum hydraulic conductivity (ARCADIS, 2008a).

Assuming the vertical barrier will recover approximately 100 percent of the potentially mobile NAPL that flows into the barrier, an even mass distribution across the 100-ft long by 20-ft wide zone along the east bank where the vertical barrier is being considered, and a conservatively high NAPL velocity of 0.1 ft/yr, the 100-ft long east bank vertical barrier (T11+50 to T12+50) would recover:

- 20,500 kg/ 20 ft X 0.1 ft/yr = 102.5 kg/yr (27 gal/yr), or a total of 3,075 kg in 30 years.

- This estimate of the vertical barrier performance indicates that, in the absence of a vertical barrier, NAPL migration from the east bank may increase the mass of NAPL under the canal (520,000 kg) by a maximum of 0.6 percent over a 30-year period. Over 30 years, a vertical barrier would recover less than 0.6 percent of the mass of potentially mobile NAPL under the canal.

4.3.5 RCM Replacement

Based on the evaluation of the vertical barrier performance, the vertical barrier would not extend the life of the RCM. Therefore, the theoretical life of the RCM for Alternative 3 is the same as the theoretical life of the RCM for Alternative 2. Thus, for Alternative 3, the theoretical life if the RCM is greater than 100 years, and the RCM would not require replacement within the 30-year design life.

4.3.6 Long-Term Operation, Maintenance, and Monitoring for Alternative 3

A long-term NAPL monitoring schedule would be developed based on the rate of NAPL accumulation in the collection sump. NAPL would be removed from the sump using a portable pump or bailer when the sump is filled to greater than 95 percent capacity. Periodic cleanout of the slotted NAPL collection pipe along the bottom of the trench would also be required. Additionally, monitoring and maintenance of the RCM and monitoring and maintenance of the horizontal barrier would also be necessary for this alternative, as described in Sections 4.1.4 and 4.2.4, respectively. For Alternative 3, in addition to the monitoring required for the RCM and the horizontal permeable barrier, each monitoring event would include inspection of the vertical barrier system to determine if maintenance is required, gauging of the vertical barrier NAPL collection system to determine the amount of accumulated NAPL, and NAPL removal if necessary.

Amended performance standards for the RCM and horizontal barrier would be as described for Alternative 2. The performance standard for the vertical barrier would be NAPL capture. The existing performance standards are included as Appendix D (Section VII, Pages 45-53 of the RD/RA SOW).

4.3.7 Preliminary Cost Estimate for Alternative 3

The preliminary capital cost estimate for Alternative 3, which includes design and construction costs, is $2.9 million. This estimate includes Alternative 2’s cost of $2.6 million plus the cost of vertical permeable barrier on the east bank of the canal, which is estimated to be approximately $0.3 million. The 30-year net present value cost, including operation, maintenance, and monitoring is estimated at approximately $4.0 million. The capital cost and the 30-year net present value of Alternative 3 are greater than costs of Alternatives 1 and 2.

Table C-1 lists unit costs used in preparing this preliminary estimate. Unit costs are based on previous experience with dredging and capping projects and the RS Means Heavy Construction Cost Data manual (RS Means 2003). Table C-4 provides a preliminary estimate of the capital costs for Alternative 3. This estimate is intended to be within -30 percent to +50 percent of actual costs; further cost evaluation would be necessary during the design phase. Appendix C provides details on the cost analysis and assumptions for the cost estimate. Table 4-1 summarizes the cost estimates for the three alternatives.

4.4 Evaluation of Alternatives

As described in Sections 4.2.6 and 4.3.6, the performance of horizontal and vertical barriers was evaluated using data from the Investigation Report. NAPL mass that migrates into the canal from peat and stratified silt and sand layers on the east bank (where the interpreted potentially mobile NAPL layer is located) must also migrate vertically approximately 5 to 10 ft through the organic silt/sediment layer, through the cap, and into the canal. A horizontal barrier beneath the cap would prevent subsurface NAPL, including NAPL migrating from beneath the banks of the canal, from migrating into the cap via hydraulic gradients. Assuming a horizontal barrier is constructed, therefore, a vertical barrier will not decrease the NAPL loading rate to the RCM cap. Consequently, a vertical barrier would not increase the effective life of an RCM. Using the estimates of the mass of potentially mobile NAPL and NAPL seepage presented in the NAPL Investigation Report, estimates of NAPL recovery for the horizontal and vertical permeable barriers are as follows.

- The vertical barrier, over a 30-year period, would recover less than 0.6 percent of the mass of potentially mobile NAPL under the canal and would not extend the life of the RCM cap in comparison with Alternative 2.

- The horizontal barrier, over a 30-year period, may recover an equivalent of approximately 6 percent of the mass of potentially mobile NAPL under the canal. This would extend the life of the RCM cap in comparison with Alternative 1.

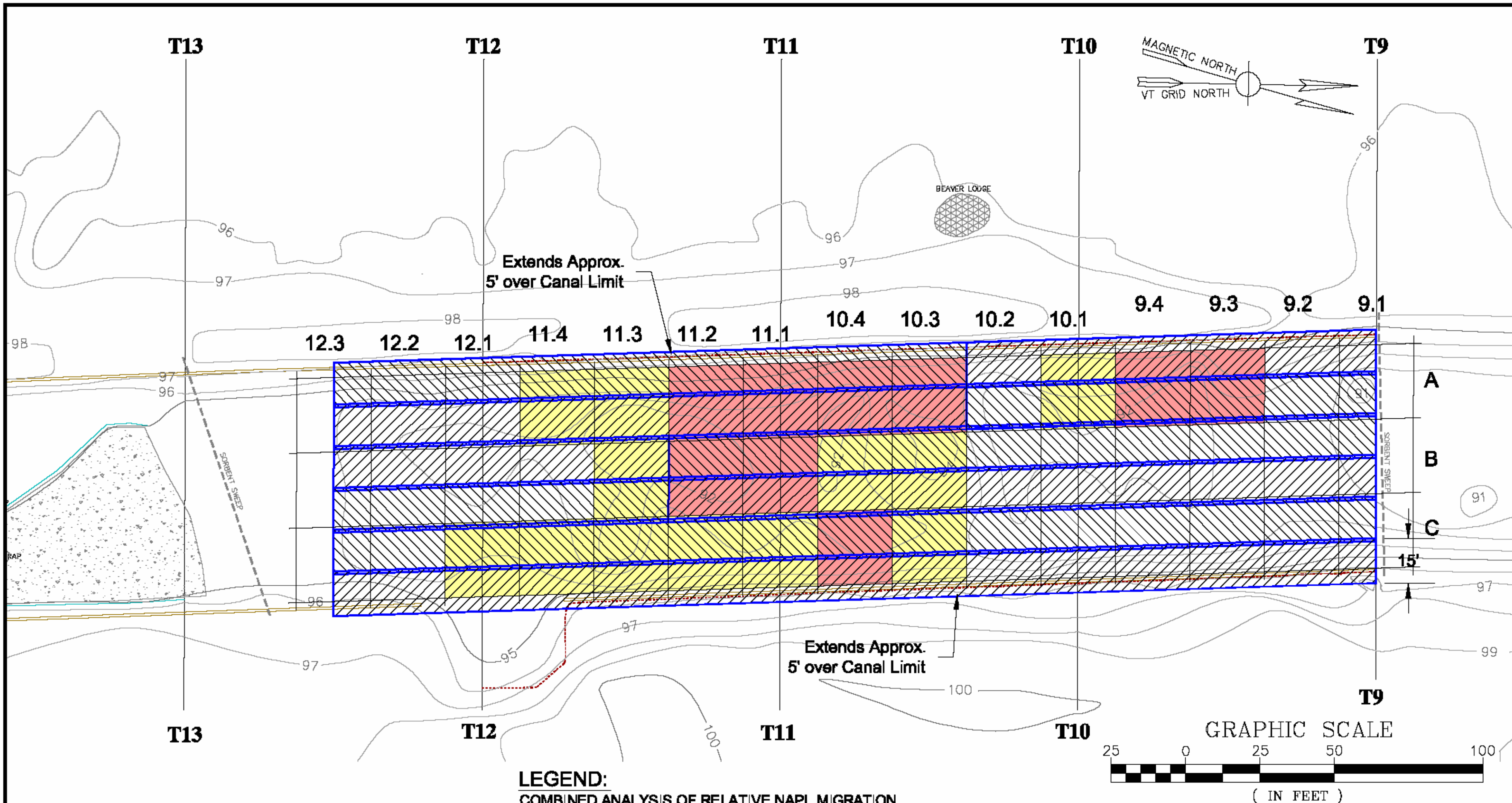
Alternative 1 is eliminated because the thickness of RCM required for a 30-year design life would not be feasible. Based on the performance evaluation of Alternatives 2 and 3, a horizontal permeable barrier would extend the life of the RCM, but adding a vertical barrier would not. In addition, the constructability and long-term performance of the vertical permeable barrier are significantly limited by site conditions, including the instability of the canal banks, the depth of the potentially mobile NAPL, the presence of low-strength and highly compressible subsurface soils, and the potential for remobilization of NAPL during construction. Alternative 3 has a low implementability and a greater capital cost ($0.3 to $1.1 million more) and 30-year present value cost ($0.5 to $0.9 million more) than the other two alternatives (Table 4-1). Alternative 2 is the recommended alternative. Alternatives 1 and 3 are not retained for further consideration.

TABLE 4-1
SUMMARY OF COST ESTIMATES FOR ALTERNATIVES

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

Alternative[1]	Capital Cost (Million $)[2]	30-Year Present Value Cost (Million $)[3]
Alternative 1: RCM	$1.8	$3.1
Alternative 2: RCM with Horizontal Permeable NAPL Barrier	$2.6	$3.5
Alternative 3: RCM with Horizontal and Vertical Permeable NAPL Barriers	$2.9	$4.0

Notes:
1. The cost estimate assumptions and backup tables are presented in Appendix C. These estimates are intended to be within -30 percent to +50 percent of actual costs.
2. The capital cost includes design and construction costs in 2008 dollars.
3. The 30-year present value cost includes capital costs, and operation, maintenance, and monitoring costs for 30 years.



LEGEND:

COMBINED ANALYSIS OF RELATIVE NAPL MIGRATION INTO THE CANAL

- MEDIUM POTENTIAL FOR NAPL MIGRATION
- HIGH POTENTIAL FOR NAPL MIGRATION
- REACTIVE CORE MAT

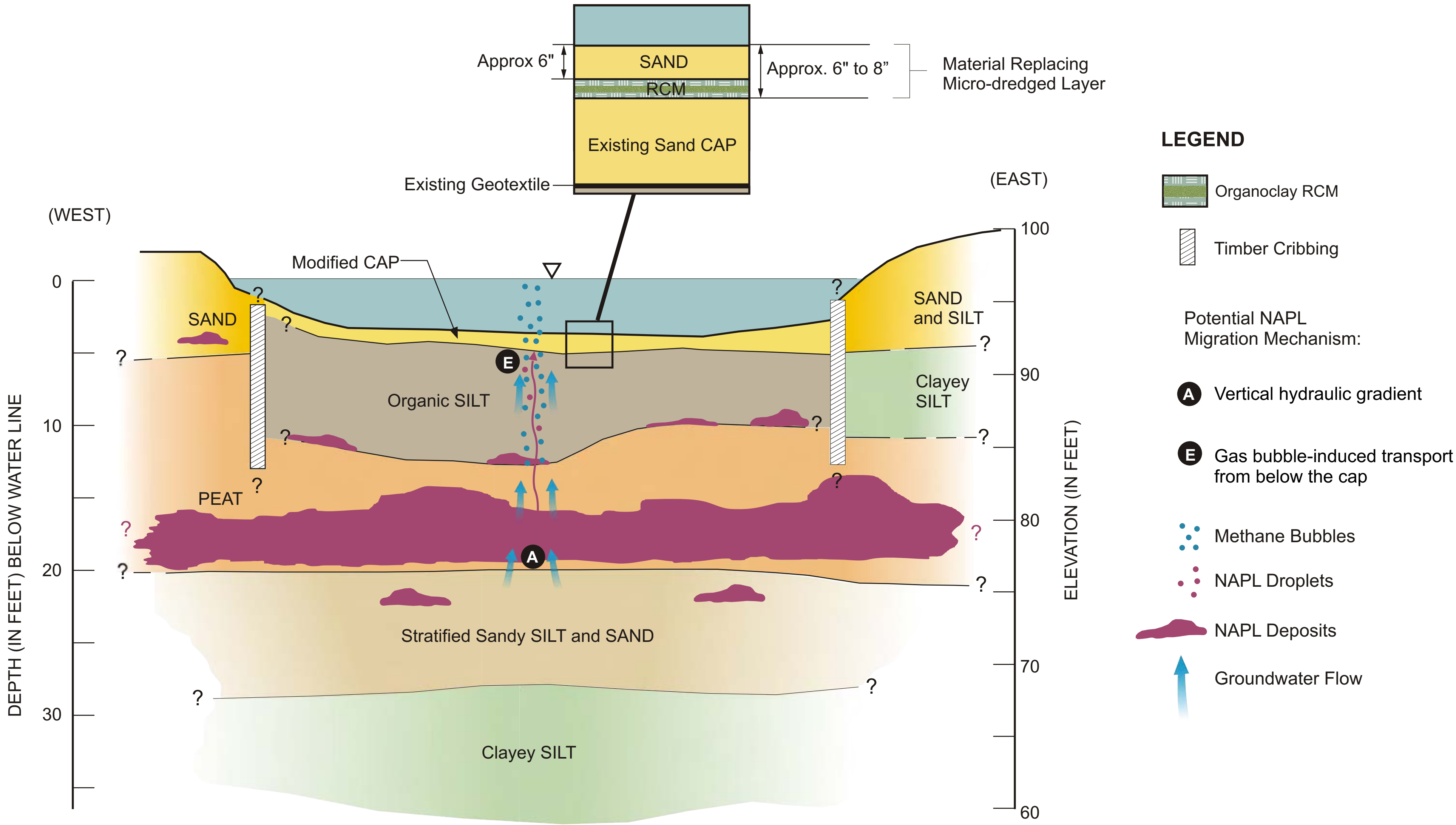
BURLINGTON, VERMONT

PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

ALTERNATIVE 1: REACTIVE CORE MAT

ARCADIS BBL
Infrastructure, environment, facilities

FIGURE
4-1



NOTE: NOT TO SCALE

BURLINGTON, VERMONT
PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

ALTERNATIVE 1: REACTIVE CORE MAT (SECTION VIEW)

ARCADIS BBL
Infrastructure, environment, facilities

FIGURE 4-2

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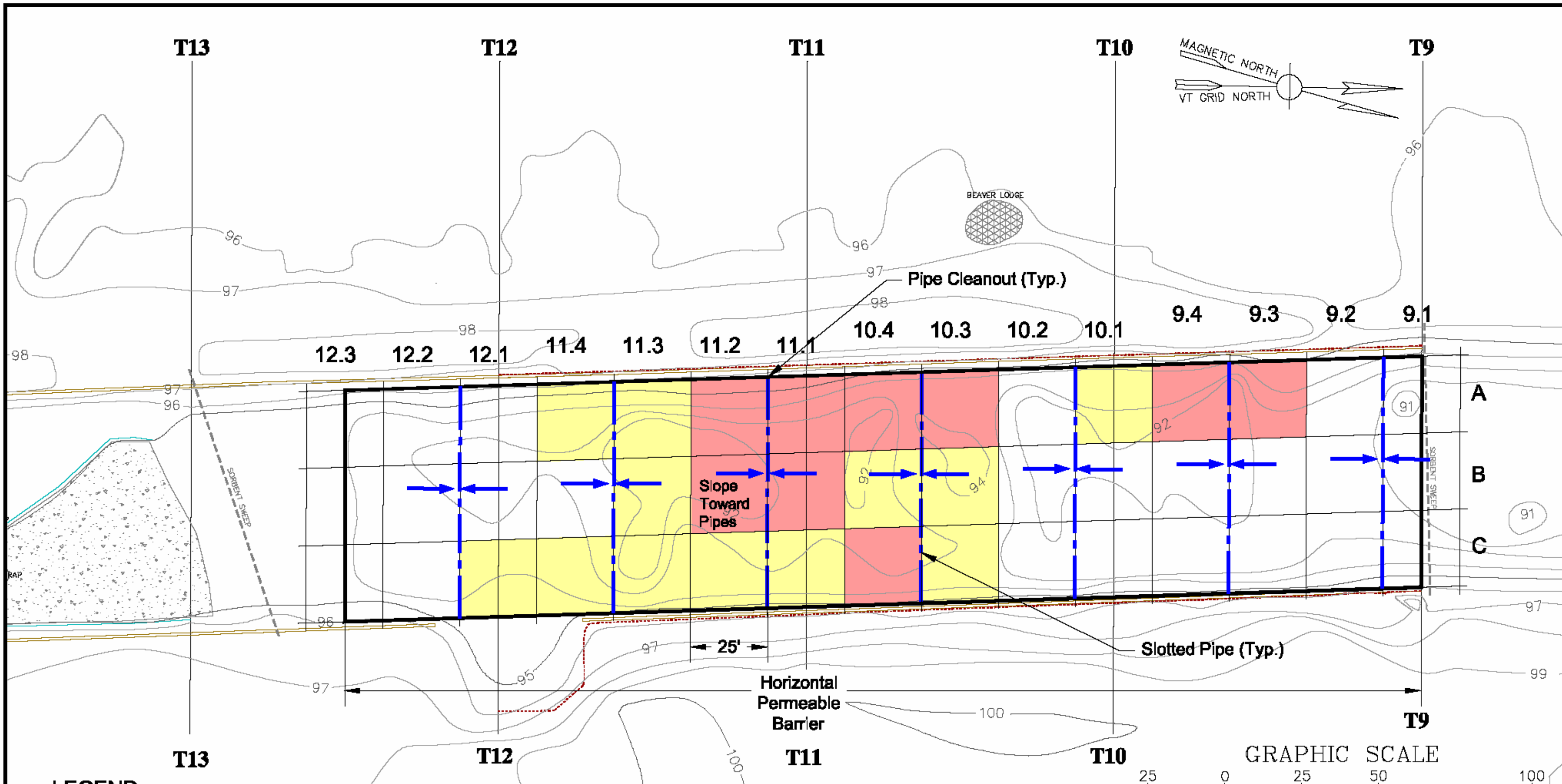
DATE: G:\project\Clients\BBL\Vermont-Pine Street\verm036rev2008.dwg



GRAPHIC SCALE

25 0 25 50 100

(IN FEET)

LEGEND:

COMBINED ANALYSIS OF RELATIVE NAPL MIGRATION INTO THE CANAL

- MEDIUM POTENTIAL FOR NAPL MIGRATION
- HIGH POTENTIAL FOR NAPL MIGRATION
- SLOTTED PIPE
- HORIZONTAL PERMEABLE BARRIER LIMITS

NOTE:

RCM CAP PLACEMENT FOR ALTERNATIVE 2 IS SAME AS ALTERNATIVE 1.

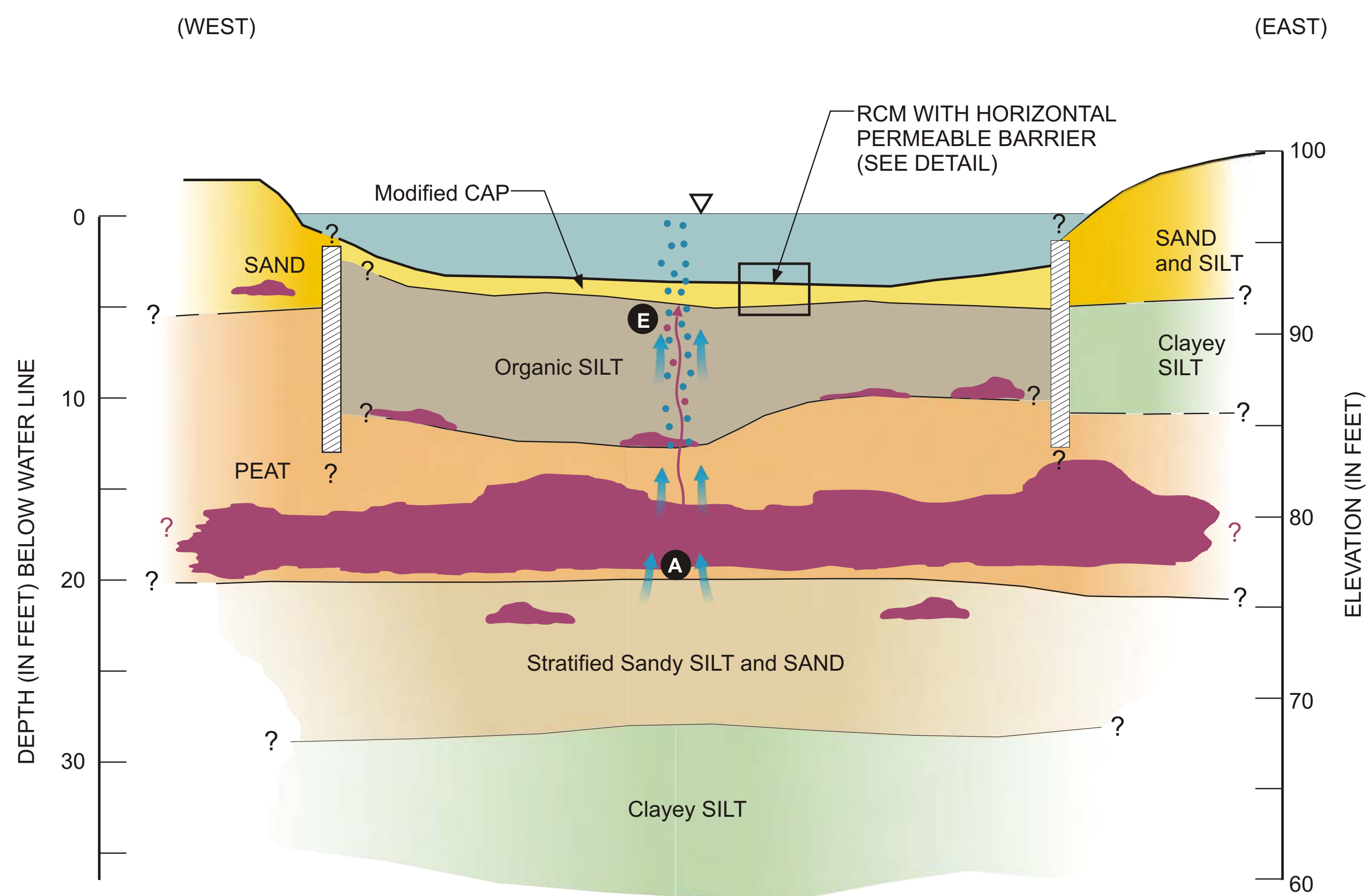
BURLINGTON, VERMONT

PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

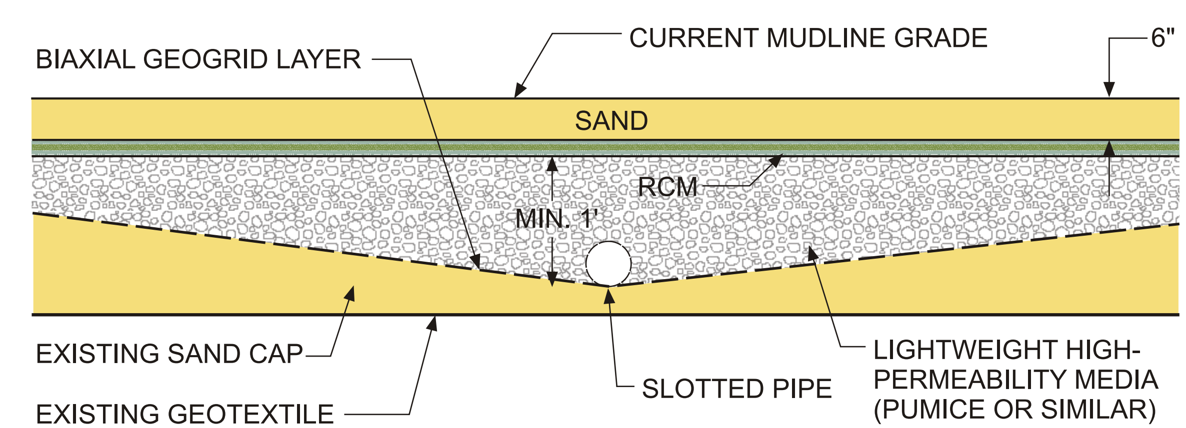
**ALTERNATIVE 2:
RCM WITH HORIZONTAL
PERMEABLE NAPL BARRIER**

ARCADIS BBL
infrastructure, environment, facilities

FIGURE
4-3



RCM AND HORIZONTAL PERMEABLE BARRIER DETAIL



LEGEND

- Organoclay RCM
- Timber Cribbing
- Lightweight High-Permeability Media

Potential NAPL Migration Mechanism:

- (A) Vertical hydraulic gradient
- (E) Gas bubble-induced transport from below the cap
- Methane Bubbles
- NAPL Droplets
- NAPL Deposits
- Groundwater Flow

BURLINGTON, VERMONT
PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

ALTERNATIVE 2: RCM WITH HORIZONTAL PERMEABLE NAPL BARRIER (SECTION VIEW)

ARCADIS BBL
infrastructure, environment, facilities

FIGURE
4-4

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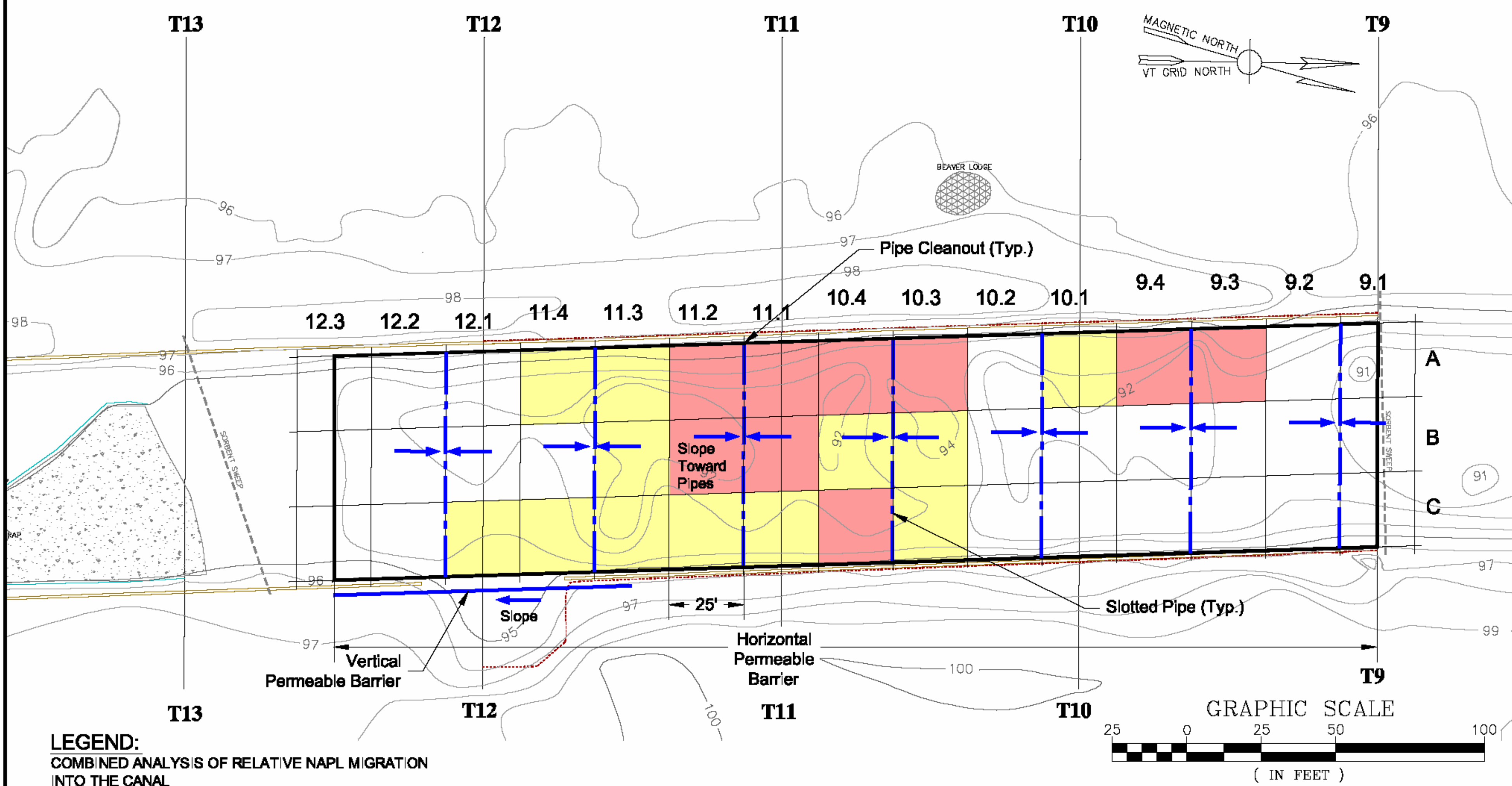


LEGEND:

COMBINED ANALYSIS OF RELATIVE NAPL MIGRATION INTO THE CANAL

- MEDIUM POTENTIAL FOR NAPL MIGRATION
- HIGH POTENTIAL FOR NAPL MIGRATION
- VERTICAL PERMEABLE BARRIER
- SLOTTED PIPE
- HORIZONTAL PERMEABLE BARRIER LIMITS

NOTE:

RCM CAP PLACEMENT FOR ALTERNATIVE 3 IS SAME AS ALTERNATIVE 1.

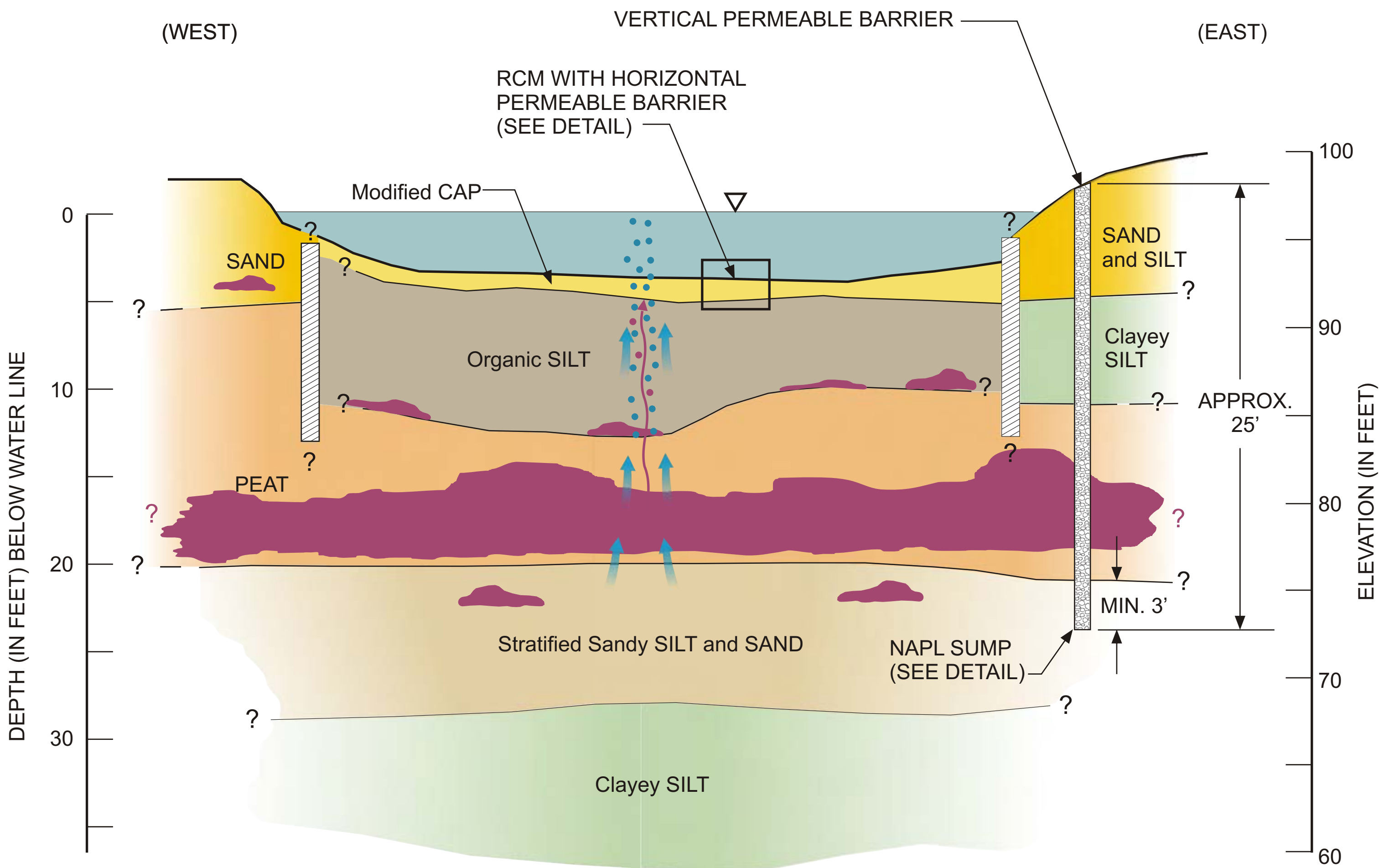
BURLINGTON, VERMONT

PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

ALTERNATIVE 3: RCM WITH HORIZONTAL AND VERTICAL PERMEABLE NAPL BARRIERS

ARCADIS BBL
infrastructure, environment, facilities

FIGURE
4-5



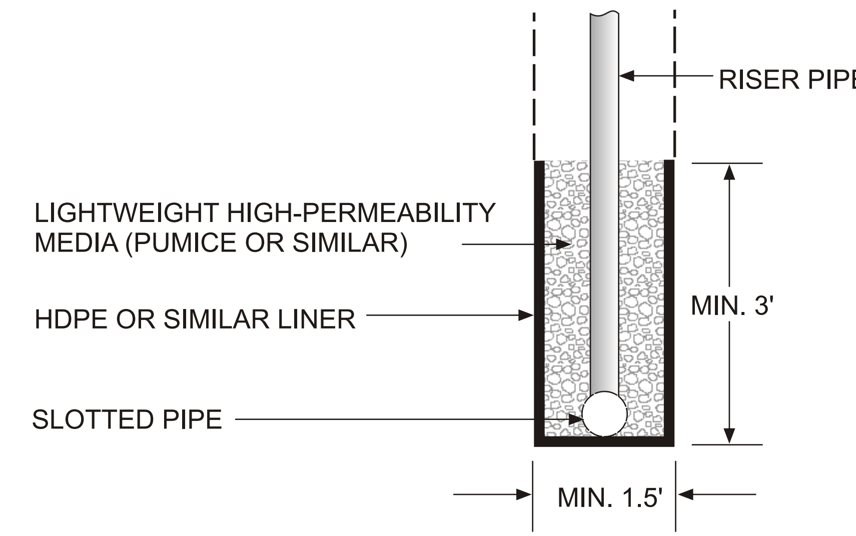
LEGEND

- Organoclay RCM
- Timber Cribbing
- Lightweight High-Permeability Media

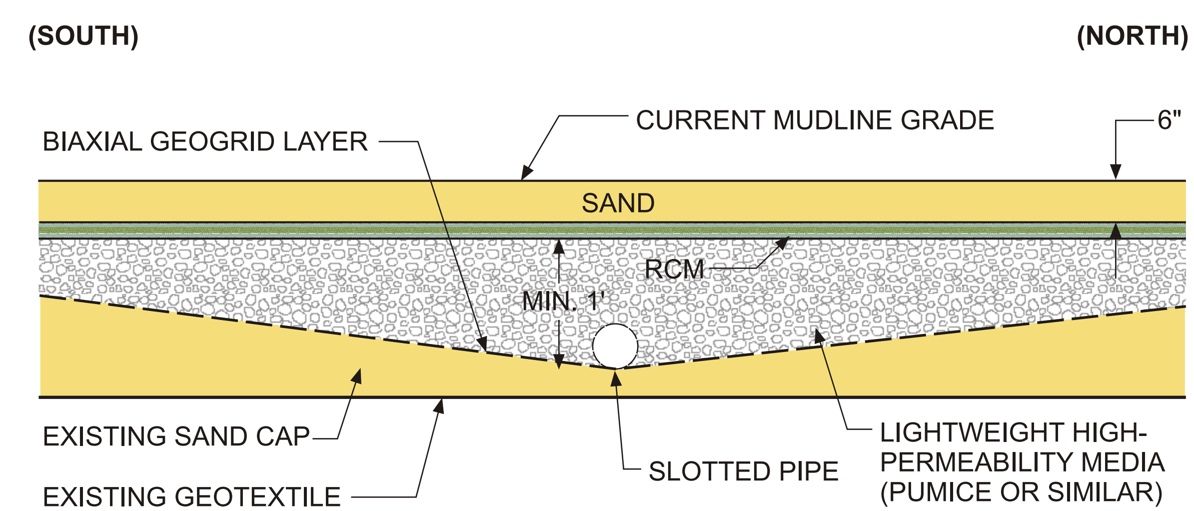
Potential NAPL Migration Mechanism:

- A Vertical hydraulic gradient
- E Gas bubble-induced transport from below the cap
- Methane Bubbles
- NAPL Droplets
- NAPL Deposits
- Groundwater Flow

NAPL SUMP DETAIL



RCM AND HORIZONTAL PERMEABLE BARRIER DETAIL



BURLINGTON, VERMONT
PINE STREET CANAL SUPERFUND SITE
FINAL NAPL CONTROLS REPORT

ALTERNATIVE 3: RCM WITH HORIZONTAL AND VERTICAL PERMEABLE NAPL BARRIERS (SECTION VIEW)

ARCADIS BBL
infrastructure, environment, facilities

FIGURE 4-6

5. Recommendations

5.1 General

The recommended alternative is Alternative 2, a cap modification which would include a RCM cap and a horizontal permeable NAPL barrier installed over an area of approximately 26,000 ft^2 (Figures 4-3 and 4-4). Based on a multi-faceted analysis, the Investigation Report concluded the contiguous area of cap requiring NAPL control is approximately 14,000 ft^2, or one-third of an acre; however, the NAPL controls area has been extended, as requested by the USEPA, to include the entire canal between T9+00 and T12+50 for a total of approximately 26,000 ft^2 or one-half acre. In comparison with the Final NAPL Investigation Report analysis, this expands the area of NAPL controls by approximately 12,000 ft^2, which is an additional 30 ft to the north and south and includes the entire canal from the west bank to the east bank. This alternative is expected to meet the objective of controlling NAPL seepage from beneath the canal into the water column. As discussed in Section 4.4, the vertical permeable barrier concept has been eliminated from further consideration.

5.2 Additional Data Needs for Pre-Design Investigation

As proposed in the Pine Street Canal Action Plan, a Pre-Design Investigation is being conducted to confirm the basis of design for the NAPL Controls. The objective of the Pre-Design Investigation is to fill the design data gaps, so that effective NAPL Controls may be designed. The data gaps related to the design of NAPL controls are as follows:

- What is the NAPL residual saturation of the organic silt/sediment, peat, and stratified silt and sand?
- Which of the available reactive core mat (RCM) media will be used?
- Is a horizontal barrier necessary to collect mobile NAPL (to extend the life of RCM)?
- Which of the available horizontal barrier media will be used?
- What is the NAPL wettability of the selected horizontal barrier media?
- What is the NAPL-removal capacity of the selected RCM media?
- What amount of NAPL seepage reduction will a RCM and a RCM with horizontal permeable barrier provide?

The Pre-Design Investigation Work Plan was submitted on January 15, 2008 (ARCADIS, 2008b). As described in the Work Plan five investigation activities will be conducted:

- Confirm NAPL residual saturation
- Confirm consolidation properties of the organic silt/sediment and peat

- Screen RCM media
- Screen horizontal permeable barrier media
- Confirm selected RCM media NAPL-removal capacity
- Conduct column testing of capping design options.

5.3 Roadmap for Design

In accordance with the Action Plan (BBL and Hart Crowser, 2006a), the Pre-Design Investigation is being conducted. As described in the Pre-Design Work Plan, the Pre-Design data will be submitted to the USEPA with the Design Report, in accordance with the Action Plan. A separate report will not be submitted for the Pre-Design Investigation.

Once the Final NAPL Controls Report is approved by the USEPA, and the Pre-Design Investigation is completed, the final design of NAPL Controls would begin. Design documentation of the NAPL Controls would consist of a design report, containing all the necessary plans and profiles necessary to construct the control elements. The design report would include proposed compliance criteria and a monitoring plan.

The attached schedule (Figure 5-1) includes the following milestones:

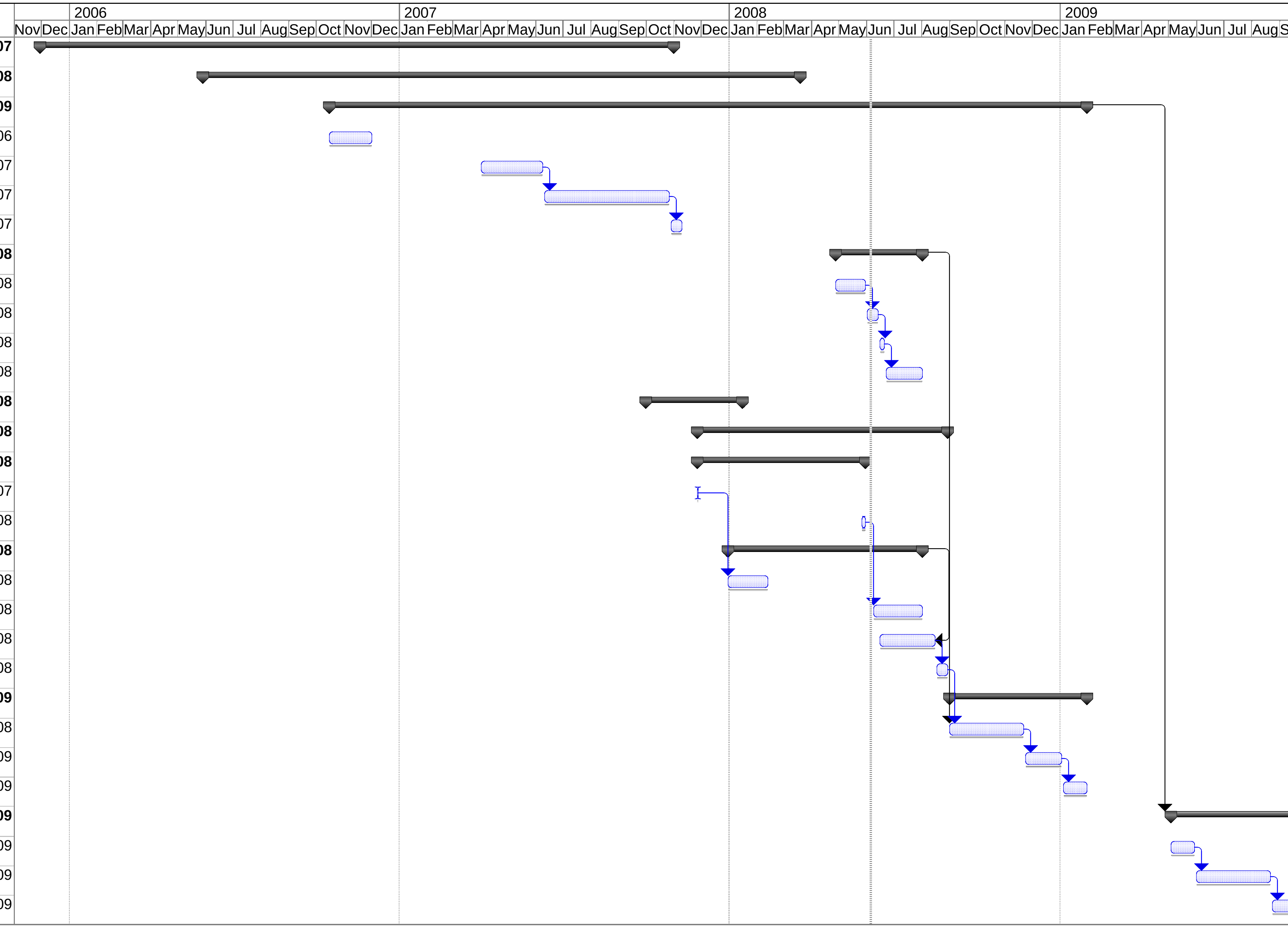
- Implementation of Pre-Design Investigation (Task 3.7) to be completed by August 29, 2008
- Design of NAPL Controls (Task 3.8) to be completed by January 30, 2009
- Construction of the NAPL controls in 2009

This schedule assumes the following:

- USEPA Approval of Final NAPL Controls Report by August 1, 2008
- USEPA Review of the Draft Design Report will be completed in 30 working days
- A ROD Amendment is not required
- Phase IV Implementation of NAPL Controls start date of May 4, 2009 assumes that weather conditions permit construction barge access in the canal during the month of May

Figure 5-1
Updated Schedule for NAPL Investigation and Control Project (June 2008)

ID	Task Name	Duration	Start	Finish
1	**Phase I - NAPL Migration Field Investigation**	**501 days**	**Wed 11/30/05**	**Wed 10/31/07**
7	**Phase II - Evaluation of NAPL Migration**	**473 days**	**Mon 5/29/06**	**Wed 3/19/08**
19	**Phase III - Pre-Design and Design of NAPL Controls**	**600 days**	**Mon 10/16/06**	**Fri 1/30/09**
20	Task 3.1 Preliminary Controls Report	35 days	Mon 10/16/06	Fri 12/1/06
21	Task 3.2 Draft Final Controls Report	10 wks	Mon 4/2/07	Fri 6/8/07
22	Task 3.3 EPA Review	100 days	Mon 6/11/07	Fri 10/26/07
23	Task 3.4 Respond to EPA Comments	10 days	Mon 10/29/07	Fri 11/9/07
24	**Task 3.5 Final NAPL Controls Report**	**70 days**	**Mon 4/28/08**	**Fri 8/1/08**
25	NAPL Controls Report Revisions	5 wks	Mon 4/28/08	Fri 5/30/08
26	ARCADIS/PD Checking	2 wks	Mon 6/2/08	Fri 6/13/08
27	Final Revisions to Report/Submit to EPA	1 wk	Mon 6/16/08	Fri 6/20/08
28	EPA Approval of Final NAPL Controls Report	30 days	Mon 6/23/08	Fri 8/1/08
29	**Task 3.6 Pre-Design Field Investigation Work Plan**	**77 days**	**Mon 10/1/07**	**Tue 1/15/08**
33	**Task 3.7 Implementation of Pre-Design Investigation**	**199 days**	**Tue 11/27/07**	**Fri 8/29/08**
34	**Pre-Design Field Work**	**134 days**	**Tue 11/27/07**	**Fri 5/30/08**
35	NAPL Collection	1 day	Tue 11/27/07	Tue 11/27/07
36	Sediment Coring	4 days	Tue 5/27/08	Fri 5/30/08
37	**Pre-design Treatability Studies**	**155 days**	**Mon 12/31/07**	**Fri 8/1/08**
38	Media Selection Treatability Studies	32 days	Mon 12/31/07	Tue 2/12/08
39	Sediment and Column Treatability Studies	40 days	Mon 6/9/08	Fri 8/1/08
40	Analytical Laboratory	45 days	Mon 6/16/08	Fri 8/15/08
41	Data Validation and Compilation	2 wks	Mon 8/18/08	Fri 8/29/08
42	**Task 3.8 Design of NAPL Controls**	**110 days**	**Mon 9/1/08**	**Fri 1/30/09**
43	Draft Design Report	60 days	Mon 9/1/08	Fri 11/21/08
44	EPA Review	30 days	Mon 11/24/08	Fri 1/2/09
45	Final Design Report	20 days	Mon 1/5/09	Fri 1/30/09
46	**Phase IV - Implementation of NAPL Controls**	**100 days**	**Mon 5/4/09**	**Fri 9/18/09**
47	Mobilization	20 days	Mon 5/4/09	Fri 5/29/09
48	Construction	60 days	Mon 6/1/09	Fri 8/21/09
49	Construction Report	20 days	Mon 8/24/09	Fri 9/18/09



Project: Pine Street Barge Canal
Date: Thu 6/5/08

Task		Progress		Summary		External Tasks		Split	
Split		Milestone		Project Summary		External MileTask			

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Appendix A

Review of Engineered Capping at NAPL-Impacted Sediment Sites

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APPENDIX A
REVIEW OF ENGINEERED CAPPING AT NAPL-IMPACTED SEDIMENT SITES

Site	Physical Setting/ Sediment Type	NAPL Type/Extent/ Migration Mechanism	Bench-Scale Results	Remedy/ Cap Type and Thickness	Status of Construction/ Performance	References
Head of the Thea Foss Waterway Commencement Bay Superfund Site Tacoma, Washington	8,000-ft-long tidally influenced waterway. Soft sediments.	Coal tar-like NAPL observed in several seeps located near the 800-ft-long head of the waterway. NAPL extends from 15 to 50 ft below mudline along west bank. NAPL is within 5 ft of mudline in the most active seep area near the centerline of the waterway. Diver observations in 2000, 2001 documented that NAPL migration at the seeps is primarily through methane bubbles from the sediment. Total NAPL flux was estimated at 110 kilograms/year (kg/yr).	At 10% loading of NAPL (by weight), organoclay capping material effectively sorbed all (100%) of the NAPL mass. At 30% NAPL by weight, 79% of the NAPL mass was sorbed, and at 50% NAPL by weight, 69% to 77% of the NAPL mass was sorbed. Based on bench-scale results, a hybrid cap was designed for the most active seeps consisting of 4 ft of organoclay and 1 ft of overlying sand. The design life of the cap was estimated to be 50 years. Estimated cost of sorbent cap = $180/ft^2.	The final remedy included plans to dredge about 7,500 cy of sediments near outfalls, cap the head of the waterway area, and build a submerged barrier wall across the waterway just north of the SR 509 bridge. Based on cost concerns, the NAPL seeps were capped with a high density polyethylene (HDPE) impervious layer and 3 to 6 ft of sand. Impervious cap covers a 60-ft by 75-ft area. Remaining areas were capped with a continuous layer of clean soil.	Completed fall 2003 Sediment samples collected from cap in August 2004 contained PAHs and sheen, the source of which was being evaluated. It is postulated that the impermeable HDPE barrier could lead to gas buildup in the capped system, thereby causing inefficiencies in its retention ability of PAH/NAPL.	Kellems et al., 2002 Braun, 2004 USEPA, 2004
McCormick & Baxter Creosoting Co. Willamette River Portland, Oregon	Poorly graded, fine- to medium-grained, clean to slightly silty sand.	Creosote NAPL. Polycyclic aromatic hydrocarbons (PAHs) up to 35 ft below sediment surface; NAPL in upper 7 ft of sediment; PAH concentrations decrease rapidly as distance from NAPL seeps increases, suggesting little lateral movement of PAH-containing sediment. Methane-mediated NAPL migration observed.	Testing conducted to assess the sorption capacity, permeability, swelling characteristics, leachability and strength of two organoclays (Aqua Technologies ET-1 and CETCO PM-200) when exposed to NAPLs. The capacity of the PM-200 was 4.82 grams NAPL/gram; ET-1 was 1.39 grams NAPL/gram. Decreased permeability of organoclay with absorption of NAPL. Mixtures with sand and organoclay would limit the permeability changes, increase the effective capacity (grams NAPL per gram organoclay) and therefore provide a lower cost per unit NAPL absorbed.	Sand cap installed across 22.5 acres. Organoclay (ET-1) was added in three specific areas to prevent NAPL seeps from breaking through the cap. Mass of organoclay added = 600 tons. During construction, areas of soft sediment extruded through the sand; repaired by excavating soft sediment and recapping. Sand*:* 1 ft Organoclay*:* 1 ft Gravel*:* 4 inches Rock armor: 10 inches Prior to capping, a sheetpile wall was installed around the upland portion of the site to eliminate the flow of NAPL to the Willamette River.	Completed November 2004. NAPL seeps observed in sand-only portion of cap in summer 2005. Organoclay mats were placed over one seep in August 2005. Two additional seeps were covered by organoclay mats in fall 2005. Cores of the organoclay cap area were collected and diver inspection of the cap was performed for signs of erosion in early October 2006. Water quality samples were collected in late October 2006. Results of these monitoring activities will be available in the annual operations and maintenance (O&M) report to be issued in summer 2007. Although migration of gas bubbles is observed in organoclay cap, NAPL migration has not been observed. It is believed that organoclay is absorbing NAPL prior to gas bubbles breaking the surface of the cap.	Ecology and Environment, Inc., 2002 Ecology and Environment, Inc., 2003 Reible D., 2005

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REVIEW OF ENGINEERED CAPPING AT NAPL-IMPACTED SEDIMENT SITES

Site	Physical Setting/ Sediment Type	NAPL Type/Extent/ Migration Mechanism	Bench-Scale Results	Remedy/ Cap Type and Thickness	Status of Construction/ Performance	References
Anacostia River Demonstration Project Washington, D.C.	Two sites originally included. Coal tar NAPL. Silty clay to silty, fine sand.	Sediment hydrocarbon concentrations ranged from 5,000 to 6,000 milligrams per kilogram (mg/kg). PAHs detected at levels between 470 micrograms per kilogram (µg/kg) and 82,360 µg/kg to depths of 7 ft. Bulk of PAHs were high-molecular-weight (4-, 5-, and 6-ring) PAHs associated with coal tar. Methane-mediated NAPL migration observed.	Objectives are to demonstrate, on a field scale, the ability to design, construct, and place caps that will provide long-term treatment of sediment contaminants while simultaneously providing containment. Cap materials under consideration included AquaBlok™, a commercial product designed to reduce the permeability at the sediment-water interface; zero-valent iron and Bion soil, which encourage reductive dechlorination conditions; apatite, designed to sorb or bind metals; and coke breeze and an organo-modified clay, both capable of absorbing hydrophobic organic contaminants. New organoclay contained approximately 24% organic carbon by weight, from the tertiary ammine modifier.	AquaBlok™: 6 inches Apatite: 6 inches Coke breeze*:* <1 inch Sand*:* 6 inches	Completed spring 2004. Methane flux decreased after one year as consolidation was complete. Monitoring is under way. Inclinometers at the AquaBlok™ cap showed slow cap deformation (uplifting) of 1 inch over 40 days followed by sudden uplifting of 2 ft. Initial indications point to buildup of methane from sediment beneath the cap during warm weather.	Hart Crowser, 2002 Horne Environmental Services, Inc., 2003 and 2004 Reible and Constant, 2004 Mutch et al., 2005
Stryker Bay Unit of the St. Louis River/Interlake/Duluth Tar Superfund Site Duluth, Minnesota	35-acre shallow water embayment with emergent wetlands at the north end of the embayment.	Approximately 1 acre of NAPL, 8 to 10 feet thick, from historical manufactured gas plant and two coal tar distillation plants. Impacted sediment volume is 135,000 cubic yards (cy). NAPL migration via gas ebullition, groundwater advection, and porewater migration caused by consolidation.	Bench-scale tests found the cohesive nature of the sediment increased the ability of gas migration to transport NAPL. Gas migration was largely from the gas-forming channels in the fine-grained sediments, with the rising bubbles eroding NAPL and sediment from the channelized walls. The investigation also found that channelization did not occur in sandy materials.	Subaqueous cap was part of the dredge/cap hybrid remedy. A 11-acre portion of Stryker Bay, including sediments with the highest naphthalene concentrations, was capped. Capping was used with a surcharge technique to consolidate the underlying sediment and isolate contaminants without reducing the bay's water depth and natural resource functions. Since bench-scale testing indicated that NAPL migration via gas bubble transport was temperature dependent, a 3-foot thick cap was proposed to insulate the sediment layer where the bubbles are generated and reduce ebullition and the associated NAPL migration via gas bubble transport. The cap construction consisted of 0.5 ft sand, activated carbon mat, and 2.5 ft sand placed in layers.	Construction at the site began in June 2006 and is ongoing. Below-water capping had been completed and above-water sand cap placement was completed at the end of November 2006. Construction of the entire site including removal of surcharge material is expected to be complete by 2009.	Costello et al., 2003a Costello et al., 2003b Costello, 2004 Huls and Costello, 2004 XIK Corp., 2005 Olsta and Hornaday, 2007

Site	Physical Setting/ Sediment Type	NAPL Type/Extent/ Migration Mechanism	Bench-Scale Results	Remedy/ Cap Type and Thickness	Status of Construction/ Performance	References
East Eagle Harbor/ Wyckoff Superfund Site Bainbridge Island, Washington	Phase I: contaminated subtidal harbor sediments capped. Phase II: contaminated nearshore sediments capped. Phase III: cap on Phase II area (slightly smaller footprint). Water depths 0 to 45 ft. Soft sediments, fine to medium sands and silt.	Creosote NAPL. Upper 3 ft of sediments impacted, but impacts identified at depths of 20 ft near the facility and at depths up to 60 ft at the edge of the intertidal zone north of the facility. Impacted area in intertidal area is approximately 115,000 sq. ft. Methane-mediated NAPL migration not observed.	NAPL and dissolved PAHs in native sediment appear to be effectively isolated by the cap and do not migrate via consolidation-induced advection.	Phase I (1993-1994): 3 ft of clean sediment for Snohomish River. Phase I cap placed before final DNAPL source controls in place as part of a Non-Time-Critical Removal Action. Phase II (2000-2001): 3 ft of clean sand. Phase III (2001-2002): 80,000 cy of clean sediment. A sheet-pile wall was installed along the shoreline to eliminate the flow of NAPL to the harbor.	Load-bearing failures suspected to have occurred during construction based on visual evidence (slicks, sheens, globules). Updated O&M Monitoring Plan currently recommends focus on two areas of minimum cleanup level exceedance in southern cap during the upcoming 2006 monitoring. Depressed PAH biodegradation rates due to cap placement have been observed.	Herrenkohl et al., 2001 Wakeman and Bachman, 2004 USACE, 2005
Pacific Sound Resources Elliott Bay Seattle, Washington	58 acres of estuarine silty sand.	Creosote NAPL. Nearshore impacts to 20 ft, trailing off to primarily surficial contamination at about 1,200 ft from shore. Upland remediation performed first. Slurry wall installed to prevent migration of upland NAPL to sediment via groundwater.	Not performed. Cap thickness refined according to a one-dimensional transport model used to estimate breakthrough times.	Sand*:* 3 ft minimum (average of 5 ft, except in intertidal areas, which will have a minimum of 5 ft). Gravel and riprap*:* 2 ft minimum. Portion of the cap was amended with 0.5% total organic carbon (TOC) by weight by adding coal. Approximately 20 acres of cap are on an 18% to 21% slope.	Completed February 2005. 30-year monitoring plan to verify the cap continues to contain sediment. No additional monitoring or performance data are currently available.	USACE, 2003 USEPA, 2005b Dunn et al., 2005
Koppers Co., Inc. Charleston, South Carolina	Classic marsh/tidal river cohesive (100% silts/clays with no sand), with a relatively high total organic carbon content.	Wood-treating NAPL. NAPL extends across 2 acres and as deep as 17 ft below ground surface (bgs). Cap will cover areas with 2 mg/kg benzo(a)pyrene and 1,150 mg/kg lead.	Unknown.	Due to public concern with sheetpiles surrounding property access and the agency's desire to avoid delays, USEPA selected capping. Geotextile: 6 inches. Sand: 18 inches (min).	Completed December 2001. No additional monitoring or performance data are currently available.	USEPA, 1999, 2003a, 2003b

APPENDIX A
REVIEW OF ENGINEERED CAPPING AT NAPL-IMPACTED SEDIMENT SITES

Site	Physical Setting/ Sediment Type	NAPL Type/Extent/ Migration Mechanism	Bench-Scale Results	Remedy/ Cap Type and Thickness	Status of Construction/ Performance	References
Salem Manufactured Gas Plant Salem, Massachusetts	Beach and intertidal sediment.	The site contains two distinct NAPL types in beach and intertidal sediment. NAPL seep and oil sheen observations have been made, as well as monitoring of NAPL seepage rate in one location.	Five sorbents (PigPeat™, coke breeze, cellulose, granular activated carbon [GAC], and organoclay) were combined with various concentrations of NAPL (0%, 25%, 50%, and 100% NAPL). Bench-scale testing indicated that cellulose (Absorbent W™) retained the highest percentage of NAPL sorbed per unit weight of solidification/ stabilization (s/s) material and was the most efficient in terms of the amount of NAPL sorbed per unit cost. Next was coke breeze for sorbtion per unit cost. PigPeat™ was the second best performer on a unit weight of s/s material basis and was third best behind cellulose on a sorption per unit cost basis. This study is directly applicable to the Pine Street Canal site, as both sorbents, their capacity, and their weights are relevant for a reactive cap at the site.	The areas of NAPL seepage incorporate three layers of CETCO™ organoclay RCM. Additionally, an underlying gravel-filled geoweb is incorporated to mitigate physical transport of hardened coal tar particulates from migrating from the beach. The RCM is also placed below Tensar™ marine mattresses so that the necessary armoring is provided, while allowing access to the RCM to monitor for visible signs of breakthrough through the monitoring period and replace as needed.	Construction planned for November/December 2006 through 2007.	None reported for this draft.
River Dredging Project Massachusetts	River bed	Coal tar DNAPL encountered unexpectedly during dredging operation inside of dewatered sheet-pile cell.	Not applicable.	Gravel DNAPL-separation layer with a screened DNAPL monitoring/collection sump, covered by a low-permeability liner, within the riverbed.	Construction completed in 2000.	None reported for this draft.
Former MGP Site Hudson, New York	Sandy silt.	Coal tar NAPL 30 ft deep in sediment.	Site separated into Operable Units. Designed and currently providing construction oversight for OU-1 which includes dry excavation and capping of NAPL-containing sediments.	NAPL impacted sediments were partially dredged, NAPL barrier to consist of impermeable liner keyed to sealed sheeting to hydraulically isolate remaining NAPL, backfilled under 8 to 10 ft of clean sand.	Completed in 2006	None reported for this draft.

APPENDIX A
REVIEW OF ENGINEERED CAPPING AT NAPL-IMPACTED SEDIMENT SITES

Site	Physical Setting/ Sediment Type	NAPL Type/Extent/ Migration Mechanism	Bench-Scale Results	Remedy/ Cap Type and Thickness	Status of Construction/ Performance	References
Collateral Channel and Bubbly Creek, Chicago Sanitary and Ship Canal and Chicago River Chicago, Illinois	Fresh water sediments with high organic content and gas ebullition Collateral Channel: one acre side channel off the Sanitary and Ship Canal Bubbly Creek: four acres, 7,500 ft long branch connected to Chicago River at Turning Basin	NAPL Contamination result of CSOs and industrial discharges PAHs, heavy metals, and PCBs present in sediment	Unknown.	Collateral Channel: one acre test site at end of canal which includes sheet pile/hydraulic control, GAC RCM, a geonet for lateral gas collection, a boardwalk overlying wetland, and a river water pump for nitrogen removal (denitrification). Bubbly Creek: four acre active capping test site. Four test plots will have different caps applied, geotextile, apatite clay, GAC, and a thin active cap, each including a wetland overburden.	The test plots were planned for construction in 2007.	Zhao, X, P. Viana, K. Yin, K. Rockne, D. Hey, J. Schuh, and R. Lanyon (2007) Combined active capping/wetland demonstration in the Chicago River In: *Fourth International Conference on Remediation of Contaminated Sediments.* January 25.

Appendix B

Review of NAPL Barrier Projects at NAPL-Impacted Sites

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APPENDIX B
REVIEW OF NAPL BARRIER PROJECTS AT NAPL-IMPACTED SITES

Site	Physical Setting	NAPL Type/ Extent/ Migration Mechanism	Bench-Scale/ Pilot-Scale/ Full-Scale Results	Remedy/ NAPL Barrier/ NAPL Trench description	Status of Construction	References
Court Street Former Manufactured Gas Plant (MGP) Site Binghamton, New York	Adjacent to Susquehanna River. Glacial outwash over dense till.	Coal tar DNAPL and LNAPL Extends to 60 ft, bgs 100 ft offsite/ migrating due to gravity and hydraulic gradient. Till is a capillary barrier to DNAPL.	FS field investigation was completed February 2005; groundwater flow model and a two-phase fluid-flow model were developed to help evaluate and select a barrier option.	Project involves constructing a 750 ft long, 60 ft deep, 30-inch wide passive NAPL barrier (vertical, gravel-filled trench), with LNAPL-skimming baffle, and NAPL monitoring/collection wells	90% complete November 2006.	None reported for this draft.
Front Street Former MGP Site Amsterdam, New York	Mohawk River/Barge Canal Alluvial sediment with sand and gravel.	NAPL was observed up to 40 ft below the sediment/water interface and approximately 400 ft away (across the river from the site).	Barrier remedy to keep LNAPL and DNAPL from discharging to the Mohawk River/Barge Canal. Involves surrounding the site on four sides with watertight sheeting, capping, and collecting accumulated NAPL with passive recovery wells.	Remedy focused on "hydraulic gradient manipulation", allowing groundwater to pass beneath sheeting to keep LNAPL behind and keep DNAPL from moving upward (due to upward gradients) into the river. Installation of 1,150 linear ft of steel sheetpile with sheet lengths of up to 70 ft. Installation of 18 4- or 6-inch-diameter NAPL recovery wells with depths up to 85 ft.	Construction completed in November 2006.	None reported for this draft.

APPENDIX B
REVIEW OF NAPL BARRIER PROJECTS AT NAPL-IMPACTED SITES

Site	Physical Setting	NAPL Type/ Extent/ Migration Mechanism	Bench-Scale/ Pilot-Scale/ Full-Scale Results	Remedy/ NAPL Barrier/ NAPL Trench description	Status of Construction	References
Coal-tar site Everett, Massachusetts	Upland fill on the water edge, widely graded sand with gravel and debris.	Coal tar NAPL observed in fill layer over interior areas of site, and adjacent river sediment.	No pilot testing done.	Involves sediment dredging and placement in a Confined Disposal Facility, with passive NAPL collection trenches on either end. Perforated pipe horizontally placed at the bottom of the trenches.	CDF was constructed in 2006 (to be part of NAPL migration barrier and contain stabilized, dredged sediment); remainder of migration barrier to be constructed in early 2007.	None reported for this draft.
Active creosote wood-treating site Guthrie, Kentucky	Upland site adjacent to creek.	Creosote DNAPL in subsurface adjacent to creek.	Site includes two areas, the M-22 area and the mudtrack area. An existing NAPL collection well and treatment system are in operation in the M-22 area. A new barrier system has been constructed in the mudtrack area to protect a nearby creek. No sheens/ DNAPL in creek to date (no DNAPL yet identified in trench sump, either.)	Design incorporates NAPL barrier trench approximately 7 ft deep (in two locations) with a collection pipe at the bottom backfilled with coke nut, lined with CETCO™ reactive mat, and incorporating phytoremediation plantation between trench and stream. French drains installed to prevent surface expression of sheen-bearing water in middle of site – these drain to coke-nut filled basin.	Barrier system construction was completed as an IRM in September 2004. No DNAPL collected as of April 2005.	None reported for this draft.

APPENDIX B
REVIEW OF NAPL BARRIER PROJECTS AT NAPL-IMPACTED SITES

Site	Physical Setting	NAPL Type/ Extent/ Migration Mechanism	Bench-Scale/ Pilot-Scale/ Full-Scale Results	Remedy/ NAPL Barrier/ NAPL Trench description	Status of Construction	References
Wood treating Site Carbondale, Illinois	Fractured clay	Creosote DNAPL. Very limited evidence of creosote on downgradient side of the barrier before construction	Two passive NAPL collection trenches installed; 5,600 gallons of NAPL has been collected from one trench since 2004; the other trench has not produced any NAPL to date.	Remedy involves two overlapping trenches 910 ft long (combined). Trenches filled with gravel; NAPL is collected using perforated collection pipe connected to sump. Downgradient monitoring locations have been installed and are NAPL-free.	Completed in November 2004	None reported for this draft.
PCB DNAPL Site Russellville, Kentucky	Karstic limestone bedrock.	PCB DNAPL migrating through openings in karstic bedrock	About five months after installation, PCB DNAPL appeared in the sump of one of the two systems. Approximately 5 liters have been collected since, over a period of about 1 year.	Remedy involves gravity separation/collection of DNAPL, CETCO™ reactive core mat, and pumping/treating of groundwater (latter as required by state).	Two barriers installed beneath areas in a creek where DNAPL was observed issuing from karstic bedrock.	None reported for this draft.
Central Hudson Former MGP Newburg, New York	Silty clayey type sediment.	NAPL extends in top 10 ft of sediment	ROD for the site was issued in 2005. Pre-design investigations started in 2006 and will be completed in 2007.	The proposed remedy is a NAPL barrier wall approximately 500 ft long designed to collect NAPL without groundwater collection/treatment to prevent potential migration of the NAPL.	Anticipated in 2008.	None reported for this draft.

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Former MGP Rockland, Maine	Site is former MGP located on a bay along the coast of Maine. Geology consists of fill over silty clay Beach frontage with 12 ft tides.	Coal-tar DNAPL.	Not available.	The trench (100 linear ft) designed to separate MGP-related material by gravity settling The trench will include collection piping and a sump to facilitate periodic collection and removal of accumulated DNAPL.	Completed in April 2007.	None reported for this draft.
Former MGP Salem, Massachusetts	Sandy silt with occasional gravel and debris.	NAPL migrate through sand layer and pervious layer of nearshore sediment.	A barrier system (subsurface HDPE sheetpile wall) was constructed on the upland portion of the site as a risk reduction measure. The team is drafting an FS that addresses ongoing coal tar seepage in the shallow subsurface below a coastal beach and the adjacent intertidal flats. The team has completed treatability studies and is undertaking pilot studies for a cutoff trench using sorptive material that would be located along the toe of the coastal beach for removal or in-situ treatment of intertidal flat sediment.	Remedy focused on 900 ft long NAPL collection trench integrated with coastal beach cap. Barrier was constructed from HDPE panels. The barrier treats groundwater (low pH and dissolved LMH organics) passively via flow-through filtered openings.	Bidding for construction completed. Construction scheduled beginning Fall of 2006.	None reported for this draft.

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Former MGP Site Rome (Kingsley), New York	Silty sand.	Coal tar LNAPL and DNAPL.	The site remedy specified in the ROD includes a barrier wall with passive treatment cells for dissolved phase constituents, with NAPL recovery and site capping. Flow-through column tests performed to test the ability of sand, coke breeze, activated carbon, and organoclay to sequester NAPL and prevent sheens in the presence of flowing water – only organoclay proved to be effective. Water collection and treatment system.	1200 ft sheet pile wall Remove approximately 400 cy of PAH-impacted sediment in the backwater area. Replace with clean material comparable to the native sediment	Three phase construction project. First phase scheduled for 2007. Two rounds of groundwater sampling are scheduled before design activities begin.	Gefell et al. 2006
Former MGP Site Saratoga, New York	Sandy sediment.	5,000 cy of PAH impacted sandy sediment.	Barrier system installed, site covered with an asphalt cap, and an active groundwater recovery and treatment system is in operation.	Barrier was constructed of watertight steel sheeting encompassing the 7-acre site and keyed 5 ft into a competent clay unit.	The O&M plan is being prepared for the barrier system; however, BBL will likely not be involved in the O&M activities.	None reported for this draft.
Industrial Facility Southington, Connecticut	Silty sand outwash and till over sandstone bedrock.	Multi-component DNAPL and LNAPL containing solvents, aromatics, ketones, and alcohols.	Full scale sheet-pile barrier wall installed.	Barrier was constructed of non-grouted, interlocking sheet piling with groundwater extraction for gradient control.	Barrier system has been working effectively since 1995.	None reported for this draft.

APPENDIX B
REVIEW OF NAPL BARRIER PROJECTS AT NAPL-IMPACTED SITES

Site	Physical Setting	NAPL Type/ Extent/ Migration Mechanism	Bench-Scale/ Pilot-Scale/ Full-Scale Results	Remedy/ NAPL Barrier/ NAPL Trench description	Status of Construction	References
Westchester County Department of Public Works Airport Harrison, New York	Not available.	Not available.	Field activities were conducted to characterize the nature and extent of petroleum hydrocarbons in the subsurface. Remedy were designed to address NAPL and petroleum impacted soils in the subsurface.	A low-permeability barrier was constructed in conjunction with a NAPL collection system.	Completed in 1999.	None reported for this draft.

Appendix C

Cost Estimates and Assumptions

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Appendix C – Cost Estimates and Assumptions

C-1 Introduction

The cost estimates presented in this appendix and the associated cost analysis information are provided for use in evaluating the costs of the three alternatives presented in the Final NAPL Controls Report. The level of accuracy of these estimated costs is "Order of Magnitude," as defined by the American Association of Cost Engineers. The accuracy of an Order of Magnitude estimate is plus 50 percent and minus 30 percent. Cost estimates at this level may be used to compare alternatives, but should not be used to plan, finance, or develop projects. However, the complexities associated with the Pine Street site (e.g., general incompatibility with conventional equipment due to soft, compressible layers), which limit access and constrain implementation, increase the risk that the actual cost of implementation will fall outside this range. Further, the necessity of keeping disturbance to a minimum to avoid remobilizing NAPL contributes to the cost risk, because a contractor's cost escalation to account for such factors is difficult to estimate at this conceptual stage of analysis.

The cost estimate was prepared in general accordance with regulatory guidance for cost estimating (USEPA 2000). Unit costs were selected based on previous dredging and capping project experience and the RSMeans Heavy Construction Cost Data Manual (2008).

Table C-1 summarizes unit costs that are applicable to the alternatives. Tables C-2 through C-4 present the preliminary cost estimates for Alternatives 1 through 3, respectively. The main assumptions in preparing these cost estimates are presented in the following sections.

C-2 Capital Cost General Assumptions

The general assumptions used in developing the cost estimates are as follows:

- **Dredge Volumes.** The estimate of dredge volumes is based on removal of the first 6 inches (Alternative 1) or 18 inches (Alternatives 2 and 3) of the existing sand cap over an area of approximately 26,250 square feet (ft^2). This results in approximately 500 cubic yards (cy) of dredged material for Alternative 1. Alternatives 2 and 3 are based on 1.5 feet of average removal (removal depth would vary due to slope) for approximately 1,500 cy of dredged material.

- **RCM Capping Area.** This area is estimated to be approximately 26,250 ft^2 based on the results of the Final NAPL Investigation Report and USEPA comments requiring RCM be installed from T9+00 to T12+50. RCMs are available in units of 100 feet by 15 feet and in custom sizes at a higher unit cost; however, using the standard sizes of RCM would be most practical for this project. Most of the capping area will include two layers of RCM with three layers of RCM assumed for areas with higher potential NAPL migration (approximately T10+50 to T11+50). We estimate it will take approximately 72,000 ft^2 of mat to place two layers of RCM over 26,250 ft^2. The estimated total square footage of RCM, including the third layer of RCM in areas with higher potential NAPL migration (T10+50 to T11+50), is 81,000 ft^2. This area accounts for 1 foot of overlap between each mat and approximately 5 feet of mat for each bank for anchoring. The actual extent and layout will be confirmed during design.

- **Sand Capping Volumes.** The total sand capping volume includes 6 inches of sand to be placed over the RCM in the 26,250 ft^2 affected area, approximately 500 cy.

- **Horizontal Permeable Barrier.** Based on the configuration shown on Figures 4-3 and 4-5 for Alternatives 2 and 3, the volume of horizontal permeable barrier is approximately 1,000 cy, assuming an average 1 foot of coarse material placed under the RCM and 6 inches of sand cap.

- **Vertical Permeable Barrier.** The dimensions of the vertical permeable barrier (Alternative 3) are assumed to be 100 feet long (Figure 4-5) by 3 feet wide by 25 feet deep, which results in an excavation and backfill volume of approximately 275 cy.

- **Disposal Volumes.** Based on our experience at other MGP sites and contact with ESMI of New Hampshire, a waste treatment facility, material dredged from the cap is eligible for thermal desorption treatment at ESMI following its dewatering and stabilization with Portland Cement as long as the dredged material contains minimal peat. Remaining dredged material would require disposal at a Subtitle D landfill. After decanting free liquids and handling them separately, we anticipate that solidification/stabilization with lime or Portland Cement will be needed to meet requirements for the paint filter test. The cost of adding Portland Cement will be considered in greater detail during the design phase when an appropriate admixture ratio will be determined. The disposal volumes for Alternatives 1 and 2 are the same as the dredge volumes for these two alternatives (500 cy and 1,500 cy). The disposal volume for Alternative 3 would include the dredge volume (1,500 cy) and the volume of material excavated from the vertical barrier (275 cy).

- **Duration of Project.** For preliminary planning purposes, we assume in this cost estimate that the project duration will be 3 months. A detailed schedule will be developed during design.

- **Construction Contingencies.** Because of the significant number of unknowns in the estimate, a contingency of 25 percent is applied to all three alternatives, which is consistent with our experience on other projects at a conceptual level of design.

C-3 Capital Costs

C-3.1 Mobilization/Demobilization

Our cost estimate for mobilization/demobilization assumes the following:

- **Mobilization/Demobilization.** Costs of $110,000 to $180,000 were assumed for Alternatives 1 through 3. These costs are based on recent bidding for the capping project at the McCormick and Baxter Superfund Site in Portland Harbor, Portland, Oregon and on our experience, which indicates that the cost of mobilization/demobilization will be approximately 6 to 10 percent of the direct capital costs. The lower cost is more applicable to less complex sites, so we have assumed approximately 10 percent of the subtotal capital cost for the purpose of this cost estimate for all alternatives. Mobilization/demobilization includes the contractor’s cost to transport equipment to the site and provide temporary facilities and staging areas, or staging area components, depending on cost breakdown.

- **Staging Area.** An on-site staging area will be required for excavated materials and to provide space to stockpile clean material. Staging immediately adjacent to the canal is not a practical alternative, so material handling will include a short haul cost in addition to the costs associated with preparing the staging area and dismantling/disposal costs, which will be considered in greater detail during design.

For the purpose of this cost estimate, we assume that mobilization costs will include the cost of constructing a staging area.

- **Additional Site Access for Alternative 3.** The additional cost of site access for Alternative 3 is included in the mobilization/demobilization lump sum. Alternative 3 requires clearing of vegetation, a staging area (or possibly use of the existing parking lot) for stockpiling the excavated material and backfill barrier materials, and temporary timber or specialty road mats. The cost of temporary mats is estimated to be approximately $15,000 for 1 month based on the information discussed below.

    - Alternative 3 requires access for either conventional equipment of smaller size or low ground pressure equipment on the east bank of the canal. Temporary road mats will be installed to allow access to the banks; the mats will be approximately 200 feet in length for the east bank. The Johnson Company previously rented temporary road mats from Mabey Shore and Bridge, Inc. The Dura-Base mats are made of high-density polyethylene, weigh about 1,050 pounds, are 4 inches thick, and are 8 feet by 14 feet. A lip along the edge of each mat allows the mats to be pinned together using a dowel. Alternatively, our experience has shown that timber mats can be double-stacked in a lightweight yet stable configuration.

    - The cost to rent the temporary road mats is approximately $57.25/mat/week, but a 30 percent discount may be applied due to the number of mats and the length of time they will be used (Mabey Shore and Bridge, Inc., January 2007). Approximately 25 mats will be needed to run the east bank length of 200 feet (which includes turnaround space). On a weekly basis, the mats will cost approximately $1,500 for the east bank. Additional costs for previous projects by The Johnson Company included flat-bed transport to the site: 40 mats/truckload, $1,200 for pickup and delivery per truck ($2,400); placement of mats, including excavator, small bucket, and labor; on-site cleaning (scraping mud off the mats is assumed to be sufficient; we assume power washing will not be needed); and a premium for damage because the mats froze in place (difficult to predict, but the mats cost $2,000 each from Dura-Base).

- **Contractor Work Plans.** Costs of $30,000 (Alternative 1) and $50,000 (Alternatives 2 and 3) were assumed for the preparation of miscellaneous work plans. This value is based on experience on the Thea Foss Waterway and Hylebos Waterway projects in Tacoma, Washington, as well as on bid information for the McCormick and Baxter capping project, for which the cost ranged from about $60,000 to $300,000. We based the range of $30,000 to $50,000 for the Pine Street project on our judgment of the project type and size relative to the projects referenced above. The contractor will be required to prepare a dredge/cap plan, sediment management/disposal plan, construction quality control plan, environmental protection plan, and health and safety plan.

C-3.2 Site Preparation

Our cost estimate for site preparation assumes the following:

- **Temporary Facilities.** All alternatives require a reasonably sized area for a site trailer and access to the parking lot near the turning basin. This was estimated at a lump sum of $50,000. The items needed include temporary fencing, silt fencing for sedimentation control, hay bales to control the flow of free liquid from the sediment, Jersey barriers to separate clean and contaminated sediment, and possibly lining or repaving of the parking lot. Flashboards may be required to raise the height of the weir and water level in the canal.

- **Erosion Control.** For Alternatives 1 and 2, the lump sum estimate of $15,000 includes labor, equipment, and materials necessary to install silt fencing to encompass the work and support areas. For Alternative 3, the lump sum cost is estimated to be $30,000 because of the additional work on the bank.

C-3.3 Dredging

Our cost estimate for micro-dredging assumes the following:

- **Dredging.** A contractor (Northwest Underwater Construction, May 11, 2008) provided a lump sum quote for diver dredging of 26,250 ft2 of sediment to a depth of 6 inches (500 cy) or 18 inches (1,500 cy). The lump sum quote for Alternative 1 (500 cy) is approximately $61,500 with an estimated duration of 5 days. The lump sum quote for Alternatives 2 and 3 (1,500 cy) is approximately $103,000 with an estimated duration of 8 days. This contractor's cost estimate for mobilization was approximately $17,500. It is assumed that a barge will also be needed to handle dredged materials. Based on cost data from the NAPL Investigation, we estimate that a barge will cost $1,100 per day plus $2,000 to set and remove the barge. Because the contractor has not had an opportunity to carefully evaluate the Pine Street Canal site, an estimate based on contract documents could be higher. However, the contractor has completed several similar projects in the Northwest and in the Great Lakes regions; generally, these projects involved dredging of sediment caps to remove contamination with dredging depths varying from several inches to several feet (Northwest Underwater Construction, 2008). The quote indicates that dredging would be conducted to +/- 1 inch of the specification.

- **Water Quality Control Measures.** A lump sum of $15,000 was assumed based on discussions with silt curtain vendors for other projects combined with our engineering judgment. This cost could be significantly underestimated depending on the approach required, which will be determined during design.

- **Dredging Verification.** Dredging verification includes post-dredge verification using multi-beam bathymetric surveys. The cost of multi-beam bathymetric surveys is approximately $\$0.02/ft^2$ based on our experience with other projects, which results in an estimate for this project of $1,000, but there is a minimum cost requirement. A cost of $10,000 may be more accurate for the Pine Street Canal site.

C-3.4 Sediment Pre-Treatment and Water Management

A unit cost of $65/cy of dredged material is estimated for sediment pre-treatment and water management based on average costs from the Fox River, Wisconsin, demonstration project ($30/cy for dewatering and $30/cy for water treatment). The unit cost for this project is estimated to be greater because of the possibility that the dredged material will have higher water content. This cost includes the use of equipment for sediment offloading, sediment handling, dewatering of sediment, water treatment, possible addition of stabilization materials, and water sampling. Landfill disposal typically requires a final moisture content of less than 50 percent.

C-3.5 Waste Disposal

ESMI, a thermal treatment facility, provided unit costs for thermal treatment of the dredged material: $46 per ton for treatment and $26 per ton for transportation, for a total of $72 per ton or $115 per cy (sediment) (ESMI of New Hampshire, May 16, 2007). A conversion of 1.6 tons per cubic yard is assumed for sediment. This unit cost of $115/cy is used for the disposal of micro-dredged sediment for all of the alternatives. ESMI indicated that peat material, such as the material which would be excavated during construction of the vertical barriers on the banks, may require conditioning or pre-treatment. If this peat material cannot be treated at the thermal treatment facility, then this material may be disposed at a Subtitle D landfill. Bids received for disposal of similar material for the Salem MGP project ranged from approximately $120 per cy to $140 per cy. Because the peat material excavated from the vertical barrier will be saturated, stabilization may be required prior to disposal; an additional $10/cy is assumed for stabilization of the material excavated from the vertical barrier, based on previous project experience. For Alternative 3, a unit cost of $150 per cy is assumed for stabilization, transportation, and treatment or disposal of the material removed from excavations for the vertical barrier.

C-3.6 Capping

Our cost estimate for capping assumes the following:

- **Sand Capping.** The unit cost of $45/cy for sand capping, including materials ($30 to $35/cy) and installation ($10/cy), was selected based on experience at the McCormick & Baxter site in Portland, Oregon, and a manufactured gas plant site in Salem, Massachusetts. The 2008 RSMeans Manual lists a unit cost of $33.50/cy for sand (material only), screened and washed at the pit, including a 10-mile haul.

- **Capping Verification.** The cost of capping verification is based on the same rationale as that applied to the cost of dredging verification (refer to Section C-3.3) and includes bathymetric surveys. A total cost of $10,000 was assumed for capping verification. Additional cap verification activities may be required beyond this assumption, which will be determined during the design.

- **RCM Capping.** The material unit cost of $1.60/ft^2 was quoted by CETCO, the vendor. The installation cost for previous projects has ranged from approximately $4 to $10/ft^2 for installation in shallow water (McCormick & Baxter site in Portland, Oregon, Salem MGP site, and Anacostia Demonstration Project). Therefore, a unit cost of $7/ft^2 is assumed for RCM installation cost.

C-3.7 Horizontal Permeable NAPL Barrier

Our cost estimate for the horizontal permeable NAPL barrier assumes the following:

- **Horizontal Permeable Barrier.** We assumed a unit cost of approximately $50/cy for the barrier media based on the materials most likely to be selected for the barrier material (pumice, recycled glass, or expanded shale). The installation unit cost is estimated to be approximately $15/cy based on 150 percent of the cost of installing sand capping.

- **Biaxial Geogrid or Microgrid**. The cost of this material, used to separate the horizontal permeable NAPL barrier layer from the underlying peat, is approximately $1.20/ft^2; this estimate is based on our experience and adjusted slightly to approximate implementation for conditions at the Pine Street Canal site.

- **NAPL Collection System.** The cost of the horizontal barrier collection system (i.e., piping and clean-outs material and installation) is estimated to be $60,000 based on passively removing NAPL without pumping. Depending on the feasibility to passively remove NAPL from the pipes using a relatively straightforward approach (e.g., a customized pipe cleanout or equivalent) then the costs could increase with level of complexity. Currently, the cost is based on an assumption that this system is approximately the same cost of the vertical permeable barrier collection system. If the design were to require fine grading to slope the pipe, and/or if complexities such as those mentioned above occur, then the costs would change to reflect these conditions.

C-3.8 Vertical Permeable NAPL Barrier

Our cost estimate for the vertical permeable NAPL barriers assumes the following:

- **Vertical Permeable Barrier.** The barriers will be installed using a biopolymer method. The unit cost of $20 to $30/ft2, including liner, is based on discussions with Geosolutions (April 2007); however, Geosolutions indicated that additional studies of the peat will be required to determine the suitability of the biopolymer method and provide design-level information. Based on a length of 100 feet, a width of 3 feet, and a depth of 25 feet, the volume of material to be excavated is approximately 275 cy. It is assumed that the same media selected for the horizontal barrier would be used in the vertical barrier. The following table provides a cost analysis of barrier construction methods:

Type of Construction		
Biopolymer	**$/ft^2**	**Cost**
Construction cost/ft2	$20 to $30	$50,000 to $75,000
Based on unit cost for construction including liner from Geosolutions, April 2007		
Continuous Trenching	**Cost**	
Mobilization and Construction	$75,000	
Does not include rock, dewatering, platform for equipment access; (3) based on rough estimate provided by Dewind Dewatering of $150,000 for 250 ft trench		
Sheet Pile Walls	**$/100 lbs**	**Cost/barrier**
Sheet Pile (Material only)	$69.85	$150,000
Assumes 40-foot-long (deep) sheets for 100 feet; material quote from Skyline Steel, 2/28/07		

- **Biaxial Geogrid or Microgrid**. The cost of this material, which would be used to line the vertical barrier to provide support for the sidewalls, is approximately $1.20/ft^2, as described for a horizontal barrier. It is estimated that approximately 5,000 ft^2 of geogrid would be required.

- **NAPL Collection System.** The cost estimate of $20,000 includes labor, equipment, and materials necessary to install a passive system (piping and sump) to recover NAPL from the permeable barrier and a coarse cap layer and is based on cost experience with previous projects.

- **Water Quality Control during Construction.** Construction of the vertical barrier on the east bank may affect subsurface NAPL. During construction of the NAPL barrier, water quality control measures would be in place to mitigate NAPL seepage. This is estimated to cost approximately $15,000.

C-3.9 Site Restoration

- Alternatives 1 and 2. Site restoration for these alternatives would include restoration of portions of the bank and canal impacted by the dredging and capping. The lump sum estimate is $15,000 for site restoration for Alternatives 1 and 2.

- Alternative 3. Additional restoration would be required for Alternative 3, potentially including restoration of areas of the east bank cleared for access and areas impacted by temporary road mats (swamp mats). The lump sum estimate is $30,000 for site restoration for Alternative 3.

The degree of site restoration required for the selected alternative will be refined during design.

C-3.10 Professional/Technical Services Indirect Capital Costs

Our cost estimate for indirect capital costs associated with professional and technical services was made using the USEPA's rule-of-thumb percentages of total project capital cost (USEPA 2000). The percentages for projects with capital costs ranging from $500,000 to $2,000,000 (i.e., Alternatives 1, 2, and 3) are:

- Project management, 6 percent
- Remedial design, 12 percent
- Construction management, 8 percent

C-4 Long-Term Operation, Maintenance, and Monitoring Costs

For each alternative, the long-term operation, maintenance, and monitoring (OMM) costs were estimated for a 30-year period. The OMM plan for the selected alternative will be written during design. Conceptual level OMM descriptions were used for estimating the costs. As with the capital costs, these are estimates are intended to represent the estimated cost within an accuracy range of -30 percent to + 50 percent.

C-4.1 Assumptions

- **Monitoring Schedule.** For all three alternatives, it is assumed that there would be six monitoring events per year for the first 2 years following construction (years 1 and 2), followed by four monitoring events per year for the following 3 years (years 3 through 5), and finally, followed by two monitoring events per year for the remaining 25 years (years 6 through 30). It is also assumed that there will not be destructive monitoring of the RCM because this would destroy the integrity of the cap and increase the potential for NAPL seepage.

- **Passive sheen monitoring.** For all three of the alternatives, it is assumed that passive sheen monitoring would be conducted twice per year for the first 2 years (years 1 and 2), once per year for the following 3 years (years 3 through 5) and once every 5 years thereafter (years 10, 15, 20, 25, and 30). Passive sheen sampling would be conducted between June and October, when the canal is not frozen and during the month(s) with the highest observed historical NAPL seepage rates.

- **NAPL observations and collection.** For Alternatives 2 and 3, it is assumed that the NAPL barriers would be included in the regular monitoring schedule and that NAPL would be removed semi-annually. The actual NAPL removal schedule would be determined based on monitoring of accumulated NAPL.

- **RCM Replacement.** For the purposes of cost estimating, the replacement intervals and areas for the RCM are estimated based on the theoretical design life of an RCM (Section 3.2.1) and the evaluation of performance of the horizontal and vertical barriers (Sections 4.2.6 and 4.3.6). However, it is important to note that these are theoretical replacement intervals and areas, and are intended to show the relative difference in RCM life and OMM costs among the alternatives. Design of the selected alternative will optimize the life of the RCM based on data gathered in the Pre-Design Investigation and the NAPL Investigation. The RCM replacement interval for each Alternative is described below:

  - **Alternative 1:** Based on the theoretical design life of an OC RCM and the average seepage rate of approximately 7 kg/yr, two layers of mat would last approximately 32 years. Thus, for areas of the canal with a seepage rate of less than or equal to 7 kg/yr, it is assumed that this area would not require replacement within the 30-year period. The area requiring replacement within 30 years is estimated to be approximately one third the NAPL controls area (8,750 ft2 of the canal), based on observed NAPL seepage rates of greater than 7 kg/yr. For the cost estimate, it is assumed this area would be replaced every 10 years based on the theoretical design life for the three layers of RCM and the maximum observed seepage rate. In summary, it is assumed that approximately 8,750 ft2 of the area of NAPL controls will be replaced every 10 years.

  - **Alternatives 2 and 3:** Based on the evaluation of the performance of the horizontal and vertical barriers presented in the report, Alternatives 2 and 3 are assumed to have the same RCM replacement intervals and areas. The horizontal barrier would extend the life of the RCM by approximately 95 percent based on the performance evaluation. Thus, it is assumed for Alternatives 2 and 3 that the RCM would not require replacement for more than 100 years.

C-4.2 Annual OMM Costs

- **RCM.** Each monitoring event would include visual observations of the canal water surface, sand cap surface, and quantitative sheen/breakthrough sampling. The cost for each monitoring event is estimated to be $4,000. This cost includes labor, expendables, and laboratory costs. This cost is included for all three of the alternatives.

- **Horizontal NAPL barrier (Cap collection system O&M).** Each monitoring event would include inspection of the system to determine if maintenance is required and gauging of the NAPL collection system to determine the amount of accumulated NAPL. The monitoring cost for the cap collection system is estimated to be approximately $2,000 per event. The cost for removal of accumulated NAPL from the collection system is estimated to be approximately $5,000 per NAPL removal event, including waste disposal. These costs are included for Alternatives 2 and 3.

- **Vertical NAPL barrier (Vertical collection system O&M).** The OMM cost for the vertical NAPL barrier is assumed to be the same as that for the horizontal barrier. This cost is included for Alternative 3.

- **Passive Sheen/Breakthrough Monitoring.** Each sheen monitoring event would require two site visits: one visit to deploy the sheen monitoring devices and a second visit to remove the sheen monitoring devices for laboratory analysis. Sheen monitoring would be conducted in the area of NAPL controls as well upstream of this area (background/control). Specific locations and monitoring procedures will be determined during design. The cost of a sheen monitoring event is estimated to be approximately $30,000, which includes labor, laboratory costs, and equipment.

- **Reporting.** A lump sum yearly reporting cost of $25,000 was assumed for the first 2 years of monitoring. A lump sum yearly reporting cost of $20,000 was assumed for the last 28 years of monitoring.

C-4.3 Periodic OMM Costs

- **OMM Mobilization and Equipment.** There would be periodic (every 5 years) mobilization and equipment costs. These costs were estimated to be a lump sum of approximately $20,000. This cost applies to all three alternatives.

- **Passive Sheen Monitoring.** As described above, during years 6 through 30, passive sheen monitoring would no longer be annual but would be a periodic cost during years 10, 15, 20, 25, and 30.

- **RCM Replacement.** The cost of replacing the RCM was estimated as the capital unit cost of Alternative 1 (the total capital cost divided by 26,000 ft2), which is approximately $69/ft2. This unit cost for RCM replacement was used in conjunction with the assumed replacement intervals and areas for each alternative.

C-5 References

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TABLE C-1
UNIT COSTS

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

Description	Unit	Unit Cost	Notes
MOBILIZATION / DEMOBILIZATION			
Diver Micro-dredging Mobilization	LS	$17,500	
SITE PREPARATION			
Temporary Fencing	LF	$6	
Hay Bales	LF	$3	
Silt Fence	LF	$1	
Asphalt Pavement	SF	$1	
Temporary Road Mat (8' x 14')	week	$57	Not including delivery or placement
DREDGING, TRANSPORT, & DISPOSAL			
Barge	day	$1,100	
Crane - Set and Remove Barge	LS	$2,000	Based on site experience
Diver Micro-dredging	LS (6")	$61,500	Lump sum costs for 6-in and 18-in of dredging over 26,250 SF
Diver Micro-dredging	LS (18")	$103,000	
Sediment and Water Management	CY	$65	
Solid Waste Disposal and/or Treatment (Peat Material)	CY	$150	Including transportation and stabilization
Soil Treatment and Disposal (dewatered dredged material)	CY	$115	Including transportation
Bathymetric Survey	SF	$0.02	A minimum cost will be involved.
CAPPING			
RCM (organoclay)	SF	$1.60	Based on updated quote in 2008
RCM Installation	SF	$7	
Sand Cap (Material & Installation)	ton	$45	
Microgrid/Geotextile (installed cost)	SF	$1.20	Installed cost
Diver Survey	week	$4,000	
PERMEABLE BARRIER			
Expanded Perlite	CY	$57	Ranges from $340 to $1,060 per ton
Expanded Shale	CY	$44	Including delivery from NY to VT
Recycled Glass	CY	$0	Currently free in Burlington area, only cost is delivery (limited reduction in weight)
Plastic Media	CY	$300	Lantec
Coke Nut	CY	$185	Including delivery and 18% fuel surcharge, size 1 1/4" X 3/4"
Pumice	CY	$15	Not including delivery from Idaho
HDPE Membrane[1]	SF	$1.50	Installed cost
Sheet Pile	ton	$1,400	Material only
Biopolymer Barrier Construction	SF	$30	Including liner for a trench up to 40 ft deep
Gravel	ton	$10	Not including delivery (15-30 miles away)
Barrier Backfill Material (installed)	ton	$250	Assuming coke nut is backfill material

Notes:
CY = cubic yards
CF = cubic feet
SF = square feet
LF = Linear foot
LS = lump sum
1. ECHOS, 2006. Environmental Remediation Cost Data – Unit Price. 12th Ed.

TABLE C-2
ALTERNATIVE 1 COST ESTIMATE

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

CAPITAL COST

Description	Quantity	Unit	Unit Cost	Total
MOBILIZATION/DEMOBILIZATION				
Mobilization and demobilization	1	LS	$110,000	$110,000
Contractor work plans	1	LS	$30,000	$30,000
SUBTOTAL				$140,000
SITE PREPARATION				
Erosion controls	1	LS	$15,000	$15,000
Temporary facilities	1	LS	$50,000	$50,000
SUBTOTAL				$65,000
DREDGING, TRANSPORT, & DISPOSAL				
Micro-dredging	1	LS	$61,500	$61,500
Barge	5	day	$1,100	$5,500
Crane - set and remove barge	1	LS	$2,000	$2,000
Sediment and water management	500	CY	$65	$32,500
Sediment disposal	500	CY	$115	$57,500
Water quality control	1	LS	$15,000	$15,000
Bathymetric survey	1	LS	$10,000	$10,000
SUBTOTAL				$184,000
CAPPING				
RCM product	81,000	SF	$1.60	$129,600
RCM installation	81,000	SF	$7.00	$567,000
Sand cap (material & installation)	500	CY	$45.00	$22,500
Cap verification	1	LS	$10,000	$10,000
Diver survey	1	week	$4,000	$4,000
SUBTOTAL				$733,100
SITE RESTORATION				
Site restoration	1	LS	$15,000	$15,000
SUBTOTAL				$15,000
SUBTOTAL				$1,137,100
Contingency	25%			$284,275
SUBTOTAL				$1,421,375
Project management	6%			$85,283
Remedial design	12%			$170,565
Construction management	8%			$113,710
TOTAL CAPITAL COST (Rounded up to next $100,000)				**$1,800,000**

TABLE C-2
ALTERNATIVE 1 COST ESTIMATE

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

OPERATION, MAINTENANCE & MONITORING COSTS (ANNUAL)

Description	Quantity	Unit	Unit Cost	Total
Years 1-2				
Cap Monitoring Visits	6	events	$4,000	$24,000
Sheen/breakthrough monitoring	2	events	$30,000	$60,000
Reporting	1	LS	$25,000	$25,000
TOTAL ANNUAL OMM COSTS (Years 1-2)				**$109,000**
Years 3-5				
Cap Monitoring Visits	4	events	$4,000	$16,000
Sheen/breakthrough monitoring	1	events	$30,000	$30,000
Reporting	1	LS	$20,000	$20,000
TOTAL ANNUAL OMM COSTS (Years 3-5)				**$66,000**
Years 6-30				
Cap Monitoring Visits	2	events	$4,000	$8,000
Reporting	1	LS	$20,000	$20,000
TOTAL ANNUAL OMM COSTS (Years 6-30)				**$28,000**

PERIODIC COSTS

Description	Year	Quantity	Unit	Unit Cost	Total
OMM Mobilization and Equipment	1	1	LS	$20,000	$20,000
OMM Mobilization and Equipment	6	1	LS	$20,000	$20,000
Replacement of RCM	10	8,750	SF	$69	$603,750
Sheen/breakthrough monitoring	10	1	event	$30,000	$30,000
OMM Mobilization and Equipment	11	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	15	1	event	$30,000	$30,000
OMM Mobilization and Equipment	16	1	LS	$20,000	$20,000
Replacement of RCM	20	8,750	SF	$69	$603,750
Sheen/breakthrough monitoring	20	1	event	$30,000	$30,000
OMM Mobilization and Equipment	21	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	25	1	event	$30,000	$30,000
OMM Mobilization and Equipment	26	1	LS	$20,000	$20,000
Replacement of RCM	30	8,750	SF	$69	$603,750
Sheen/breakthrough monitoring	30	1	event	$30,000	$30,000

TABLE C-2
ALTERNATIVE 1 COST ESTIMATE

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

PRESENT VALUE ANALYSIS

Year	Capital Cost	Annual Cost	Periodic Cost	Total Cost Per Year	Discount Factor (7 %)	Present Value
0	$1,800,000	$0	$0	$1,800,000	1	$1,800,000
1	$0	$109,000	$20,000	$129,000	0.93	$120,561
2	$0	$109,000	$0	$109,000	0.87	$95,205
3	$0	$66,000	$0	$66,000	0.82	$53,876
4	$0	$66,000	$0	$66,000	0.76	$50,351
5	$0	$66,000	$0	$66,000	0.71	$47,057
6	$0	$28,000	$20,000	$48,000	0.67	$31,984
7	$0	$28,000	$0	$28,000	0.62	$17,437
8	$0	$28,000	$0	$28,000	0.58	$16,296
9	$0	$28,000	$0	$28,000	0.54	$15,230
10	$0	$28,000	$633,750	$661,750	0.51	$336,400
11	$0	$28,000	$20,000	$48,000	0.48	$22,804
12	$0	$28,000	$0	$28,000	0.44	$12,432
13	$0	$28,000	$0	$28,000	0.41	$11,619
14	$0	$28,000	$0	$28,000	0.39	$10,859
15	$0	$28,000	$30,000	$58,000	0.36	$21,022
16	$0	$28,000	$20,000	$48,000	0.34	$16,259
17	$0	$28,000	$0	$28,000	0.32	$8,864
18	$0	$28,000	$0	$28,000	0.30	$8,284
19	$0	$28,000	$0	$28,000	0.28	$7,742
20	$0	$28,000	$633,750	$661,750	0.26	$171,009
21	$0	$28,000	$20,000	$48,000	0.24	$11,593
22	$0	$28,000	$0	$28,000	0.23	$6,320
23	$0	$28,000	$0	$28,000	0.21	$5,907
24	$0	$28,000	$0	$28,000	0.20	$5,520
25	$0	$28,000	$30,000	$58,000	0.18	$10,686
26	$0	$28,000	$20,000	$48,000	0.17	$8,265
27	$0	$28,000	$0	$28,000	0.16	$4,506
28	$0	$28,000	$0	$28,000	0.15	$4,211
29	$0	$28,000	$0	$28,000	0.14	$3,936
30	$0	$28,000	$633,750	$661,750	0.13	$86,932

TOTAL PRESENT VALUE OF ALTERNATIVE (Rounded up to next $100,000) **$3,100,000**

TABLE C-3
ALTERNATIVE 2 COST ESTIMATE

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

CAPITAL COST

Description	**Quantity**	**Unit**	**Unit Cost**	**Total**
MOBILIZATION/DEMOBILIZATION				
Mobilization and demobilization	1	1	$160,000	$160,000
Contractor work plans	1	1	$50,000	$50,000
SUBTOTAL				$210,000
SITE PREPARATION				
Erosion controls	1	LS	$15,000	$15,000
Temporary facilities, access	1	LS	$50,000	$50,000
SUBTOTAL				$65,000
DREDGING, TRANSPORT, & DISPOSAL				
Micro-dredging	1	1	$103,000	$103,000
Barge	10	day	$1,100	$11,000
Crane - set and remove barge	1	LS	$2,000	$2,000
Sediment and water management	1,500	CY	$65	$97,500
Sediment disposal	1,500	CY	$115	$172,500
Water quality control	1	LS	$15,000	$15,000
Bathymetric survey	1	LS	$10,000	$10,000
SUBTOTAL				$411,000
CAPPING				
RCM product	81,000	SF	$1.60	$129,600
RCM installation	81,000	SF	$7.00	$567,000
Sand cap (material & installation)	500	CY	$45.00	$22,500
Coarse layer material	1,000	CY	$50.00	$50,000
Coarse layer installation	1,000	CY	$15.00	$15,000
Separation microgrid/geotextile	26,250	SF	$1.20	$31,500
NAPL passive collection system	1	LS	$60,000	$60,000
Cap verification	1	LS	$10,000	$10,000
Diver survey	2	week	$4,000	$8,000
SUBTOTAL				$893,600
SITE RESTORATION				
Site restoration	1	LS	$15,000	$15,000
SUBTOTAL				$15,000
SUBTOTAL				$1,594,600
Contingency	25%			$398,650
SUBTOTAL				$1,993,250
Project management	6%			$119,595
Remedial design	12%			$239,190
Construction management	8%			$159,460
TOTAL CAPITAL COST (Rounded up to next $100,000)				**$2,600,000**

TABLE C-3
ALTERNATIVE 2 COST ESTIMATE

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

OPERATION, MAINTENANCE & MONITORING COSTS (ANNUAL)

Description	Quantity	Unit	Unit Cost	Total
Years 1-2				
Cap Monitoring Visits	6	events	$4,000	$24,000
Sheen/breakthrough monitoring	2	events	$30,000	$60,000
Cap collection system monitoring	6	events	$2,000	$12,000
Cap collection system NAPL remova	2	events	$5,000	$10,000
Reporting	1	LS	$25,000	$25,000
TOTAL ANNUAL OMM COSTS (Years 1-2)				**$131,000**
Years 3-5				
Cap Monitoring Visits	4	events	$4,000	$16,000
Sheen/breakthrough monitoring	1	events	$30,000	$30,000
Cap collection system monitoring	4	events	$2,000	$8,000
Cap collection system NAPL remova	2	events	$5,000	$10,000
Reporting	1	LS	$20,000	$20,000
TOTAL ANNUAL OMM COSTS (Years 3-5)				**$84,000**
Years 6-30				
Cap Monitoring Visits	2	events	$4,000	$8,000
Cap collection system monitoring	2	events	$2,000	$4,000
Cap collection system NAPL remova	2	events	$5,000	$10,000
Reporting	1	LS	$20,000	$20,000
TOTAL ANNUAL OMM COSTS (Years 6-30)				**$42,000**

PERIODIC COSTS

Description	Year	Quantity	Unit	Unit Cost	Total
OMM Mobilization and Equipment	1	1	LS	$20,000	$20,000
OMM Mobilization and Equipment	6	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	10	1	event	$30,000	$30,000
OMM Mobilization and Equipment	11	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	15	1	event	$30,000	$30,000
OMM Mobilization and Equipment	16	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	20	1	event	$30,000	$30,000
OMM Mobilization and Equipment	21	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	25	1	event	$30,000	$30,000
OMM Mobilization and Equipment	26	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	30	1	event	$30,000	$30,000

TABLE C-3
ALTERNATIVE 2 COST ESTIMATE

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

PRESENT VALUE ANALYSIS

Year	Capital Cost	Annual Cost	Periodic Cost	Total Cost Per Year	Discount Factor (7 %)	Present Value
0	$2,600,000	$0	$0	$2,600,000	1	$2,600,000
1	$0	$131,000	$20,000	$151,000	0.93	$141,121
2	$0	$131,000	$0	$131,000	0.87	$114,420
3	$0	$84,000	$0	$84,000	0.82	$68,569
4	$0	$84,000	$0	$84,000	0.76	$64,083
5	$0	$84,000	$0	$84,000	0.71	$59,891
6	$0	$42,000	$20,000	$62,000	0.67	$41,313
7	$0	$42,000	$0	$42,000	0.62	$26,155
8	$0	$42,000	$0	$42,000	0.58	$24,444
9	$0	$42,000	$0	$42,000	0.54	$22,845
10	$0	$42,000	$30,000	$72,000	0.51	$36,601
11	$0	$42,000	$20,000	$62,000	0.48	$29,456
12	$0	$42,000	$0	$42,000	0.44	$18,649
13	$0	$42,000	$0	$42,000	0.41	$17,429
14	$0	$42,000	$0	$42,000	0.39	$16,288
15	$0	$42,000	$30,000	$72,000	0.36	$26,096
16	$0	$42,000	$20,000	$62,000	0.34	$21,002
17	$0	$42,000	$0	$42,000	0.32	$13,296
18	$0	$42,000	$0	$42,000	0.30	$12,426
19	$0	$42,000	$0	$42,000	0.28	$11,613
20	$0	$42,000	$30,000	$72,000	0.26	$18,606
21	$0	$42,000	$20,000	$62,000	0.24	$14,974
22	$0	$42,000	$0	$42,000	0.23	$9,480
23	$0	$42,000	$0	$42,000	0.21	$8,860
24	$0	$42,000	$0	$42,000	0.20	$8,280
25	$0	$42,000	$30,000	$72,000	0.18	$13,266
26	$0	$42,000	$20,000	$62,000	0.17	$10,676
27	$0	$42,000	$0	$42,000	0.16	$6,759
28	$0	$42,000	$0	$42,000	0.15	$6,317
29	$0	$42,000	$0	$42,000	0.14	$5,904
30	$0	$42,000	$30,000	$72,000	0.13	$9,458

TOTAL PRESENT VALUE OF ALTERNATIVE (Rounded up to next $100,000) **$3,500,000**

TABLE C-4
ALTERNATIVE 3 COST ESTIMATE

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

CAPITAL COST

Description	Quantity	Unit	Unit Cost	Total
MOBILIZATION/DEMOBILIZATION				
Mobilization and demobilization	1	1	$180,000	$180,000
Contractor work plans	1	1	$50,000	$50,000
SUBTOTAL				$230,000
SITE PREPARATION				
Erosion controls	1	LS	$30,000	$30,000
Temporary facilities, access	1	LS	$50,000	$50,000
Access to east bank	1	LS	$15,000	$15,000
SUBTOTAL				$95,000
DREDGING, TRANSPORT, & DISPOSAL				
Micro-dredging	1	1	$103,000	$103,000
Barge	10	day	$1,100	$11,000
Crane - set and remove barge	1	LS	$2,000	$2,000
Sediment and water management	1,500	CY	$65	$97,500
Sediment disposal	1,500	CY	$115	$172,500
Water quality control	1	LS	$15,000	$15,000
Bathymetric Survey	1	LS	$10,000	$10,000
SUBTOTAL				$411,000
CAPPING				
RCM product	81,000	SF	$1.60	$129,600
RCM installation	81,000	SF	$7.00	$567,000
Sand cap (material & installation)	500	CY	$45.00	$22,500
Coarse layer material	1,000	CY	$50.00	$50,000
Coarse layer installation	1,000	CY	$15.00	$15,000
Separation microgrid/geotextile	26,250	SF	$1.20	$31,500
NAPL passive collection system	1	LS	$60,000	$60,000
Cap verification	1	LS	$10,000	$10,000
Diver survey	2	week	$4,000	$8,000
SUBTOTAL				$893,600
VERTICAL PERMEABLE BARRIER				
Permeable barrier backfill material	275	CY	$50.00	$13,750
Biopolymer construction	2,500	SF	$30.00	$75,000
Separation microgrid/geotextile	5,000	SF	$1.20	$6,000
NAPL passive collection system	1	LS	$20,000	$20,000
Water quality control	1	LS	$15,000	$15,000
Waste stabilization and disposal	275	CY	$150	$41,250
SUBTOTAL				$171,000
SITE RESTORATION				
Site restoration	1	LS	$30,000	$30,000
SUBTOTAL				$30,000
SUBTOTAL				$1,830,600
Contingency	25%			$457,650
SUBTOTAL				$2,288,250
Project management	6%			$137,295
Remedial design	12%			$274,590
Construction management	8%			$183,060
TOTAL CAPITAL COST (Rounded up to next $100,000)				**$2,900,000**

TABLE C-4
ALTERNATIVE 3 COST ESTIMATE

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

OPERATION, MAINTENANCE & MONITORING COSTS (ANNUAL)

Description	Quantity	Unit	Unit Cost	Total
Years 1-2				
Cap Monitoring Visits	6	events	$4,000	$24,000
Sheen/breakthrough monitoring	2	events	$30,000	$60,000
Cap collection system monitoring	6	events	$2,000	$12,000
Cap collection system NAPL removal	2	events	$5,000	$10,000
Vertical barrier monitoring	6	events	$2,000	$12,000
Vertical barrier NAPL removal	2	events	$5,000	$10,000
Reporting	1	LS	$25,000	$25,000
TOTAL ANNUAL OMM COSTS (Years 1-2)				**$153,000**
Years 3-5				
Cap Monitoring Visits	4	events	$4,000	$16,000
Sheen/breakthrough monitoring	1	events	$30,000	$30,000
Cap collection system monitoring	4	events	$2,000	$8,000
Cap collection system NAPL removal	2	events	$5,000	$10,000
Vertical barrier monitoring	4	events	$2,000	$8,000
Vertical barrier NAPL removal	2	events	$5,000	$10,000
Reporting	1	LS	$20,000	$20,000
TOTAL ANNUAL OMM COSTS (Years 3-5)				**$102,000**
Years 6-30				
Cap Monitoring Visits	2	events	$4,000	$8,000
Cap collection system monitoring	2	events	$2,000	$4,000
Cap collection system NAPL removal	2	events	$5,000	$10,000
Vertical barrier monitoring	2	events	$2,000	$4,000
Vertical barrier NAPL removal	2	events	$5,000	$10,000
Reporting	1	LS	$20,000	$20,000
TOTAL ANNUAL OMM COSTS (Years 6-30)				**$56,000**

PERIODIC COSTS

Description	Year	Quantity	Unit	Unit Cost	Total
OMM Mobilization and Equipment	1	1	LS	$20,000	$20,000
OMM Mobilization and Equipment	6	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	10	1	event	$30,000	$30,000
OMM Mobilization and Equipment	11	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	15	1	event	$30,000	$30,000
OMM Mobilization and Equipment	16	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	20	1	event	$30,000	$30,000
OMM Mobilization and Equipment	21	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	25	1	event	$30,000	$30,000
OMM Mobilization and Equipment	26	1	LS	$20,000	$20,000
Sheen/breakthrough monitoring	30	1	event	$30,000	$30,000

TABLE C-4
ALTERNATIVE 3 COST ESTIMATE

FINAL NAPL CONTROLS REPORT
PINE STREET CANAL SUPERFUND SITE
BURLINGTON, VERMONT

PRESENT VALUE ANALYSIS

Year	Capital Cost	Annual Cost	Periodic Cost	Total Cost Per Year	Discount Factor (7 %)	Present Value
0	$2,900,000	$0	$0	$2,900,000	1	$2,900,000
1	$0	$153,000	$20,000	$173,000	0.93	$161,682
2	$0	$153,000	$0	$153,000	0.87	$133,636
3	$0	$102,000	$0	$102,000	0.82	$83,262
4	$0	$102,000	$0	$102,000	0.76	$77,815
5	$0	$102,000	$0	$102,000	0.71	$72,725
6	$0	$56,000	$20,000	$76,000	0.67	$50,642
7	$0	$56,000	$0	$56,000	0.62	$34,874
8	$0	$56,000	$0	$56,000	0.58	$32,593
9	$0	$56,000	$0	$56,000	0.54	$30,460
10	$0	$56,000	$30,000	$86,000	0.51	$43,718
11	$0	$56,000	$20,000	$76,000	0.48	$36,107
12	$0	$56,000	$0	$56,000	0.44	$24,865
13	$0	$56,000	$0	$56,000	0.41	$23,238
14	$0	$56,000	$0	$56,000	0.39	$21,718
15	$0	$56,000	$30,000	$86,000	0.36	$31,170
16	$0	$56,000	$20,000	$76,000	0.34	$25,744
17	$0	$56,000	$0	$56,000	0.32	$17,728
18	$0	$56,000	$0	$56,000	0.30	$16,568
19	$0	$56,000	$0	$56,000	0.28	$15,484
20	$0	$56,000	$30,000	$86,000	0.26	$22,224
21	$0	$56,000	$20,000	$76,000	0.24	$18,355
22	$0	$56,000	$0	$56,000	0.23	$12,640
23	$0	$56,000	$0	$56,000	0.21	$11,813
24	$0	$56,000	$0	$56,000	0.20	$11,040
25	$0	$56,000	$30,000	$86,000	0.18	$15,845
26	$0	$56,000	$20,000	$76,000	0.17	$13,087
27	$0	$56,000	$0	$56,000	0.16	$9,012
28	$0	$56,000	$0	$56,000	0.15	$8,423
29	$0	$56,000	$0	$56,000	0.14	$7,872
30	$0	$56,000	$30,000	$86,000	0.13	$11,298

TOTAL PRESENT VALUE OF ALTERNATIVE (Rounded up to next $100,000) **$4,000,000**

Appendix D

Performance Standards

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Appendix D – Performance Standards

The Performance Standards (Section VII, Pages 45-53) from the Remedial Design/Remedial Action (RD/RA) Statement of Work (SOW) are attached.

Frequency: Years 1, 3, and 5, Post-construction

6. Cap Interstitial Water Chemistry

a. Location of Sampling
Three seepage meters shall be installed in each of the following Areas: 1, 2, and 8; for a total of nine (9) locations. The meters shall be placed in the deeper water portions of these areas to reduce the potential for ice damage of the meters.

b. Sampling Methods
The methods of purging and sample collection shall be described in the Monitoring Workplan.

c. Frequency
Samples shall be collected from the nine (9) seepage meters a total of three times during the first five years following certification of completion of construction. The first round of sampling shall be performed within 6-9 months (season permitting) following the completion of construction of the cap to reflect baseline conditions. The second and third rounds shall be performed in years 2 ½ and 5, respectively. The need for interstitial water chemistry monitoring after year five shall be reassessed during the five year data review.

d. Analytical Parameters
The water samples from the seepage meters shall be filtered and analyzed for PAHs using EPA Method 8270.

VII. PERFORMANCE STANDARDS

A. Remedy Overall

The Performing Defendants shall design, construct, operate, monitor, and maintain the remedy in compliance with all statutes and regulations identified in Section X of the ROD, and all requirements of the Consent Decree and this SOW.

The Performing Defendants shall achieve the following performance standards for the individual components of the remedy. The performance standards from Section X of the ROD are incorporated herein by reference. If EPA, after reasonable opportunity for review and comment by VTDEC, determines that a performance standard is no longer being attained, it may take additional action consistent with the terms of the Consent Decree.

B. Cap Construction

For Subareas 1, 2, 3, 7, and 8 of the Site, and the area of elevated concentrations of chemicals of concern in the scrub/shrub wetlands south of Subarea 8, the Performing Defendants shall design and implement the remedial component of capping as described in Section III above, in accordance with the performance standards described below.

1. Isolation of Contaminants

The subaqueous cap in Subareas 1, 2, and 8 shall prevent contact between the underlying contaminated sediments and benthic organisms and fish in the biologically active portion of the benthic habitat (1-10 cm) at ecologically harmful levels. It shall be a barrier to the effects of burrowing benthic macroinvertebrate organisms (bioturbation). It shall prevent or minimize the migration of contaminants (by erosion, diffusion, advection or bioturbation) from the contaminated sediments through the cap. It shall also provide resistance to erosion caused by surface water currents, waves caused by wind, ice scouring, and propeller wash, as well as the effects of bioturbation.

Cap materials in Subareas 1, 2, and 8 shall be selected and applied so as to isolate ecological receptors from the contaminated soils and sediments that will remain in place below the cap. Cap thickness, after settling and compaction, shall be sufficient to prevent exposure of benthic organisms that recolonize the cap to underlying contaminants. Increases in the elevation in bottom of the canal and turning basin shall be minimized to the extent possible. The water column above the subaqueous cap shall be maintained at sufficient depth to minimize the potential for cap erosion.

In Subareas 3 and 7, cap materials shall be selected and applied so as to provide a suitable substrate for wetland plant species. Cap materials shall include wetland soils or topsoil without exotic plant seeds (e.g., purple loosestrife, *Phragmites*) and containing 3-4% organic matter. Cap thickness, after settling and compaction, shall be sufficient to prevent exposure to ecological receptors. The cap shall be designed to provide resistance to erosion caused by, waves and propeller wash, as well as the effects of bioturbation from the activities of benthic organisms. Increases in the elevation in the bottom of the Subareas 3 and 7 shall be minimized to the extent possible.

Cover materials for the area of elevated concentrations of contaminants of concern in the scrub/shrub wetlands south of Subarea 8 shall be selected and applied so as to provide a suitable substrate for wetland plant species. The cover material shall include topsoil without exotic plant seeds (e.g., purple loosestrife, *Phragmites*) and containing 3-4% organic matter.

Cover thickness, after settling and compaction, shall be sufficient to prevent exposure of ecological receptors to underlying contaminants.

Long-term monitoring of the physical integrity of the constructed caps and covers in Subareas 1, 2, 3, 7 , and 8, and of the cover in the small area in the scrub/shrub wetlands south of Subarea 8, shall be conducted to ensure that they remain an effective physical barrier to exposure to contaminants. Regular inspections shall be conducted to identify areas of erosion or signs of cap and cover failure.

2. <u>Construction Impacts</u>

The means and methods for capping and covering shall be specified so as to reduce, to the maximum extent possible, impacts to air, surface water, or adjacent wetland areas that are not designated for remediation. Means and methods that reduce the potential for mobilization of underlying contaminated sediments/soils during cap installation, shall be employed. Erosion and sedimentation controls, dust control, and volatile emissions control measures shall be implemented as necessary to limit migration of contaminants and habitat disturbances during cap and cover placement operations and dredging and/or excavation operations (if dredging and/or excavation is necessary).

1. <u>Constructed Cap Integrity</u>

a. Weight of Evidence Data Evaluation

The performance standards for the subaqueous cap involve an evaluation of data using a weight of evidence approach. In summary, if monitoring of the mid-zone of the sediment cap indicates concentrations of copper, lead, mercury, or zinc above the ER-M value (Long, et al., 1995), or a sum of concentrations of the 13 PAHs listed in Table 4 of Long, et al., 1995, above 21 ppm (see Table 1), additional data review and investigation shall be required, as described below. The surface stratum of the cap is defined as 0-10 cm below the sediment surface. The mid-zone of the cap is defined as the middle third of the cap. (For example, for a 3-foot cap, the mid-zone would be between 30 and 60 cm below the cap surface.) Final definition of the mid-cap strata will be made after the As-built Design of the cap has been completed.

(i) If the average of the measured benchmark parameters listed in Table 1 within any sub-area of the capped area exceeds the benchmark value established for the mid-zone, a weight-of-evidence analysis shall take place to determine if the exceedence was caused by failure of the cap. The weight-of-evidence analysis, which is described below, shall take into account the quality of the available data, based on accuracy, reliability and precision of the monitoring data collected for the Long Term Monitoring program and look to the degree of concurrence between lines of evidence.

(ii If contaminant concentration data for one or more individual sampling locations within the midzone of any subarea exceed a benchmark value, but the average of the concentrations within the same subarea do not exceed the benchmark, the location where the exceedence occurred shall be re-sampled as soon as practical and reanalyzed. If the second analysis does not show concentrations above benchmark values, the long term monitoring shall continue on the annual schedule and no further data analysis will be performed.

(iii) If the re-sampling confirms the exceedence of the benchmark ER-M value, the available data for the location shall be evaluated by the Performing Defendants using best professional judgement to determine if a potential problem with cap performance exists. This evaluation shall be presented to the EPA and the Vermont Department of Environmental Conservation for review and consideration. If EPA, after opportunity for review and comment by VT DEC, concurs with the Performing Defendants' analysis that the data do not indicate a potential problem with cap performance, no further data analysis will be performed and normal long term monitoring will continue. If EPA, after opportunity for review and comment by VT DEC, concurs with the Performing Defendants analysis that a potential problem does exist, the Performing Defendants shall commence the full Weight-of-Evidence Analysis. If EPA, after opportunity for review and comment by VT DEC, does not concur with the Performing Defendants recommendation, EPA's decision shall be binding, unless the Performing Defendants invoke the dispute resolution procedures set out in Section XIX of the Consent Decree. See the attached Figure 1 for a schematic diagram of this decision process.

b. Elements of the Weight-of-Evidence Analysis

The weight-of-evidence analysis will be a qualitative analysis that utilizes the existing monitoring data and additional data collected expressly for that analysis including trend analysis. The elements of the weight-of-evidence analysis will be as follows. An asterisk next to the item indicates new data will be collected by the Performing Defendants. All other items will rely on existing data.

- Physical evaluation of the cap integrity
- Bioassay of site sediments - endpoints will be survival and growth for test organisms using whole sediment bioassays*
- Open water benthic macroinvertebrate sample data
- Comparison of chemical, physical, and biological benthic conditions to non-remediated areas of the site and similar environments in the immediate area.
- Trend analysis of sediment chemistry data, including vertical profiles
- Evaluation of stormwater data
- Evaluation of surface water data
- sediment transport monitoring
- groundwater data

Analysis of existing data may indicate the need for additional data collection. Best professional judgement shall be a key factor in data evaluation. The weighting of the lines of evidence shall take into account the accuracy, reliability and precision (i.e. variability) of the available data, concurrence of different lines of evidence, and uncertainties associated with the different lines of evidence.

c. Time Frames for Analysis

The re-sampling for the exceedence of a benchmark at a single point shall be conducted as soon as practical given site and weather conditions. The validated analytical results of a single point exceedence shall be submitted to the EPA and the Vermont DEC within forty-five (45) days of the re-sampling event. The results of a single point exceedence data analysis shall be submitted to the EPA and the Vermont DEC within thirty (30) days of receipt of validated data confirming the benchmark exceedence. The results of a full weight-of-evidence analysis shall be submitted to the EPA and the Vermont DEC within six months of the receipt of the first laboratory results indicating an exceedence.

d. EPA, after reasonable opportunity for review and comment by VT DEC, will review the weight of evidence analysis and determine whether this performance standard has been attained. If EPA determines that this performance standard has not been attained, it may require additional work consistent with the terms of the Consent Decree.

Table 1 Pine Street Canal Superfund Site Cap Monitoring Benchmarks	
Metals	ER-M[1] ppm dry wt.
Copper Benchmark	**270**
Lead Benchmark	**218**
Mercury Benchmark	**0.71**
Zinc Benchmark	**410**
PAHs	ER-M[1] ppb dry wt.
Acenaphthene	500
Acenaphthylene	640
Anthracene	1100
Fluorene	540
2-methyl naphthalene	670
Naphthalene	2100
Phenanthrene	1500
Benzo(a)anthracene	1600
Benzo(a)pyrene	1600
Chrysene	2800
Dibenzo(a,h)anthracene	260
Fluoranthene	5100
Pyrene	2600
Sum of PAHs Benchmark	**21 ppm dry wt.**
1. Long, et al., 1995.	

4. Preservation of Historical Resources

Historic sunken barges and marine railways shall be left in place. Cap materials shall be placed over and around them in such a way as to avoid or minimize harm to the resources to the maximum extent possible. Removal of the barges shall not be attempted. Identification and evaluation of the historic resources at the Site shall be completed. If the barges or any other structure at a portion of the Site are determined to be eligible for listing on the Registry of Historic Places, the impacts of the remedy and construction on these resources shall be mitigated. Remedial activities shall comply with the National Historic Preservation Act of 1966, the Vermont Historic Preservation Law, and Executive Order 11593.

C. Groundwater

1. Chemical

The chemical concentrations that are detected in the groundwater samples collected outside the Class IV groundwater boundary are not expected to exceed Maximum Contaminant Limits (MCLs). If exceedances of MCLs are detected, additional work may be required consistent with the terms of the Consent Decree.

a. Mass Flux

The mass flux of the contaminants migrating in the groundwater beyond the Class IV groundwater boundary shall be estimated. A statistically significant increase in the mass flux shall trigger a detailed data review to determine the cause, significance and additional measures or monitoring that should be implemented.

b. Cross Sectional Area of Contamination

The Performing Defendants shall analyze changes in cross-sectional (north-south cross-section, west of the canal) of the contaminants in the groundwater above MCLs. A statistically significant increase in the cross sectional area will trigger a detailed data review to determine the cause, significance and additional measures or monitoring that should be implemented.

D. Surface Water

1. Construction/Post Construction

By comparing the upstream and downstream physical and chemical parameters, ensure that the engineering controls at the outlet to

Lake Champlain are functioning as intended.

2. Long Term Monitoring
   a. Surface water shall be monitored to ensure protection of the Canal and Lake Champlain and the protectiveness of the remedy over the long term.
   b. The analytical results shall be compared to the ambient water quality criteria (AWQC). Because AWQC are not currently exceeded in the Canal and Lake Champlain, attainment of AWQC is not a performance standard for the remedial action. However, if AWQC are exceeded, those criteria will be considered, along with other relevant factors, to determine whether additional work will be required consistent with the terms of the Consent Decree.

E. **Stormwater Inflow Monitoring**

Performing Defendants shall conduct monitoring to determine whether stormwater may be creating an unacceptable risk to ecological receptors in remediated areas.

F. **Sediment Transport Monitoring**

The Performing Defendants shall prevent sediment transfer to Lake Champlain at levels that would create an unacceptable risk to receptors in Lake Champlain.

G. **Natural Cap**

The Performing Defendants shall monitor the natural capped areas to ensure that they are still functioning to isolate the site specific contamination remaining on site. The performance standard shall be no significant increase in concentration of site related contaminants identified in these areas. If the performance standard is not met, additional work may be required consistent with the terms of the Consent Decree.

H. **Aquatic and Wetlands Habitat Restoration**

Cap and cover materials shall be selected and applied so as to provide a suitable substrate for benthic organisms and wetland plant species, as appropriate for the subarea being capped. If consolidation of underlying sediments will not be sufficient to maintain desired water levels in each subarea with the minimum required cap thickness, the area will be dredged and/or excavated to remove sediments as needed before the cap is applied. Contaminated sediments shall be deposited in Subarea 8 (turning basin) before that subarea is capped. Appropriate restoration activities shall be undertaken so as to permit benthic species and emergent vegetation (e.g., cattail) to colonize the restored areas up to the maximum depth the species shall tolerate. Long-term monitoring shall be conducted to determine whether the cap and cover continues to provide a suitable habitat.

Additional performance standards for aquatic and wetlands habitat restoration are discussed below:

1. Palustrine Open Water (Areas 1, 2, 4/5 and 8)
   Performance Standard for benthic macroinvertebrates: Presence of a macrobenthic invertebrate community consistent with sediment type, grain size, water depth, and total organic carbon content of sediments after three years. Performance standard for Submergent plant community: Presence of submergent vegetation after three years.

2. Palustrine Emergent Wetland (Areas 3 and 7)
   Performance Standard:
   - Water table (or saturated soils) ≤ 12 inches from the surface established for 3 out of the first 5 years (spring-time measurements).
   - Vegetative cover of disturbed areas established after year 1. A stable vegetative community after year 5.
   - Plant community > 50% of dominant wetland plants are wetland indicators.
   - Soils show a trend toward hydric conditions (morphologies) at close of year 10.

3. Palustrine Scrub-Shrub Wetland (Area 3)
   Performance Standard:
   - Vegetative cover of disturbed areas established after year 1. 70% successful establishment of 80% of the planted wetland obligate or facultative species after three growing seasons. A stable vegetative community after year 5.
   - Water table (or saturated soils) ≤ 12 inches from the surface established for 3 out of the first 5 years (spring-time measurements).
   - Plant community > 50% of dominant wetland plants are wetland indicators.
   - Soils show a trend toward hydric conditions (morphologies) at close of year 10.

I. Institutional Controls

The performance standard for institutional controls shall be the establishment, maintenance, and appropriate enforcement, where necessary , of use restrictions on all parcels for which institutional controls are required.

Appendix E

Pre-Design Testing of Organoclay NAPL Capacity and Vendor Specifications

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Appendix E – Pre-Design Testing of Organoclay NAPL Capacity and Vendor Specifications

Batch Testing of Selected RCM Media

NAPL-removal capacity of the selected RCM media (organoclay) was determined quantitatively using a modified ASTM D425-01. The batch testing included five different masses of NAPL added to the organoclay (OC). This test consists of adding several masses of NAPL to samples of organoclay and centrifuging the NAPL-organoclay mixtures. After centrifuging, the amount of NAPL that was removed from each organoclay mixture is determined by a mass balance and verified with laboratory analysis. For each batch test, samples of the organoclay mixed with the NAPL before and after centrifuging were submitted to Katahdin for laboratory analysis of total petroleum hydrocarbons (TPH).

Based on our qualitative screening test which showed that the OC NAPL-removal capacity was greater than 20% NAPL by weight and the vendor claimed oil adsorption capacity of 50% by weight minimum, modified ASTM D425-01 was conducted by STI using organoclay with 20%, 30%, 40%, 50%, and 60% NAPL by weight. A duplicate of each percentage was run. The STI and Katahdin laboratory reports for this testing are attached. Table E summarizes the test results.

In each of the batch tests, no NAPL was removed from the sample during centrifuging, and no sheen or free NAPL was observed on the organoclay after centrifuging. This suggests that the NAPL-removal capacity of the organoclay is greater than 60% by weight. This is consistent with the vendor's (CETCO™) specified oil adsorption capacity of 50% by weight minimum. The higher percentage (50% and 60%) NAPL samples were observed to be very stiff and dense after centrifuging. The samples were difficult to remove and a lot of material stuck to the inside of the crucible.

Since no NAPL flowed out of the samples, the post-centrifuge sample had the same NAPL content as the pre-centrifuge sample. Thus, difference in TPH concentrations between the pre and post-centrifuge samples is not due to exceedance of the organoclay NAPL-removal capacity. The variation between pre and post TPH concentrations (-20% to 17%) is likely due to heterogeneity in the NAPL-organoclay mixture, material sticking to the crucible, and normal laboratory precision limits. Based on this batch testing, the qualitative NAPL capacity screening, and the vendor specified oil adsorption capacity, a NAPL-removal capacity of 50% to 60% by weight for organoclay is a conservative design criteria.

Table E: Organoclay Batch Test Results

NAPL added to Pre sample (by % weight)	Sample Name	TPH (mg/kg)	Difference in TPH (pre-post) (mg/kg)	TPH percent difference	Mass of NAPL removed by centrifuging (g)
20%	PRE-RS-OC-20%A	180,000	0	0%	0
	POST-RS-OC-20%A	180,000			
	PRE-RS-OC-20%B	180,000	-20,000	-11%	0
	POST-RS-OC-20%B	200,000			
30%	PRE-RS-OC-30%A	250,000	-50,000	-20%	0
	POST-RS-OC-30%A	300,000			
	PRE-RS-OC-30%B	300,000	40,000	13%	0
	POST-RS-OC-30%B	260,000			
40%	PRE-RS-OC-40%A	340,000	10,000	3%	0
	POST-RS-OC-40%A	330,000			
	PRE-RS-OC-40%B	340,000	-50,000	-15%	0
	POST-RS-OC-40%B	390,000			
50%	PRE-RS-OC-50%A	430,000	0	0%	0
	POST-RS-OC-50%A	430,000			
	PRE-RS-OC-50%B	480,000	80,000	17%	0
	POST-RS-OC-50%B	400,000			
60%	PRE-RS-OC-60%A	470,000	10,000	2%	0
	POST-RS-OC-60%A	460,000			
	PRE-RS-OC-60%B	520,000	60,000	12%	0
	POST-RS-OC-60%B	460,000			

The Residual Saturation of NAPL pertaining to organoclay was performed on February 13th, 2008. The procedure that was followed in general accordance with ATSM method D-425, which is a method for the Centrifuge Moisture Equivalent of Soils. Method variations include: using a stainless steel crucible, no filter paper, large high speed centrifuge, fixed rotor. ASTM D-425 uses porcelain crucible 20 ml volume, filter paper and bench top centrifuge with swinging bucket rotor. However in this determination, organoclay is used with NAPL, rather than water, to calculate a residual saturation of the NAPL pertaining to organoclay. The procedure performed is as follows:

A sample of organoclay was placed in a metal dish and weighed in grams. NAPL sample used was P2-103-112707. NAPL was added to each organoclay sample in duplicate at 20, 30, 40, 50, and 60 % by weight. The NAPL added to the organoclay and was homogenized within 15 minutes from the addition of NAPL. It was noticed that the organoclay would become very stiff and therefore difficult to homogenize after it had more than 5 minutes to absorb into the NAPL. Therefore, efforts were made to homogenize the NAPL with the organoclay immediately after the addition.

An portion of each homogenized sample was transferred into an 8-ounce wide-mouth glass jar using a decontaminated metal spoon. The sample was immediately sealed, labeled, and placed in refrigeration awaiting sample shipment.

The remaining homogenized samples were individually transferred into designated stainless steel crucibles with perforated stainless steel bottom plates, without filter paper. First the supportive ring, and then crucible were placed in the centrifuge tube. The purpose of the ring underneath the crucible was to prevent the crucible from sitting on the bottom of the centrifuge tube. **Photos 1 and 2** show the centrifuge, ring and crucible apparatus. The sample weights of the empty centrifuge tube, ring, and crucible were measured before sample was placed inside the crucible. The centrifuge tube, ring, crucible and sample were again weighed after the sample was placed inside the crucible. Weights are recorded in **Table 1**.

The centrifuge was placed at 1000 rotations per minute (RPM) for 60 minutes at 17.5 +/- 1.0 ° celsius, at 1000 times the force of gravity on the center of gravity of the test specimen. The interior of the centrifuge is shown in **Photo 3**.

After the centrifuge cycle was complete, the sample was removed gently from the centrifuge. The entire centrifuge tube containing the sample was weighed to ensure the centrifuge tube did not leak. None of the centrifuge samples showed evidence of a leak. Then the apparatus was disassembled and the empty centrifuge tube and ring were weighed again, assuming any NAPL that left the crucible and sample would adhere to the centrifuge tube and ring. In some cases, grains of organoclay perforated the crucible bottom, and they were replaced into the corresponding crucible before taking weights. Refer to **Table 1** for identification of samples in which organoclay grains perforated the crucible bottom. Any free NAPL or sheen was noted. NAPL was not visible on the interior of the centrifuge for any of the samples.

The final weight of the samples, post centrifugation was measured by subtracting any weight gain of the ring or the empty centrifuge tube that would be caused by release of NAPL from the organoclay sample. Any loss in weight of the centrifuge tube or ring was not accounted in the calculation and assumed to be system error.

Samples were immediately transferred to sample containers using a decontaminated metal spoon and then prepared for shipment to Katahdin Laboratory for analysis under Chain of Custody.

It was noticed than when the higher percentage NAPL samples were removed from the crucibles, the sample was very stiff and dense. The sample was difficult to remove and much stuck to the inside of the crucible. Cleaning the crucibles was very difficult for concentrations of 50 and 60% because the organoclay/NAPL mixture was extremely stiff and sticky.

In all the analysis, neither the ring nor the empty centrifuge tube gained weight due to NAPL released from the sample (beyond instrumental variation). In addition no NAPL was visible on the empty centrifuge tubes or the rings.

Table 1. Residual Saturation Data and Results

Sample Name	Sample Homogenization		Pre-Centrifugation			Post Centrifugation			After Sheen Notes and comments
	Dry organoclay (g)	NAPL added (g)	Cent. Tube Empty (g)	Ring Empty (g)	Wt. of Sample in Crucible (g)	Cent. Tube Empty (g)	Ring Empty (g)	Wt. of Sample in Crucible (g)	
Organoclay 20 % A	200.00	41.01	908.20	46.40	112.00	908.19	46.40	112.00	No NAPL removed, no Sheen noticed. Lost a few grains of Organoclay
Organoclay 20 % B	200.01	40.08	908.20	46.45	90.61	908.18	46.45	90.61	No NAPL removed, no Sheen noticed. Lost a few grains of Organoclay
Organoclay 30 % A	200.03	60.03	905.60	33.10	113.30	905.61	33.10	113.29	No NAPL removed, no Sheen noticed. Lost a few grains of Organoclay
Organoclay 30 % B	200.02	60.03	905.60	33.01	99.21	905.63	32.96	99.19	No NAPL removed, no Sheen noticed. Lost a few grains of Organoclay
Organoclay 40 % A	200.03	80.02	907.71	36.30	114.20	907.71	36.35	114.15	No NAPL removed, no Sheen noticed
Organoclay 40 % B	200.01	80.06	907.91	36.45	109.81	907.91	36.45	109.81	No NAPL removed, no Sheen noticed
Organoclay 50 % A	200.00	100.02	976.67	36.61	79.20	976.69	36.62	79.17	No NAPL removed, no Sheen noticed. Sample very stiff and sticky.
Organoclay 50 % B	200.01	100.04	976.72	35.64	125.20	976.72	35.65	125.19	No NAPL removed, no Sheen noticed. Sample very stiff and sticky.
Organoclay 60% A	200.02	120.02	885.30	46.04	67.01	885.31	46.05	66.99	No NAPL removed, no Sheen noticed. Sample very stiff and sticky.
Organoclay 60 % B	200.01	120.01	885.40	46.04	36.60	885.42	46.03	36.58	No NAPL removed, no Sheen noticed. Sample very stiff and sticky.

Photo 1. In order from left to right: Ring which supports crucible, Crucible, and centrifuge tube. All are composed of stainless steel. The crucible is placed on top of metal ring inside of the centrifuge tube during centrifugation of the sample

Photo 2. View from above. The ring and crucible inside of centrifuge tube. Can see the perforated bottom of crucible.

Photo 3. View from above. The inside of the centrifuge, showing 6 centrifuge tube compartments.

Technical Data

ORGANOCLAY REACTIVE CORE MAT™

MATERIAL PROPERTY	TEST METHOD	VALUE
ORGANOCLAY[1]		
Bulk Density Range	CETCO Test Method	44 – 56 lbs/ft^3
Moisture Content	CETCO Test Method	$\leq$ 5%
Oil Adsorption Capacity	CETCO Test Method	0.5 lb of oil per lb of organoclay, minimum
Quaternary Amine Content	CETCO Test Method	25 – 33% quaternary amine loading
FINISHED RCM PRODUCT		
Organoclay Mass per Area	CETCO Test Method	0.8 lb/ft^2
Mat Grab Strength[2]	ASTM D4632	90 lbs. MARV
Hydraulic Conductivity[3]	Mod. ASTM D4491	1 x 10^{-3} cm/sec minimum

Notes

1 Organoclay properties performed periodically on material prior to incorporation into the RCM.
2 All tensile testing is performed in the machine direction.
3 Permittivity at constant head of 2 inches is converted to hydraulic conductivity using Darcy's Law and RCM thickness per ASTM D5199 for geotextiles.

A permeable composite of geotextiles and a non-swelling granular clay compound that reliably adsorbs oil and similar organics from water.
Roll Size: 15' x 100'
Packaged on 4" PVC core tubes, and wrapped with polyethylene plastic packaging.

CETCO SEDIMENT REMEDIATION TECHNOLOGIES

1500 West Shure Drive 5th Floor, Arlington Heights, IL 60004 USA 800.527.9948 Fax 847.577.5566
For the most up-to-date product information please visit our website, www.sedimentremediation.com
A wholly owned subsidiary of AMCOL International Corporation

Appendix F

USEPA, VTDEC, and USFWS Comments

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Pine Street Barge Canal Superfund Site
Draft Final NAPL Controls Report (June 2007)
Responses to USEPA, VT DEC and US F&WS Comments dated October 26, 2007

Comment Number	USEPA, VT DEC and US F&W Comments	ARCADIS BBL Response (November 9, 2008)	Location Comment Incorporated into June 20, 2008 version
General Comments			
1	EPA's scientific understanding about contaminated sediments sites has evolved in the ten years that have passed since Region 1 incorporated the recommendations of the Pine Street Barge Canal Coordinating Council into a Record of Decision. It is with current EPA policies, directives and guidance documents in mind that we evaluate additional remedial actions to address the ongoing releases of coal tar into the canal. In addition to *Contaminated Sediment Remediation Guidance for Hazardous Waste* Sites (December 2005) which is cited as a reference in this report, we are relying on *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (OSWER Directive 9285.6-08, February 2002) and *Guidelines for the OSRTI Review of Consideration Memos on Tier 1 Sediment Sites* (EPA, updated March 1, 2004). These documents reflect an Agency bias towards source control at those sites where migration could result in significant recontamination.	Comment accepted. We are familiar with these documents and took them into consideration, although they are not specifically referenced in the report. We understand the importance of source control, which is provided by the horizontal permeable NAPL barrier in Alternative 2. We will revise the NAPL Controls Report to recommend Alternative 2. Alternative 1 (RCM without permeable barrier) would only be selected if bench-scale testing demonstrates the horizontal permeable barrier does not provide a significant contribution to the RCM design life. See response to comment 3 for more information on how the horizontal permeable barrier acts as source control.	Section 4.4 was revised to recommend Alternative 2. Section 5.1 was updated to recommend Alternative 2. An evaluation of the effect of a horizontal and vertical permeable barrier on the RCM cap life was added to Sections 4.2, 4.3, and 4.4.
2	As stated in our comments (dated October 3, 2007) on the NAPL Investigation Report, we believe that the conceptual site model which forms the basis for the NAPL Controls Report underestimates the location of potentially mobile NAPL that exists outside the peat layer. Historical observations and TarGOST data show that potentially mobile NAPL is located above the peat in the organic silt/sand layer, to a limited extent in the sand cap, and also in the peat and silt outside of the canal. Also underestimated is the significance of transport mechanisms other than gas bubble-enhanced transport. The influence this has on our thinking as we prepare to mobilize for the third time to address the contamination includes the following: • The potential for future migration of NAPL from the subsurface into and through the cap is greater than that assumed in the NAPL Investigation Report. • The presence of potentially mobile NAPL in the subsurface is a better indicator of where NAPL controls are needed than are the features discussed in the report (i.e., NAPL mass that has already migrated to the sand cap; relative thickness of sand cap or location of seeps observed during occasional site visits). Case in point is the large release observed by EPA and Johnson Company personnel on August 9, 2007, in an area where no controls were proposed. As such, it is expected that NAPL controls will be needed over a wider area than proposed in this report. • Not enough is known about the extent, mobility and connectivity of the NAPL (particularly to the east of the canal) to conclude that vertical barriers beneath the banks would not significantly increase the effectiveness or life of a reactive cap. Performing Defendants should re-evaluate the impact of vertical barriers or trenches in the context of	Comment accepted. This comment is similar to comments 2, 4 and 39 on the Draft NAPL Investigation Report. As stated in the response to comments on the Draft NAPL Investigation Report, we will update the conceptual model to accurately show the location of potentially mobile NAPL. The updated conceptual model will be included in the revised NAPL Controls Report. The alternative proposed in the NAPL Controls Report will address all of the ongoing and expected secondary NAPL migration mechanisms in the areas of potential seepage. The horizontal permeable barrier and the RCM will capture any NAPL seepage through the cap, regardless of migration mechanism. The design of the remedy will take a conservative approach that addresses uncertainties in magnitude and mechanism of NAPL seepage. For more detail on how the design will accomplish this, see response to comment 17. The remedial design will include a spatial analysis of NAPL seepage probability to provide a conservative design, as well as proposed monitoring standards to ensure that the cap successfully controls NAPL seepage. We agree that NAPL controls will be needed over a wider area than proposed in the draft report. As stated above, the remedial design will include a spatial analysis of NAPL seepage probability to provide a conservative design. However, mobile NAPL is present in the peat layer everywhere beneath the canal (Figure 4-9, NAPL Investigation Report). Using potentially mobile NAPL in the peat layer as the criteria for where the	Figures 1-3, 3-1, 3-2, 3-3, 3-4, 3-5, 4-4, and 4-6 were revised according to the Final Investigation Report Figure 5-2. The area of NAPL controls was increased for each of the Alternatives to the entire canal between Transects T9+00 and T12+50, an area of approximately 26,000 sf. The text, figures, and cost estimate were updated based on this area. The area

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	the revised conceptual site model. NAPL levels in wells within close proximity to the canal in the area of ongoing releases are known to fluctuate[1]. Full consideration must be given to this observed site condition as well as the possibility that an inward NAPL gradient would develop over time (e.g., NAPL from outside the canal would flow to the canal to fill newly-vacated pore spaces).	remedy would be implemented could result in recapping the entire canal. Monitoring data since completion of the west bank cap (i.e., three years of monitoring data) indicate that the majority of the cap is functioning. EPA's five year review determined that the cap is protective and functioning as intended except in Areas 1 and 2 between transects T9 and T14 (EPA, 2006). The Final NAPL Investigation Report will include an evaluation of the amount of potentially mobile NAPL under the canal versus on the banks. The Final NAPL Controls Report will re-evaluate the impact of vertical barriers or trenches in the context of the revised conceptual site model and the evaluation of the amount of potentially mobile NAPL under the canal versus on the banks.	of NAPL controls will be revaluated during design. The Final NAPL Investigation Report included an evaluation of the amount of potentially mobile NAPL under the canal versus on the banks. See Comment 1, the vertical barrier was reevaluated based on the revised conceptual model and the evaluation of the amount of NAPL under the canal versus on the banks.
	To help address the uncertainties surrounding extent, mobility and connectivity of the NAPL in the subsurface outside the canal, the Performing Defendants are being asked to: a) Perform a comprehensive review of subsurface soil-boring data, NAPL location and groundwater monitoring data collected to date (including Johnson Company, Metcalf & Eddy, and PEER data) to better understand NAPL distribution at the site and how NAPL has migrated over time, both in terms of location and accumulated thicknesses.	A comprehensive review of applicable soil, NAPL, and groundwater data will be conducted as requested, and the results will be summarized in the Final NAPL Investigation Report. The evaluation will include comparing historical data on extent of NAPL to TarGOST results. Historical chemistry data will be compared to NAPL Investigation Report chemistry.	Item a was completed in the Final NAPL Investigation Report.
	b) Conduct an expanded TarGOST investigation on the east bank of the canal, as EPA recommended during the winter field work.	We agree to evaluate whether additional TarGOST data from the east bank of the canal are needed based on the recommended NAPL controls approach. Part of this evaluation will be based on what is determined in response to comment a, above. If conducted, the expanded TarGOST bank investigation would need to be conducted during the winter months to prevent mobilization of subsurface NAPL due to equipment loading.	A statement was added to Section 4.3.3 to indicate that additional TarGOST data from the east bank of may be required if Alternative 3 was selected.
	c) Remove NAPL from one or more wells in the NAPL zone (as shown in Figures 4.2.1 to 4.2.6 of the Additional Remedial Investigation Report, July 1997) and observe the rate at which it refills, as well as the impact, if any, on NAPL levels in nearby monitoring wells. [1] For example, NAPL in MW-11B was measured at 11 ft in May 2006, 10 ft in Aug 2006, and 9.4 ft in Feb 2007 – a change of 1.6 ft over nine months.	The data gathered to date indicate that vertical barriers are not necessary. This will be reassessed when the conceptual model is updated. A NAPL bail-down test would not provide data essential or necessary to the design or selection of a NAPL controls alternative. In addition, experiences at other sites have shown that product recovery (pumping) of DNAPL is not an effective technology. See response to comment 14.	A statement was added to Section 4.3.3 to indicate that NAPL recovery testing may be required if Alternative 3 was selected.
3	It is the opinion of EPA, VT DEC and US Fish and Wildlife Service (US F&WS) that a reactive cap alone (Alternative 1) is not a long-term solution to address the ongoing releases at Pine Street. It is our position that some amount of NAPL recovery is necessary to prevent recontamination from a mobile NAPL source and to address the impact of transport mechanisms other than gas bubble-enhanced transport. NAPL recovery from beneath the canal and/or the banks will also serve to prolong the life of a reactive cap reducing the frequency of cap changeout. During a presentation to EPA's	Comment accepted. All of the issues included in this comment are important and will be addressed by the recommended approach. Alternative 2, which will be the recommended alternative in the Final NAPL Control Report, includes control of NAPL as a source to the cap through the use of the horizontal permeable barrier, i.e., the NAPL collects in the barrier rather than becoming a direct-contact area load to the RCM. This would preserve sorptive capacity of the RCM and extend the design life. The design process will include an evaluation of the most effective and practical	See Comment 1.

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	National Sediment Forum on August 23, 2007, Danny Reible stated that while reactive caps are effective for addressing residual NAPL, an "effectively infinite migrating NAPL source" will eventually overcome and compromise any sorbent material. The long-term record of performance of reactive caps at NAPL sites is unknown and there do not yet appear to be proven methods for monitoring their performance. The ability of the remedy to meet performance standards, including those for benthic and wetland habitat restoration will continue to be impacted for an extended period of time and potentially on short-cycle turnarounds if an effective, multi-faceted remedial approach is not implemented.	approach to address any accumulating NAPL in the permeable barrier. This will build upon the information presented in the report for Alternative 2, which incorporates NAPL gravity flow for collection and passive NAPL removal. See response to comment 17 for more details on the design of the recommended alternative.	
4	It appears that only capital costs of the process options were evaluated for this report. The ongoing operations, maintenance and monitoring of the technologies under consideration will be considerable, and perhaps affect costs by an order of magnitude. Estimate these costs, state the assumptions behind them, and include them in the report.	Comment accepted. The report will be revised to include estimated operation, maintenance and monitoring costs, and the assumptions used in developing the costs.	The cost estimate tables and text (Appendix C) were revised to include estimated operation, maintenance and monitoring (OMM) costs, and the assumptions used in developing the costs. Sections 4.1.6, 4.2.7, 4.3.7 were updated with the revised costs, including the OMM costs.
Specific Comments			
5	Page 1-1, *Purpose and Objective*: Although this report is not intended to be a stand alone document, it would be helpful to those less familiar with the site to include the performance standards for the remedy. A simple way to do this would be to copy Section VII. Performance Standards from the February 2000 RD/RA SOW and include it as a new Appendix D.	Comment accepted. The ROD performance standards will be added to the report.	Appendix D includes the performance standards. Reference to Appendix added to Page 1-1.
6	Page 1-2, *Summary of NAPL Investigation Findings*: This section will need to be modified, as appropriate, to incorporate the agencies' comments on the Draft Final NAPL Investigation Report, June 2007. Note too that not all the figures referenced are provided.	Comment accepted. This section will be updated accordingly.	Section 1-3 updated with text from Final Investigation Report.
7	Page 1-5, *Site Constraints*: Although not required by the ROD, US F&WS recommends that the habitat layer described in the 4th bullet as 6 inches of clean sand be augmented with a minimum of 5% TOC to facilitate benthic re-colonization. The proposed remedies must also: • Take into account the monitoring for and replacement of a reactive cap when the material has reached its total capacity to sorb NAPL. • Ensure that it does not disturb the subsurface flow regime such that a new equilibrium system forms that allows/forces NAPL to surface in a different area than we have seen before. • Consider the potential for significant NAPL releases during construction of additional remedial actions. • Ensure that the wetland/habitat balance required by the ROD is maintained.	Comment accepted. The sand cap provides a clean substrate for the recolonization by benthic organisms (EPA, 2005). Caps are quickly recolonized by benthic organisms. Compliance monitoring at the site indicates that the cap at the site was recolonized by benthic organism within one year after completion of construction and that the number of organisms and the number of species has generally increased with each year (Johnson Company, 2005). This occurred without any TOC requirement for the cap. However, we will evaluate the need for a TOC requirement in the design. Comment accepted. These items are very important and will be considered during design; Section 4 of the report includes construction and long-term operation maintenance and monitoring considerations for each alternative. The report will be revised to include maintaining wetland/habitat balance as a site requirement. The potential for NAPL releases or disruption of equilibrium due to the proposed alternative will be further evaluated during design.	Added evaluation of need for TOC in sand caps to Section 4.1.3. Added maintaining wetland/habitat balance to site constraints in Section 1.4.

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8	Page 2-2, *Sand Caps*: The text states that NAPL migration via gas bubbles is temperature dependent. We agree with this conclusion though note that Section 5-1 of the NAPL Investigation Report states otherwise.	Comment not accepted. Section 5-1 of the NAPL Investigation Report does not discuss NAPL migration due to gas bubbles. However, Section 5-4 which deals with NAPL migration due to gas bubbles states several times that gas transport of NAPL at the site appears to be temperature dependent. Comment 40 on the NAPL Investigation Report also deals with this issue.	No revisions necessary
9	Page 2-2, *Reactive Caps*: Expand this section to include a discussion of the effectiveness of a reactive cap in addressing preferential NAPL transport pathways from the subsurface; the potential for preferential pathways to develop within the reactive cap, and how NAPL will behave/flow in an area where the reactive cap has become saturated. Finally, activated carbon or geomembrane-activated carbon sandwiches may also warrant consideration during design, if this technology is selected.	Comment accepted. The text will be expanded to provide more detail on the effectiveness of RCMs. Comment accepted. RCMs are not constructed using geomembranes. RCMs consist of a thin-layer of reactive media stitched between two geotextile layers. Reactive media which may be used in RCMs includes organoclays and granular activated carbon (GAC). During pre-design, several reactive media, including organoclay, will be screened. A GAC RCM will be considered during design.	Text was added to Section 2.2.1. The potential effect of preferential pathways on the RCM will also be evaluated during design and Pre-Design. Additional details regarding the theoretical design life of an OC RCM were added to Section 3.2.1. The results of site-specific Pre-Design OC capacity were included in new Appendix E and used to update the estimated theoretical design life.
10	Page 2-2, *Reactive Caps*: Please provide a copy of (or, if available a website link for) the reference Kahanam, 2006, to provide clarification on a number of items such as how gas flows through organoclay, how the gas flow rate of 1 liter per square was estimated, how the bearing capacity of organoclay was estimated (it appears very high), etc.	Comment accepted. A copy of Khanam, 2006 will be provided.	Uploaded to project website on May 1, 2008 under Outside Documents/Khanam.
11	Page 2-4, Removal and Recovery Technologies: We agree that the potential for resuspension and residual contamination present significant challenges at this site; ones that would need to be addressed during design with extensive and redundant controls to prevent releases to Lake Champlain.	Comment accepted. Resuspension and recontamination controls needed during construction of the NAPL controls will be evaluated and incorporated during design.	No revisions required
12	Page 2-6, Relative Cost: The screening of process options will be viewed as incomplete without consideration of the relative cost associated with ongoing operation, maintenance and monitoring.	Comment accepted. See response to comment 4.	Section 2.3.3 revised to indicate that relative capital and OMM costs were considered.
13	Page 2-6, *Screening Results*: Re-evaluate the results of the screening of NAPL control technologies within the context of a revised conceptual site model that has potentially mobile NAPL not just in the peat layer beneath the canal, but in the organic silt/sand layer and sand cap in the canal, as well as outside the canal.	Comment accepted. The results of the screening of NAPL control technologies will be re-evaluated once the Conceptual Site Model is updated in the final report.	The results of the NAPL screening technologies were reevaluated based on the revised Conceptual Site Model; however, this did not result in any changes to the screening results.
14	Table 2-2, *NAPL Recovery*: Product recovery (pumping) appears to have been eliminated due to low short- and long term effectiveness at removing NAPL from the peat layer. However, collecting NAPL from the recovery wells seated in the upper sediments, where mobile NAPL has also come to reside, during construction along the west bank has contributed to the effectiveness of the west bank cap. Retain product recovery as a potential control technology.	Comment not accepted. Product recovery of DNAPL has been attempted but was not successful at several sites including Libby, Montana and Wyckoff-Eagle Harbor Superfund site, Washington, and thus, product recovery was eliminated due to low short-term and long-term effectiveness. We are not aware of any successful applications where pumping of DNAPL was instrumental in site cleanup. This would not be an effective technology in any of the layers at the site. Prior to the installation of the West Bank Cap, several large trees were	Table 2-2 was revised to retain product recovery. Text was revised in Section 2.4. Summaries of the NAPL recovery systems at these sites and their applicability to NAPL controls were added to Section 2.4.

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		removed from the footprint of the cap. The extensive root mass of those trees contained numerous voids and macropores where NAPL was observed. The installation of recovery wells and removal of NAPL both prior to and during installation of the West Bank Cap was performed not to enhance the effectiveness of the Cap, but rather to avoid a potential release of NAPL into the Canal during Cap construction.	
15	Table 2-2, *Enhanced Extraction* and *Bioremediation*: Explain more fully why these technologies do not meet the objective of partial replacement for, augmentation of, or addition to the existing sand cap.	Comment accepted. Additional explanation will be added to Table 2-2. Enhanced extraction would not control NAPL seeps through the existing sand cap and, thus does not meet the objective. Bioremediation is not a proven technology for DNAPL or sediments and would not control NAPL seeps through the sand cap. In fact, both of these technologies would likely increase the mobility of NAPL, and bioremediation would increase gas production.	Table 2-2 was revised to retain enhanced extraction and bioremediation. Text was revised in Section 2.4.
16	Page 3-1, *Identification of NAPL Control Concepts*: To better our understanding of the long-term effectiveness of the technologies proposed here for consideration, there should be a more detailed discussion about the potential for releases of NAPL during construction; the impact of localized seepage points and preferential pathways on the lifespan of reactive materials; monitoring; and maintenance (i.e., replacement) of spent reactive materials. Please also address the concern that any activity on the cap surface such as micro dredging and/or placement of an RCM could act to change the subsurface pressure conditions and potentially mobilize/remobilize NAPL.	Comment accepted. The text will be revised to include additional details regarding long-term effectiveness and impacts from construction. The design-life of the selected alternative will be determined during design. Monitoring and maintenance of each alternative is described in Section 4. Additional details regarding operation, maintenance, and monitoring of the selected alternative will be determined during design. We agree that the potential for mobilization of NAPL due to construction of the selected alternative is a significant issue. This issue will be addressed further during design.	Additional details regarding short-term construction impacts were added to Section 3.7 and Table 3-1. The potential effect of preferential pathways on the RCM will be evaluated during design and Pre-Design. Sections 4.1.4, 4.2.5, and 4.3.5 were added to discuss RCM replacement intervals for the three alternatives. A conceptual-level description of monitoring and maintenance was added to Sections 4.1.5, 4.2.6, and 4.3.6.
17	Page 3-1, *Reactive Core Mat*: We believe that the estimated theoretical life span of eight months (which is likely an overestimation since it does not take into account known localized seepage points) makes the use of RCM alone impractical for this site. To stay ahead of NAPL releases, which must be controlled in perpetuity, the system would have to be significantly disturbed at regular intervals to replace sections of mat. Even if the addition of multiple layers of RCM lengthens the period between change-outs (assuming it can be demonstrated that the weight of the multiple layers will not increase the rate at which NAPL is mobilized due to compression), RCM replacement would be "complex and costly" (page 4-1) and not consistent with the long-term establishment of vegetation or colonies of benthic organisms on the cap surface.	Comment accepted. We understand your concern about the estimated theoretical life span of "eight months" reported in the draft controls report. However, this estimated theoretical life span does not represent an expected design life for a RCM. The selected alternative will ultimately be designed to have a design-life on the order of 30 years. During design, data from the NAPL Investigation and the Pre-Design Investigation will be used to design a cap with the appropriate design life. The Pre-Design Investigation will include confirmation of the NAPL residual saturation, screening of reactive and barrier media, and column testing of capping alternatives. See response to comment 7 regarding benthic organisms.	Updated Sections 3.2.1 and 3.3.1 with calculation of theoretical design life based on Pre-Design testing of organoclay NAPL-sorption capacity. Added NAPL-sorption capacity testing data from Pre-Design and vendor specifications as Appendix E.
18	Page 3-6, *Description of Concept*: What is the "lightweight, coarse material" that is being proposed? Can the light coarse material be placed below the water table into the trench?	Comment accepted. The material has not been proposed yet. Screening of several light-weight coarse materials is planned as part of the Pre-Design	Added text to Sections 3.5.1, 3.5.3, 4.2.2 and 4.3.2 to clarify that the media will be

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	Note that "gravel" is shown on Figure 3-4; also, the top of the trench should be covered with low permeability materials.	Investigation. The light-weight material will not be lighter than water unless engineering controls are incorporated into the design to effectively use "floating" materials.	selected based on Pre-Design testing. Revised Figure 3-4 to indicate that vertical barrier backfill material would be light-weight, coarse material.
19	Figures showing cross sections of remedial concepts beginning with Figure 3-1: As with the cross sections in the NAPL Investigation Report, these figures should reflect the fact that potentially mobile NAPL is also in the organic silt/sediment both directly below the canal cap and to the sides of the canal.	Comment accepted. Figures will be revised to be consistent with the NAPL Investigation Report (See response to comment 39 for the NAPL Investigation Report).	The background of Figures1-3, 3-1, 3-2, 3-3, 3-4, 3-5, 4-2, 4-4, and 4-6 were updated based on Figure 5-2 from the Final NAPL Investigation Report.
20	Page 4-3, *Reactive Core Mat with Horizontal Permeable NAPL Barrier*: This alternative may be very difficult to design and construct to achieve necessary QA/QC, especially while there is water in the canal. Of particular concern is its ability to remain intact and functional as the soft sediments consolidate (perhaps heterogeneously) in response to the weight of the new cap. Only one previous application is cited in the report; EPA knows of a second horizontal system being installed as part of a project on the Chicago Sanitary Ship Canal (Karl Rockne, University of Illinois at Chicago). Provide more detailed information addressing the constructability of a horizontal system at Pine Street, and how performance would be monitored.	Comment accepted. We understand your concern regarding construction of the horizontal barrier. However, ARCADIS BBL has the sediment, capping, and geotechnical expertise needed to design and construct the horizontal barrier. The Final NAPL Controls Report will include more detailed information addressing the constructability of a horizontal barrier at Pine Street, and how performance would be monitored. The Pre-Design Investigation will include screening and testing of media for the horizontal barrier. Final performance monitoring will be specified during design. A January 2007 reference[2] was found for the Chicago Sanitary Ship Canal Active Capping Project (Karl Rockne, University of Illinois at Chicago). This reference discusses bench scale testing of gas ebullition but not a NAPL barrier. No design or construction information for this project was found.	This site was added to Appendix A. Also requested update on status from author.
21	Page 4-3, *Reactive Core Mat with Horizontal Permeable NAPL Barrier*: While this alternative may provide a better solution than RCM alone, it does not address the buildup of gas pressure that mobilizes NAPL. Consider replacing the 12-inch thick layer of lighter permeable material beneath the RCM with a gas relief layer comprised of geocomposite nets (0.25 -0.5 inch thick) or strip drains, and discharge the gas to a side vent system. A sketch of this alternative design is attached to these comments. References for the design of a gas layer include: • Koerner, R.M., 1998, <u>Designing with Geosynthetics</u>, 4th Edition, pages 465-469. • Thiel, R.S., 1998, Design Methodology for a Gas Pressure Relief Layer Below a GM Landfill Cover to Improve Slope Stability, Geosynthetics International, volume 5, number 6, pages 589-617.	Comment not accepted. Gas build-up does not occur with RCMs. As noted in Appendix A of the report, gas bubbles have been observed to migrate through the RCM (with the RCM removing NAPL from the gas bubbles) at the McCormick & Baxter Site. During the Pre-Design column testing, observations will be made to verify that gas build-up does not occur beneath the proposed capping alternative. If gas buildup is indicated, a gas relief layer will be considered during design.	No revisions required
22	Figures 4-4 and 4-6: Indicate "north-south" on the cutout cross-sections.	Comment accepted. The perspective of the detail will be clarified on Figures 4-4 and 4-6.	Figures 4-4 and 4-6 were revised to indicate the perspectives of the cutouts.

[2] Viana, P., K. Yiu, K. Zhao and K. Rockne. "Modeling and Control of Gas Ebullition in Capped Sediments", Paper D-027, in: E.A. Foote and G.S. Durell (Conference Chairs), *Remediation of Contaminated Sediments—2007*. Proceedings of the Fourth International Conference on Remediation of Contaminated Sediments (Savannah, Georgia; January 2007).

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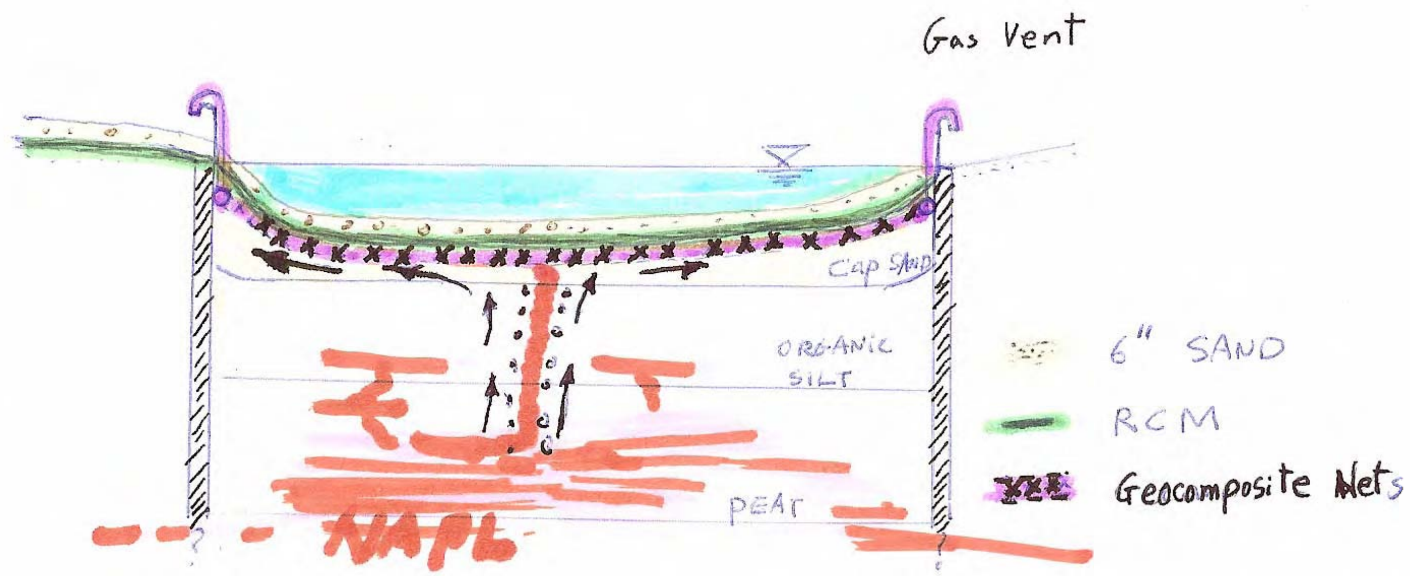
23	Page 5-1, *Recommendations*: See General Comments.	See responses to comments 1 through 4.	See comments 1 through 4. In addition, Section 5.2 was updated with details from the Pre-Design Investigation Work Plan. Section 5.3 was updated with the latest schedule.
24	Remedial design-specific studies: Estimates of NAPL fluxes in the layers beneath the sand cap may be needed to help in specifying RCM or reactive cap material design life, or sizing and locating any NAPL collection system. NAPL fluxes through the sand cap have been developed based on the NAPL seep observations, but NAPL fluxes in the deeper subsurface layers remain somewhat of an uncertainty. The McCormick and Baxter site was mentioned as an example of a previous application of an RCM cap and a bulk organoclay cap. Recently, a sophisticated, detailed analysis of LNAPL and DNAPL migration pathways at McCormick and Baxter was conducted (Blischke, H., et al, *NAPL Mobility Assessment at the McCormick and Baxter Creosoting Company Site, Oregon,* In: Proceedings of the Fifth International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Battelle Press, May 2006). The purpose of the analysis by Blischke et al. was to understand LNAPL and DNAPL migration pathways and fluxes in six different pathways at the McCormick and Baxter site, and their potential impact on the service life of an RCM and organoclay cap. Discuss the applicability of a similar analysis for Pine Street.	Comment accepted. The Pre-Design Investigation will include confirmation of the NAPL residual saturation, batch testing of capping media, and column testing of capping alternatives. These data will be used in the design of the alternative. The estimated NAPL flux to the canal will be confirmed through field testing during design (details will be provided at a later date). The flux of NAPL in the subsurface layers is not an essential element of the cap design and will not be estimated. We have read the mentioned abstract and do not believe that this analysis is directly applicable to Pine Street. As mentioned above, the Pre-Design Investigation will gather the additional data needed for design of the alternative. A detailed analysis of migration pathways was included in the NAPL Investigation Report, and the NAPL flux to the canal was estimated. Following implementation of an alternative at Pine Street, an update of the conceptual model to reflect post-remedy conditions will be conducted.	No revisions required



RCM with GAS RELIEF LAYER