FEASIBILITY STUDY

Crownhill Elementary School

Prepared for: Bremerton School District

Project No. 100094 • November 24, 2014 Final

Aspect CONSULTING

earth + water

FEASIBILITY STUDY

Crownhill Elementary School

Prepared for: Bremerton School District

Project No. 100094 • November 24, 2014 Final

Aspect Consulting, LLC

Dave Heffner, PE
Associate Remediation Engineer
dheffner@aspectconsulting.com

Doug Hillman, LHG
Principal Hydrogeologist
dhillman@aspectconsulting.com

V:\100094 BSD Crownhill Elementary RIFS\Deliverables\FS Report\Final\FS_24Nov2014_Final.docx

Contents

List of Tables

List of Figures

List of Appendices

1 Introduction

This Feasibility Study (FS) report addresses environmental contamination associated with historical landfilling activities at the Bremerton School District Crownhill Elementary School Site (Site). The Crownhill Elementary School (School) is located at 1500 Rocky Point in Bremerton, Washington (Figure 1). The purpose of the FS is to develop and evaluate cleanup action alternatives to enable selection of a cleanup action for the Site. This report has been prepared as required and in accordance with the Agreed Order between the Washington Department of Ecology (Ecology) and the Bremerton School District (BSD) dated September 20, 2010 (Agreed Order No. DE7916).

As stated in the Agreed Order, *the Site includes property owned by BSD and is defined by the extent of contamination caused by the release of hazardous substances at the Site, which may extend to adjacent properties*. Adjacent properties are primarily residential, with the Bremerton United Methodist Church (Church) located on the adjacent property to the south.

Contaminants at concentrations above cleanup levels were found only on the School and Church properties. These properties were used for sand and gravel mining up to the 1930s, and the mined area was backfilled with municipal and industrial wastes in the 1930s and 1940s. The original school building was constructed in 1956, and partially burned down in 1993. A series of environmental investigations were conducted during the period between that fire and construction of the current school building, completed in 1996. Additional investigations were conducted beginning in 2009, culminating in the preparation of a Remedial Investigation (RI) report (Aspect, 2013). The purpose of the RI was to collect data necessary to adequately characterize the nature and extent of Site contamination, so that cleanup action alternatives could be developed and evaluated in this FS.

The remainder of this report includes information required by the Washington State Model Toxics Control Act (MTCA), and is organized into the following sections:

- Section 2 – Site Areas/Media Warranting Evaluation of Cleanup Alternatives
- Section 3 – Cleanup Standards
- Section 4 – Remedial Action Objectives
- Section 5 – Applicable or Relevant and Appropriate Requirements
- Section 6 – Extent of Cleanup Level Exceedances
- Section 7 – Identification of Applicable Remedial Technologies
- Section 8 – Development of Remedial Alternatives
- Section 9 – Evaluation of Remedial Alternatives
- Section 10 – Summary and Conclusions

2 Site Areas/Media Warranting Evaluation of Cleanup Alternatives

The goal of a cleanup action is protection of human health and the environment from hazardous substances at the Site. Based on the RI results, soil contamination correlates closely with the occurrence of landfilled materials. Using multiple lines of evidence (e.g., historical photographs, site assessment activity, construction observations), two generalized areas of landfill accumulation (designated the ‘north’ and ‘south’ landfill areas) were identified in the RI. These areas, the interpreted boundaries of which are shown on Figure 2, cover approximately 5.5 acres. While typically encountered at depths of less than 15 feet below ground surface (bgs), landfilled materials were found as deep as 40 feet bgs at some locations.

As discussed in the RI report, Site contamination has the potential to adversely impact human health via the following exposure pathways:

- Direct contact (skin contact or incidental ingestion) with contaminants in soil;
- Inhalation of vapor-phase contaminants resulting from the volatilization of contaminants in soil (soil-to-vapor pathway); and
- Consumption of groundwater impacted by contaminants leaching from soil (soil-to-groundwater pathway), and by light non-aqueous-phase liquid (LNAPL) floating on the groundwater table.

The RI identified constituents of potential concern (COPCs) and implemented a grid-based sampling approach to delineate areas of near-surface soil contamination. Refer to Section 3.2 for discussion of constituents of concern in Site soil.

Two interim actions were completed while the RI was underway. A soil removal interim action was first conducted (in spring 2012) to ensure protective conditions were maintained as the RI/FS process was completed. The RI implemented a grid-based sampling approach to identify near-surface soil concentrations exceeding unrestricted land use screening levels. Exceedances were identified at less than 1-foot depth within a roughly 5,800-square-foot area situated primarily on the Church property. Soil in this area was excavated to 1-foot depth and disposed of offsite. A geotextile fabric was then placed in the excavation, and fill soil was imported and hydroseeded to provide a finished clean soil and sod barrier layer at least one foot thick.

Ecology subsequently required that a second interim action be conducted at two locations on the School property where lead screening level exceedances were identified in the 1- to 3-foot depth range, to better ensure the long-term integrity of the barrier layer. These areas, which together comprise approximately 7,300 square feet, were covered in summer 2013 with a geotextile fabric (placed directly on the undisturbed ground surface), and an additional 1-foot thickness of fill soil was imported and hydroseeded to supplement the pre-existing clean soil and sod barrier layer. The interim action areas are shown on Figure 2.

To investigate potential inhalation exposure via vapor intrusion (VI), two rounds of sub-slab vapor sampling were completed at 6 locations inside the main school building.

COPCs were identified and screening levels were established at 10 times the most stringent MTCA Method B air cleanup levels, which conservatively accounts for soil vapor attenuation across a floor slab in accordance with Ecology guidance. During the first round (August 2010; Aspect 2010a), which was conducted with the school's HVAC system shut down, COPC concentrations exceeded screening levels at 2 of the sampling locations. However, no screening level exceedances were measured during the second round (in November 2010; Aspect, 2010b), conducted while the HVAC system was running. It is standard practice for the system to be run continuously during the school day. Operation of the HVAC system appears to provide some positive pressurization in the building (relative to outdoor air), and this decreases VI potential. Based on the results of the two monitoring rounds, it was recommended that the standard practice of running the HVAC system throughout the school day be continued (Aspect, 2010b). As long as this is done, indoor air concentrations due to VI are expected to remain below levels of concern.

Beneath a portion of the north landfill area, LNAPL has been observed floating on the water table at 120 to 130 feet bgs in four monitoring wells (MW-8, MW-13, MW-14, and MW-16). A maximum LNAPL layer thickness of approximately 4.9 feet has been measured (in MW-13). LNAPL is also present in soil pore spaces along the entire vadose zone soil column (e.g., at MW-13). Petroleum hydrocarbons have leached to groundwater beneath the impacted soils, forming a localized dissolved contaminant "plume." Other COPCs, including several metals and trichloroethene (TCE), have also been detected in one or more monitoring wells installed on the School property, but at concentrations that only marginally exceed screening levels. Groundwater flows in a southwesterly direction. Monitoring results suggest that groundwater impacts do not extend beyond the School property boundary.

A Terrestrial Ecological Evaluation (TEE) was conducted as part of the RI to determine whether the hazardous substances in Site soils have the potential to adversely impact the environment (i.e., plants and animals). The TEE was conducted in accordance with MTCA TEE procedures (WAC 173-340-7490) and Ecology online guidance. The Site qualified for a simplified TEE, which concluded that hazardous substances in Site soils do not pose a potential risk to plants and animals. Therefore, cleanup alternatives need only address potential human health impacts.

On the basis of the RI results summarized above, Site areas/media warranting evaluation of cleanup alternatives can be broadly categorized as follows:

1. Landfilled materials and near-surface impacted soils; and
2. Deep petroleum hydrocarbon and groundwater impacts.

In Section 8 of this FS report, cleanup alternatives addressing landfilled materials and near-surface impacted soils are developed separately from those addressing deep petroleum hydrocarbon and groundwater impacts. Then, in Section 9, four Site-wide cleanup alternatives (i.e., combinations of the area/media-specific alternatives) are assembled and evaluated with respect to MTCA criteria, and a "preferred" Site-wide cleanup alternative is identified.

3 Cleanup Standards

This section provides a summary of applicable cleanup standards and identifies constituents of concern (COCs) at the Site. Media-specific cleanup standards consist of compound-specific concentration limits referred to as "cleanup levels" and designate a "point of compliance;" that is, the physical location at which the cleanup levels must be achieved.

3.1 Groundwater Cleanup Standards

The Washington State MTCA provides two "methods" for deriving groundwater cleanup levels for unrestricted land use. Both are based on protection of groundwater for its highest beneficial use (i.e., drinking water). MTCA Method A cleanup levels, available for the more common contaminants, are "intended to provide conservative levels," and are typically used for routine cleanup actions at relatively simple sites. Method B cleanup levels are provided for a much more extensive list of contaminants, and can be used at all sites. Current values for both Method A and Method B can be looked up in the Cleanup Level and Risk Calculations (CLARC) database available on Ecology's website.

Table 1 lists available Method A and Method B groundwater cleanup levels for each of the COPCs identified in the RI report. The last column in the table lists the cleanup levels proposed for use at this Site. On this basis, Site COCs in groundwater include:

- Total petroleum hydrocarbon (TPH) in the diesel and motor oil ranges;
- The metals arsenic and lead; and
- Trichloroethene (TCE).

In addition, MTCA addresses protection of groundwater from the potential impacts of non-aqueous-phase liquid (NAPL) by requiring that soil with NAPL exceeding "residual saturation" be removed. WAC 173-340-747(10) defines residual saturation as the concentration above which NAPL in soil will continue to migrate due to gravimetric and capillary forces and may eventually reach groundwater. As discussed in the RI report, although a wide range of petroleum hydrocarbon liquids were likely disposed of at the Site, many decades of weathering (since landfilling activities ceased by the mid-1950s) has left behind a high-viscosity mixture of relatively low-solubility compounds. LNAPL in vadose zone soils is likely trapped in the soil pore spaces (i.e., no longer moving downward), and the thickness and areal extent of LNAPL at the water table are unlikely to increase over time.

Whenever practicable, the point of compliance for achieving groundwater cleanup levels is throughout the aquifer. As discussed later in this report, achieving cleanup levels in the immediate vicinity of the deep petroleum hydrocarbon impacts is not practicable, and a conditional point of compliance near the School property boundary is proposed.

Hereafter in this FS, the term "clean groundwater" refers to groundwater that does not contain COCs at concentrations in excess of the Table 1 proposed cleanup levels.

3.2 Soil Cleanup Standards

Table 2 lists Method A and Method B soil cleanup levels for each of the COPCs identified in the RI report. The two Method B columns address different exposure pathways. One addresses direct contact exposure, which generally applies to soils within 15 feet of ground surface. Cleanup levels for protection of direct contact exposure can be looked up in Ecology's CLARC database. The other column addresses the soil-to-groundwater pathway (drinking water protection), which applies to soils at all depths. Site-specific cleanup levels for protection of drinking water were calculated using the procedures in WAC 173-340-747(4). Table 2 identifies Site COCs in soil and lists proposed cleanup levels for direct contact and drinking water protection. Site COCs in soil include:

- Total petroleum hydrocarbon (TPH) in the diesel and motor oil ranges;
- The metals antimony, arsenic, chromium (III), copper, lead, and zinc;
- TCE; and
- Carcinogenic polycyclic aromatic hydrocarbons (cPAHs).

Hereafter in this FS, the term "clean soil" refers to soil that does not contain COCs at concentrations in excess of the Table 2 proposed cleanup levels.

3.3 Air/Soil Vapor Cleanup Standards

COPCs in air/soil vapor were identified in consultation with Ecology during development of the site-specific Soil Vapor Intrusion Assessment Work Plan in 2010 (Aspect, 2010c). These are listed in Table 3 along with their current Method B air cleanup levels (from the CLARC database). As noted above, two rounds of sub-slab vapor sampling have been completed inside the main school building. A major reason for choosing to sample sub-slab vapor rather than sampling indoor air directly is that, for many of the COPCs, the analytical laboratory's reporting limits were considerably higher than the corresponding Method B air cleanup levels. Sampling sub-slab vapor allows a cross-slab attenuation factor of 10 to be applied, which effectively raises the target concentrations against which the sampling results are compared.

4 Remedial Action Objectives

Remedial action objectives (RAOs) are medium-specific or site-specific goals for protecting human health and the environment. They are established based on the nature and extent of contamination, the receptors that are currently and potentially threatened, and the potential for human and environmental exposure. Proposed RAOs for this Site include the following:

- Minimize the potential for direct-contact exposure to landfilled materials and soils with contaminant concentrations exceeding cleanup levels;
- Continue to ensure that the air in Site structures is not unacceptably impacted by soil vapor intrusion;

- Remediate LNAPL to the maximum extent practicable;
- Minimize the potential for ingestion of groundwater with contaminant concentrations exceeding cleanup levels; and
- Meet groundwater cleanup levels at a conditional point of compliance established near the School property boundary.

5 Applicable or Relevant and Appropriate Requirements

Any future remedial action at the Site must comply not only with MTCA requirements, but also with the environmental standards set forth in other applicable laws. In addition, even though Ecology may select the cleanup remedy based on its ability to comply with state hazardous waste cleanup laws, the remedy must also comply with the substantive elements of other applicable environmental reviews and permitting requirements. This section discusses applicable or relevant and appropriate requirements (ARARs) that may apply to any future remedial action at the Site.

5.1 Chemical-Specific ARARs

Chemical-specific ARARs are allowable concentration limits for COCs in affected media. Chemical-specific ARARs that may apply to COCs in Site soil, groundwater, and air/soil vapor are listed below:

- Washington State Model Toxics Control Act (WAC 173-340)
- Federal Safe Drinking Water Act (40 CFR Part 141)
- Washington State Safe Drinking Water Act (WAC 246-290)
- Federal Clean Water Act (33 USC 466 et seq.)
- National Toxics Rule (40 CFR Part 131)

5.2 Location-Specific ARARs

Location-specific ARARs are regulations and requirements that apply to the Site based on its geographic location or physical condition. Location-specific ARARs for the Site may include:

- National Historic Preservation Act

5.3 Action-Specific ARARs

Action-specific ARARs are specific to technologies applied or actions taken in implementing a remedy at a hazardous waste site. Action-specific ARARs that may apply at the Site include:

- State Environmental Policy Act (WAC 197-11)
- National Pollutant Discharge Elimination System (NPDES)

- Washington Water Pollution Control Act (WAC 137-201A)
- Washington State Waste Discharge Program (WAC 173-216)
- Resource Conservation and Recovery Act (RCRA)
- Washington State Minimum Functional Standards for Solid Waste Handling (WAC 173-304)
- Washington State Dangerous Waste Regulations (WAC 173-303)
- USDOT/WSDOT Regulations (49 CFR Parts 171-180, WAC 173-160)
- Washington State Water Well Construction Regulations (WAC 173-160)

6 Extent of Cleanup Level Exceedances

6.1 Landfilled Materials and Near-Surface Impacted Soils

Cleanup level exceedances in Site soils closely correlate with the distribution of landfilled materials. Grid-based sampling was conducted during the RI to investigate soil quality to a depth of 15 feet bgs. An initial round of sampling covered the entire historical footprints of the north and south landfill areas. A 50-foot grid spacing was used, and soil samples were collected for laboratory analysis from three depth intervals: 0 to 3, 6 to 9, and 12 to 15 feet bgs. Based on initial round results, a second round of sampling was conducted north of the portable classroom building and south of the main school building using a 25-foot grid spacing and sampling the 0- to 1-foot depth interval. Sampling results for arsenic, lead, and petroleum contaminants are shown on Figures 14 through 17 of the RI report (Aspect, 2013). Results indicated that soils within 1 foot of ground surface were impacted at concentrations in excess of the RI screening levels in a portion of the south landfill area. (For these constituents, the soil cleanup levels proposed in Table 2 are the same as the RI screening levels.) Those soils were excavated and disposed of off-site in the spring 2012 interim action described in Section 2. Two additional areas within the second-round sampling boundaries, where soil screening levels were exceeded in the 1- to 3-foot depth range, were subsequently addressed in the summer 2013 interim action.

Comparing post-interim action soil quality with the proposed soil cleanup levels (Table 2), there are five Site locations with cleanup level exceedances within 3 feet of ground surface. As shown on Figure 3, three of these are interim action areas. The remaining two are identified as exploration locations. At those locations, the COC causing the cleanup level exceedance (arsenic or lead) and the magnitude of the exceedance are shown on the figure. Existing conditions within 3 feet of ground surface at the five locations are summarized as follows:

- **Spring 2012 Interim Action.** Cleanup level exceedances in the 1- to 3-foot depth range for motor oil-range TPH, benzo(a)pyrene, and several metals are covered (bottom to top) by a geotextile fabric, a minimum 1-foot thickness of clean soil, and sod.

- **Summer 2013 Interim Action, South Landfill Area.** Inferred cleanup level exceedances for lead in the 2- to 3-foot depth range are covered by a minimum 2-foot thickness of clean soil and sod, with a geotextile fabric installed at approximately 1 foot bgs.
- **Summer 2013 Interim Action, North Landfill Area.** Same conditions as described above for the Summer 2013 Interim Action, South Landfill Area.
- **Exploration SG-J10.** Soil sampling results at this location indicate clean soil to 1-foot depth and a marginal cleanup level exceedance for arsenic in the 1- to 3-foot depth range. Ecology did not require that this location be addressed in the summer 2013 interim action because: 1) the arsenic detection was barely above the proposed cleanup level; and 2) the location is not on school property.
- **Exploration NG-M4.** The 0- to 3-foot soil sample result at this location exceeds the proposed cleanup level for lead. Ecology did not require that this location be addressed in the summer 2013 interim action because it is paved. This is the only Site location where a soil cleanup level exceedance has been detected outside the two landfill areas, irrespective of sampling depth.

6.2 Deep Petroleum Hydrocarbon and Groundwater Impacts

A 3-D visualization of deep petroleum hydrocarbon impacts in the north landfill area is provided on Figure 4. Petroleum hydrocarbon is present in soils beneath the landfilled materials as TPH in the diesel and motor oil ranges adsorbed to vadose zone soils and as LNAPL. LNAPL is present at the water table, as well as in soil pore spaces along the entire vadose zone soil column (e.g., at MW-13). As discussed in Section 3.1, the viscosity of the LNAPL has increased over many decades of weathering, and further downward movement through the soil column, or lateral movement at the water table, is unlikely.

Water table LNAPL thicknesses were measured during groundwater monitoring rounds using an oil/water interface probe. LNAPL thickness measurements were highly variable from one monitoring round to the next. Reasons for this high variability likely included the following:

- Measurement error (As discussed in Section 4.2.4 of the RI, the viscous, sticky nature of the LNAPL resulted in inconsistent readings using the oil/water interface probe.)
- Fluctuations in water table elevation (Measured LNAPL thicknesses typically decrease with increasing water table elevation.)
- Delayed entry of the viscous LNAPL into a newly-installed well (This may explain why LNAPL was not observed initially in MW-16.)
- LNAPL removal during the November 2012 bailing test (discussed in Section 4.2.3 of the RI) resulted in a large reduction in LNAPL thickness in MW-13. Subsequent thickness increases measured in that well can also likely be attributed to post-removal recovery (i.e., return to dynamic equilibrium).

Table 4 provides a summary of LNAPL thicknesses measured during the RI/FS, along with LNAPL volumes removed in a bailing test. LNAPL has been observed in four wells, with a maximum thickness of 4.9 feet measured (in MW-13) on December 17, 2013. Figure 4 depicts LNAPL thicknesses measured on August 7, 2013. Measurements on that date were used to estimate the TPH mass of water table LNAPL for the purpose of developing and evaluating remedial alternatives in this FS. The TPH concentrations used to estimate TPH mass in vadose zone soils are also shown on Figure 4 (selected borings). Calculations for TPH mass at the water table and in vadose zone soils are provided in Appendix A. Resulting mass estimates are:

• **Water table LNAPL**	**60,000 kg**
• **TPH in vadose zone soils**	**<u>600,000 kg</u>**
TPH mass in soils beneath landfilled materials:	**660,000 kg**

Figure 5 shows TPH concentrations measure in groundwater samples collected in fall 2012 along with the estimated areal extent of the dissolved TPH “plume” (i.e., concentrations above proposed groundwater cleanup levels). The TPH plume extends only a short distance downgradient of the water table LNAPL. This is evidenced by the fact that LNAPL was consistently observed in MW-8 during the RI, but TPH concentrations in groundwater collected from MW-15, approximately 40 feet downgradient of MW-8, were consistently below proposed cleanup levels. Dissolved TPH concentrations are likely attenuated via biological processes and, due to the age of the release, the plume is expected to be either stable or retreating. The TPH mass dissolved in groundwater is negligible compared to the mass of water table LNAPL.

Figure 5 also shows groundwater cleanup level exceedances detected in fall 2012 for arsenic (at well MW-6) and TCE (at well MW-9). In both cases, measured concentrations only marginally exceed the respective proposed cleanup levels, and wells located short distances downgradient (and in other directions) demonstrate the localized nature of the exceedances. As discussed in the RI report, other wells initially exhibited marginal exceedances for arsenic and lead, but those concentrations declined over the course of the RI to below proposed cleanup levels. That is why lead is identified as a COC in groundwater even though there are no current cleanup level exceedances.

In summary, the water table LNAPL and plumes of impacted groundwater are of limited extent (exclusively on School property) and are likely no longer advancing.

7 Identification of Applicable Remedial Technologies

7.1 Landfilled Materials and Near-Surface Impacted Soils

Containment is typically the most practical general response action for landfilled materials. Containment technologies generally include covers and caps. Covers typically consist of clean soil layers with shallow-rooting vegetation (e.g., sod) and may include a geotextile fabric, as is the case in the interim action area covers. The primary purpose of covers is to provide a barrier for protection against direct contact exposure to underlying contaminants. Caps include a low permeability layer (e.g., a geomembrane or clay layer) which can also provide protection against the soil-to-groundwater pathway (by limiting surface water infiltration) as well as the vapor intrusion pathway. WAC 173-304-460(3)(e) provides specifications for a minimum functional standards (MFS) cap for closure of non-hazardous (Subtitle D) landfills. ”Hard” surface features such as pavement and buildings provide protection against direct contact exposure and also reduce surface water infiltration.

Excavation and offsite disposal can be a practical option for localized areas of near-surface impacted soils, as exemplified by the spring 2012 interim action. *In situ* treatment technologies are not generally considered practical for landfilled materials and associated impacted soils due the wide range of contaminants present and the heterogeneous nature of the contaminated media.

7.2 Deep Petroleum Hydrocarbon and Groundwater Impacts

Excavation of TPH-impacted soils is impracticable due to their depth, quantity, and location beneath landfilled materials. Physical removal of mobile LNAPL (e.g., by pumping or bailing it from wells) was assessed via an LNAPL bailing test conducted during the RI. Test results, as well as experience at other LNAPL sites, suggest that only a small fraction of the LNAPL present at the Site is likely recoverable using physical removal methods.

At the groundwater table, water and LNAPL coexist in the soil pores. As LNAPL is removed, the fraction of pore space occupied by water increases, and LNAPL flow paths become more restricted. This further reduces LNAPL mobility. Ultimately, the LNAPL breaks into discontinuous blobs and ganglia trapped within the larger soil pore spaces. For this reason, even the more aggressive removal methods, such as dual pump systems that recover large volumes of groundwater that must be processed, would likely be unable to remove a substantial fraction of the LNAPL at the water table.

Potentially applicable technologies for *in situ* treatment of deep petroleum hydrocarbon at this site include thermal (steam and electrical), surfactants, and chemical oxidants. Primary factors limiting these technologies are uncertain efficacy and high cost. Properly applied, one or a combination of these technologies could likely remove a large fraction of the LNAPL. However, treatment efficiencies approaching 100 percent are not realistic, and residual LNAPL contamination would continue to leach to groundwater. The cost of *in situ* treatment must be weighed against the benefits derived. Table 5 compares site-specific conditions where the need for *in situ* treatment of LNAPL is more apparent (e.g., known impacts to receptors from the LNAPL source) and less apparent (e.g., stable or shrinking dissolved-phase plume with no known impacts to receptors). Based on the factors identified in the table, the need for *in situ* treatment of LNAPL is low.

Contaminated groundwater plumes at this Site are of limited extent, and are confined to the School property. Although LNAPL continues to leach petroleum hydrocarbon constituents to groundwater, the dissolved TPH plume extends only a short distance downgradient of the water table LNAPL. As long as some portion of this TPH source remains there would be limited benefit to implementing a technology specifically aimed at reducing TPH concentrations in groundwater. On the other hand, TPH concentrations in groundwater would be expected to rapidly attenuate following effective treatment of the TPH source.

As discussed in the RI report, the arsenic exceedance at well MW-6 is likely caused by the impact of the upgradient TPH contamination on subsurface conditions (increasing arsenic mobility in groundwater). Therefore, it is probably not useful to consider technologies for reducing arsenic concentrations in groundwater; addressing the TPH exceedances in groundwater would likely address the arsenic exceedances as well.

The TCE exceedance in groundwater beneath the northern portion of the north landfill area (at well MW-9) is probably due to leaching from the landfilled materials. The groundwater impacts would likely be most efficiently addressed by reducing the leaching or by eliminating the source itself. *In situ* chemical oxidation is a candidate technology for treating TCE in groundwater.

7.3 Institutional Controls

Institutional controls are mechanisms for ensuring the long-term performance of cleanup actions. While not considered a stand-alone remedial technology, institutional controls would be an integral component of remedies where contaminants exceeding cleanup levels remain at the Site. Institutional controls involve administrative/legal tools to provide notification regarding the presence of contaminated materials, regulate the disturbance/management of these materials and the cleanup action components, and provide for long-term care of cleanup actions including long-term monitoring. Under MTCA, the legal instruments for applying institutional controls are termed environmental covenants, equivalent to restrictive covenants for a specific property or portion of a property.

Examples of institutional controls that would be potentially applicable to this Site include a requirement to monitor the integrity of landfill cap/cover features and a prohibition against the installation of drinking water wells. Institutional controls proposed for inclusion in specific remedial alternatives are described in Section 8 in sufficient detail to facilitate alternative evaluation in Section 9. Following remedy selection, details of the required institutional controls and their implementation will be further developed in the Cleanup Action Plan (CAP) and remedy implementation work plans.

8 Development of Remedial Alternatives

In this section, applicable technologies are assembled into a range of area/media-specific remedial alternatives, including three alternatives (A1 through A3) addressing landfilled materials and near-surface impacted soils, and four (B1 through B4) addressing deep petroleum hydrocarbon and groundwater impacts. Each alternative is described, and conceptual design criteria and assumptions are briefly discussed. This provides the basis for estimating the cost of each alternative. Net Present Value (NPV) costs, in 2013 dollars, were estimated using a discount rate of 1.6 percent. Long-term inspection, monitoring, and maintenance (IM&M) costs were evaluated over a 30-year period, consistent with EPA guidance. The estimates are order-of-magnitude, with an intended accuracy in the range of -30 to +50 percent. Sunk costs for the completed interim actions are included in the estimates for the alternatives addressing landfilled materials and near-surface impacted soils.

The components that make up each area/media-specific remedial alternative are summarized in Table 6, and itemized cost estimates for each alternative are presented in Appendix B.

8.1 Remedial Alternatives for Landfilled Materials and Near-Surface Impacted Soils

The remedial technologies that were discussed in Section 7.1 as being applicable to landfilled materials and near-surface impacted soils were assembled into the following alternatives:

- Alternative A1 – No Additional Action
- Alternative A2 – Institutional Controls and Maintenance of Existing Cover
- Alternative A3 – Landfill Cap

Each of these remedial alternatives is described below. Excavation (beyond that accomplished in the spring 2012 interim action) was not included as a component of any alternative since containment of contaminated media is provided by existing cover features, and in-place containment is the “presumptive remedy” for landfilled materials.

8.1.1 Alternative A1 – No Additional Action

Under this “no action” alternative, no additional remediation or long-term monitoring would take place, and future Site activities would not be restricted by institutional controls. The purpose of this alternative is to provide a “baseline” against which the other alternatives addressing landfilled materials and near-surface impacted soils are compared.

The cost estimate for this alternative includes the cost of the completed interim actions (sunk cost), but assumes that there are no future costs.

8.1.2 Alternative A2 – Institutional Controls and Maintenance of Existing Cover

The results of the RI grid sampling of near-surface soils indicate that landfilled materials and soil with cleanup level exceedances are currently covered by either hard surface features or a minimum 1-foot thickness of clean soil. In addition, sub-slab vapor sampling indicated that air quality is acceptable inside the school building under current conditions. Under Alternative A2, the existing cover features that provide protection against direct contact exposures would be maintained, and controls would be put in place to minimize the potential for exposure to contaminants remaining at the Site. Components of this alternative would likely include the following:

Cover Inspection and Maintenance – The existing visible cover features (soil, sod, and pavement) that provide protection against direct contact exposure to landfilled materials and near-surface impacted soils would be periodically inspected, and maintenance would be performed as needed to ensure continued protection. An inspection and maintenance manual would be developed addressing inspection procedures, routine maintenance, and documentation requirements.

Engineering Control and Periodic Testing Addressing School Indoor Air – These components would include a requirement to run the HVAC system in the existing school building throughout the school day, and to periodically test sub-slab soil vapor and/or indoor air quality, to reconfirm that vapor intrusion is not a concern.

Institutional Controls – Environmental covenants would be recorded with Kitsap County for the School and Church properties where contaminants remain above cleanup levels. The covenants would prohibit or restrict activities on the properties that would interfere with the integrity of the existing cover or continued protection of human health. Specific restrictions and requirements for Site use may include:

- A requirement to use only personnel with health and safety training for any invasive work performed in the north and south landfill areas, and to notify such personnel of subsurface conditions;
- A requirement to evaluate vapor intrusion potential and/or incorporate vapor controls into future buildings constructed in the immediate vicinity of the north or south landfill areas; and
- A requirement to monitor the integrity of the existing cover features that provide protection against direct contact exposures, and provide reports to Ecology.

8.1.3 Alternative A3 – Landfill Cap

Except for the building footprint and paved areas, the existing cover systems at the Site do little to impede water infiltration, which can result in leaching of contaminants to groundwater. In Alternative A3, a cap would be installed over the landfill areas and areas of impacted soils. For purposes of alternative evaluation in this FS, it is assumed that the cap would be designed to meet Washington State standards for closure of a solid waste landfill in accordance with WAC 173-304-460(3)(e). These include:

- A final cover soil layer consisting of a minimum 2-foot thickness of 1x10-6 cm/sec or lower permeability soil. Artificial liners may replace soil covers provided that a minimum of 50 mils thickness is used.
- The grade of surface slopes must be 2 percent minimum, and the grade of side slopes may not exceed 33 percent.
- A minimum 6-inch thickness of top soil seeded with grass, other shallow-rooted vegetation, or other native vegetation.

This alternative would include requirements similar to those outlined above for Alternative A2 with respect to cover inspection and maintenance, engineering/institutional controls, and periodic air quality testing.

For cost estimating purposes, it was assumed that pavement would be removed and replaced in areas to be capped, but the main school building would remain in place. The total cap area was assumed to be 20 percent larger than the combined north and south landfill areas (approximately 6.6 acres).

8.2 Remedial Alternatives for Deep Petroleum Hydrocarbon and Groundwater Impacts

The remedial technologies that were discussed in Section 7.2 as being applicable to deep petroleum hydrocarbon and groundwater impacts were assembled into the following alternatives:

- Alternative B1 – No Action;
- Alternative B2 – Physical Removal of LNAPL, Institutional Controls, and Long-Term Monitoring;
- Alternative B3 – *In Situ* Treatment of Water Table LNAPL; and
- Alternative B4 – *In Situ* Treatment of LNAPL, Impacted Vadose Zone Soils, and Groundwater.

Each of these remedial alternatives is described below.

8.2.1 Alternative B1 – No Action

Under this alternative, no additional remediation or long-term monitoring would take place, and future Site activities would not be restricted by institutional controls. The purpose of this alternative is to provide a "baseline" against which the other alternatives addressing deep petroleum hydrocarbon impacts are compared.

8.2.2 Alternative B2 – Physical Removal of Mobile LNAPL, Institutional Controls, and Long-Term Monitoring

Under this alternative, mobile LNAPL would be physically removed from the subsurface to the extent practicable, the potential for exposure to deep contamination would be minimized by implementing institutional controls, LNAPL thickness/extent and groundwater quality would be monitored on a long-term basis, a contingency plan would be developed addressing contaminant migration, and a conditional point of compliance would be established near the School property boundary.

Physical Removal of Mobile LNAPL – This would likely be accomplished by bailing the LNAPL from existing monitoring wells on a periodic basis. Bailing would be conducted in accordance with an LNAPL Removal Work Plan, at a frequency dictated by the rate at which LNAPL re-enters the well (i.e., periodic LNAPL removal will continue until the rate at which LNAPL enters a well is reduced to the point that further periodic removal from that well is impracticable). Recovered LNAPL would be temporarily stored at the site in secured 55-gallon drums prior to offsite recycling or disposal. Based on remedial technology evaluation and on results of the LNAPL bailing test conducted during the RI, this removal technique is expected to recover only a limited extent of the water table LNAPL.

Institutional Controls – An environmental covenant would be recorded with Kitsap County prohibiting invasive activities such as drinking water well installation that may result in exposure to LNAPL and groundwater contamination.

Long-Term Monitoring and Contingency Plan – Long-term monitoring would include:

- Periodic LNAPL layer thickness monitoring, to verify that the volume and areal extent of LNAPL is stable or shrinking.
- Periodic groundwater quality monitoring, to verify that the areal extent of contaminated groundwater is stable or shrinking.

The long-term monitoring proposed in this alternative is distinct from monitored natural attenuation (MNA) in that there is no expectation that the contamination will attenuate over a "reasonable restoration time frame." Similar to a containment solution for the landfilled materials (the presumptive remedy), the goal here is to ensure that the LNAPL and groundwater contamination do not spread beyond their current boundaries. A contingency plan would be developed which specifies how monitoring results are evaluated and the steps to be taken in the event that LNAPL or contaminated groundwater migration closer to the current property boundary is indicated.

Conditional Point of Compliance for LNAPL Migration – Existing monitoring well MW-6 is proposed as an appropriate conditional point of compliance for LNAPL migration. If LNAPL is detected during periodic monitoring of this well, more aggressive measures to prevent further LNAPL migration would need to be considered.

Conditional Point of Compliance for Achieving Groundwater Cleanup Levels – A conditional point of compliance for contaminants dissolved in groundwater would be established near the School property boundary. Monitoring results indicate that groundwater cleanup level exceedances (TPH, TCE, and arsenic) are confined to the School property, and dissolved contaminant plumes are likely either stable or shrinking. Existing monitoring well MW-10 is proposed as an appropriate conditional point of compliance for achieving groundwater cleanup levels.

8.2.3 Alternative B3 – In Situ Treatment of Water Table LNAPL

Under this alternative, LNAPL at the water table would be treated *in situ* with the goal of maximizing removal of LNAPL mass. As discussed in Section 7.2, multiple *in situ* technologies are available for treating petroleum hydrocarbon-based LNAPL. For the purposes of evaluating this alternative and estimating costs, it is assumed that electrical resistance heating (ERH) is selected for implementation.

ERH was developed in the petroleum industry for heating oil sands and shales to enhance oil recovery. Electrical current is passed into the targeted portion of the subsurface (in this case the water table LNAPL area) through a grid of closely spaced vertical electrodes. As the current causes the target area temperature to rise, petroleum hydrocarbons are volatilized and extracted via soil vapor extraction (SVE) wells. The extracted vapor mixture is passed through an air/water separator (AWS) tank. The tank's vapor effluent passes through a heat exchanger and another AWS to condense contaminants and water vapor. The vapor effluent from the second AWS is sent through a catalytic oxidizer (CATOX) to treat the remaining VOCs before being discharged to the atmosphere. The liquid effluents from both AWS tanks are separated by gravity into petroleum hydrocarbon and aqueous streams. The aqueous stream may be re-injected to maintain moist conditions at the electrodes.

The rise in temperature of soils in the target area is tracked by an array of thermocouples. The treatment endpoint is typically established as achieving a minimum target temperature throughout the treatment area. In addition to contaminant volatilization, other potential ERH treatment mechanisms (either short- or long-term) are enhanced biodegradation and abiotic reactions such as hydrolysis.

Potential advantages of ERH relative to other *in situ* treatment technologies include rapid remediation, less sensitivity to soil heterogeneities, no introduction of chemicals to the subsurface, and promotion of biotic and abiotic contaminant degradation processed (due to elevated temperatures). Potential disadvantages include high capital cost, high power consumption, and the need to capture and manage the vapors generated.

The Navy evaluated the cost and performance of ERH in five full-scale applications at other sites (NFESC, 2007). Treatment costs, excluding site preparation, project oversight and management, and other costs incurred by the site owners, reportedly ranged from $4 to $20 per cubic foot of aquifer treated. For estimating the ERH treatment cost in this alternative, we assumed an aquifer treatment area 20 percent larger than the LNAPL area shown on Figure 5, an aquifer treatment thickness of 10 feet, and a unit cost of $20/ft^3 (the high end of the cost range reported by the Navy, due to the considerable depth of the water table LNAPL).

By aggressively treating water table LNAPL, some treatment of contaminants in adjacent groundwater and vadose zone soils would also result; however, the majority of vadose zone soil contamination would not be treated. Unless an impermeable cap is installed over the north landfill area (Alternative A3), vadose zone soils and the landfilled materials would continue to act as sources of contaminants leaching to groundwater.

8.2.4 Alternative B4 – In Situ Treatment of LNAPL, Impacted Vadose Zone Soils, and Groundwater

Under this alternative, it is assumed that ERH is applied to TPH-impacted vadose zone soils as well as to water table LNAPL. For estimating the ERH treatment cost, we assumed an aquifer treatment volume 10 percent larger than the impacted vadose zone soil volume calculated in Appendix A, and a unit cost of $12/ft^3 (the midpoint of the cost range reported by the Navy).

After ERH treatment is completed, it is assumed that *in situ* chemical oxidation (ISCO) is used to treat TPH and TCE dissolved in groundwater. (Arsenic concentrations in the vicinity of well MW-6 are expected to naturally attenuate to below the cleanup level due to altered geochemical conditions resulting from ERH treatment.) Two chemical injection events are assumed to be required, with follow-up confirmation groundwater quality monitoring. The cost of ISCO treatment of groundwater is expected to be negligible compared to that of ERH treatment of soils.

TPH contamination in soils beneath the north landfill area is assumed to be largely (but not completely) removed or treated in this alternative. However, unless an impermeable cap is installed over the north landfill area (Alternative A3), the landfilled materials may continue to act as sources of TPH and TCE leaching to groundwater.

9 Evaluation of Remedial Alternatives

9.1 Feasibility Study Evaluation Criteria

This section discusses the minimum requirements and procedures for selecting cleanup actions under MTCA (WAC 173-340-360).

9.1.1 MTCA Threshold Requirements

Cleanup actions selected under MTCA must meet four “threshold” requirements identified in WAC 173-340-360(2)(a) to be accepted by Ecology. All cleanup actions must:

- Protect human health and the environment;
- Comply with cleanup standards;
- Comply with applicable state and federal laws; and
- Provide for compliance monitoring.

9.1.2 MTCA Selection Criteria

When selecting from remedial alternatives that meet the threshold requirements, the following three criteria, identified in WAC 173-340-360(2)(b), must be evaluated:

- **Use permanent solutions to the maximum extent practicable.** A disproportionate cost analysis (DCA) is conducted to assess the extent to which the remedial alternatives address this criterion. The general procedure for conducting a DCA is described in Section 9.1.3.
- **Provide a reasonable restoration time frame.** MTCA places a preference on remedial alternatives that can be implemented in a shorter period of time. Factors to be considered in evaluating whether an alternative provides for a reasonable restoration time frame (per WAC 173-340-360(4)(b)) are listed in Table 8.
- **Consider public concerns.** Consideration of public concerns is an inherent part of the Site cleanup process under MTCA. This Draft FS report will be issued for public review and comment, and Ecology will determine whether changes to the report are needed in response to public comments.

9.1.3 MTCA Disproportionate Cost Analysis

A DCA is conducted to determine whether a cleanup action uses permanent solutions to the maximum extent practicable. This is done by evaluating the relative benefits and costs of remedial alternatives. Seven criteria are considered in the evaluation as specified in WAC173-340-360(3)(f):

- **Protectiveness –** overall protectiveness of human health and the environment, including the degree to which existing site risks are reduced, time required to reduce the risks and attain cleanup standards, on-site and off-site risks during implementation, and improvement in overall environmental quality.
- **Permanence –** degree to which the alternative reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of destroying hazardous

substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of treatment, and the characteristics and quantity of the treatment residuals.

- **Cost –** Remedy design, construction, and long-term O&M costs to implement the alternative.
- **Long-term effectiveness –** degree of certainty that the alternative will successfully and reliably address contamination that exceeds applicable cleanup levels until cleanup levels are attained, the magnitude of the residual risk with the alternative in place, and the effectiveness of controls to manage treatment residue and remaining wastes.
- **Short-term risk management –** the risks to human health and the environment during construction and implementation of the alternative, and the effectiveness of measures that will be taken to manage such risks.
- **Implementability –** includes consideration of whether the alternative is technically possible; the availability of necessary offsite facilities, services, and materials; administrative and regulatory requirements; scheduling, size, and complexity of the alternative; monitoring requirements; access for construction, operations, and monitoring; and integration with existing facility operations and other current or potential remedial actions.
- **Consideration of public concerns –** concerns from individuals, community groups, local governments, tribes, federal and state agencies, and other interested organizations will be addressed by Ecology responding to public comments on this Draft FS report and the subsequent Draft CAP.

The DCA is based on a comparative evaluation of an alternative's cost against the other six criteria (environmental benefits). Per WAC 173-340-360(3)(e)(i), cost is disproportionate to benefits if the incremental cost of an alternative over that of a lower-cost alternative exceeds the incremental degree of benefits achieved by the alternative over that of the lower-cost alternative.

9.2 Screening Evaluation with Respect to Threshold Criteria

In Section 9.3, Site-wide remedial alternatives are assembled for detailed evaluation as combinations of the area/media-specific alternatives developed in Section 8. In order to limit the detailed evaluation to a manageable number of Site-wide alternatives, the area/media-specific alternatives are first screened to eliminate from further consideration any alternatives that clearly do not satisfy the threshold criteria.

9.2.1 Screening of Alternative A1

Under Alternative A1, the existing cover features would not be maintained and institutional controls would not be implemented to prevent potential future exposures to impacted soil and landfilled materials. Therefore, this alternative is not adequately protective of human health and the environment (the first of the threshold criteria) under future conditions. Since Alternative A1 does not fully satisfy this threshold criterion, it is excluded from further consideration.

9.2.2 Screening of Alternative B1

Under Alternative B1, institutional controls would not be implemented to prevent activities such as water supply well installation in or near the north landfill area that could result in exposure to impacted groundwater. Therefore, this alternative is not adequately protective of human health and the environment under future conditions. Since Alternative B1 does not fully satisfy this threshold criterion, it is excluded from further consideration.

9.2.3 Screening of Other Area/Media-Specific Alternatives

Unlike the “baseline” alternatives A1 and B1, area/media-specific alternatives A2, A3, and B2 through B4 were specifically developed to comply with the threshold criteria. Combinations of these alternatives are assembled into Site-wide alternatives below, for detailed evaluation with respect to the MTCA criteria. Compliance of the Site-wide alternatives with the individual threshold criteria is discussed in Section 9.4.

9.3 Assembly of Site-Wide Alternatives for Detailed Evaluation

The area/media-specific alternatives retained above were combined into the following three Site-wide remedial alternatives:

- **Alternative A2/B2 –** Periodic inspection and maintenance of the existing cover and physical removal of LNAPL from existing wells;
- **Alternative A3/B3 –** Landfill cap and *in situ* treatment of LNAPL at the water table; and
- **Alternative A3/B4 –** Landfill cap and *in situ* treatment of impacted vadose zone soils, LNAPL at the water table, and groundwater.

The elements of each Site-wide alternative are listed in Table 7. Table 9 lists the estimated cost of each Site-wide alternative, which is simply the sum of the estimated costs for the two area/media-specific alternatives that comprise the Site-wide alternative. Estimated costs for both area/media-specific and Site-wide alternatives are summarized in Table B.1 (Appendix B).

9.4 Evaluation with Respect to MTCA Threshold Requirements

The three Site-wide remedial alternatives are evaluated for compliance with the MTCA threshold criteria in this section. Evaluation results are summarized in Table 7.

9.4.1 Protection of Human Health and the Environment

Human health and the environment are protected under current exposure conditions. The areal extent of water table LNAPL and groundwater impacts is confined to the School property, and there are no water supply wells in the vicinity of those impacts. The deep impacted media are effectively isolated from the ambient environment. All landfilled materials and near-surface impacted soils are covered by one of the following protective barriers:

- A minimum 1-foot thickness of clean cover soil; or
- A “hard” surface (e.g., asphalt pavement).

These barriers would not be modified in Alternative A2/B2. In Alternatives A3/B3 and A3/B4, a low-permeability cap designed to meet Washington State standards for closure of a solid waste landfill would be installed over all impacted areas outside the main school building. The primary incremental benefit from cap installation would be reduced infiltration of contaminants to groundwater, not additional protection against direct contact exposure to soil. (However, this benefit would be minimal since, after years without an impermeable cap, the groundwater contamination is localized and does not appear to be spreading.) Thus, Alternatives A3/B3 and A3/B4 would provide enhancements to the existing surface barrier features; however, those enhancements are not considered necessary to effectively protect against direct contact exposures. That is, following implementation of the interim actions, barrier features now in-place at the Site provide adequate protection against direct contact exposure to Site contaminants, and further enhancements are not needed for that purpose.

All three Site-wide alternatives would be protective of human health and the environment under future exposure conditions as well. All three include periodic inspection and maintenance of the cover/cap systems, with reporting to Ecology. Institutional controls would protect personnel performing invasive work, and would require evaluation of vapor intrusion potential if new buildings are constructed in or near impacted areas.

With respect to deep petroleum hydrocarbon and groundwater impacts, Alternative A2/B2 achieves protection through recording of an environmental covenant prohibiting activities that could result in exposure to LNAPL and groundwater contamination. Since LNAPL would remain floating on the water table in this alternative, leaching of petroleum hydrocarbons to groundwater would continue. Alternative A3/B3 would treat water table LNAPL *in situ*. By doing so, the area addressed by covenant prohibitions could potentially be reduced, but an environmental covenant similar to that in Alternative A2/B2 would still likely be required to achieve protection because LNAPL would remain in vadose zone soils. The extensive *in situ* treatment of impacted vadose zone soils and groundwater in Alternative A3/B4, along with landfill capping, may obviate the need for an environmental covenant. However, recording an environmental covenant remains an option in this alternative, if post-treatment conditions indicate that it is needed. Therefore, protection will be achieved in Alternative A3/B4 irrespective of treatment effectiveness.

9.4.2 Compliance with Cleanup Standards

All three Site-wide alternatives would comply with soil cleanup standards primarily through containment of landfilled materials and impacted soils exceeding cleanup levels. (Alternative A3/B4 would also treat vadose zone soils beneath the north landfill area.) The existing cover in Alternative A2/B2 and the landfill cap in Alternatives A3/B3 and A3/B4 would provide a barrier against human direct contact and terrestrial ecological exposures, thereby satisfying the MTCA definition of “containment.” Per WAC 173-340-355(2), a cleanup action involving containment of soils exceeding cleanup levels at the point of compliance may be determined to comply with cleanup standards, provided the requirements specified in WAC 173-340-740(6)(f) are met. Those requirements are[1]:

- The selected remedy is permanent to the maximum extent practicable;
- The cleanup action is protective of human health and terrestrial ecological receptors;
- Institutional controls are put in place that prohibit or limit activities that could interfere with the long-term integrity of the containment system;
- Compliance monitoring and periodic reviews are designed to ensure the long-term integrity of the containment system; and
- The types, levels, and amount of hazardous substances remaining on-site and the measures that will be used to prevent migration and contact with those substances are specified in the draft cleanup action plan.

All three alternatives would be designed and implemented such that the above requirements would be met. Therefore, the alternatives would comply with soil cleanup standards upon completion of remedy construction, development of compliance monitoring plans, and recording of environmental covenants.

Alternatives A2/B2 and A3/B3 would comply with groundwater cleanup levels at a proposed conditional point of compliance near the School property boundary. Aggressive *in situ* treatment of groundwater, water table LNAPL, and vadose zone soils beneath the north landfill area in Alternative A3/B4 may result in groundwater cleanup levels being achieved throughout the aquifer upon completion of remedy construction (although this is not a certainty). If not, the same conditional point of compliance (near the School property boundary) would be established in that alternative to achieve compliance.

Compliance with groundwater cleanup standards also encompasses the MTCA requirement to remove soil with NAPL exceeding residual saturation. This requirement would be addressed in Alternative A2/B2 through periodic LNAPL removal from existing wells, and in Alternatives A3/B3 and A3/B4 through *in situ* treatment of LNAPL at the water table.

9.4.3 Compliance with Applicable State and Federal Laws

Through identification of ARARs (Section 5) and compliance with the MTCA regulation, all three alternatives would comply with applicable state and federal laws.

9.4.4 Provisions for Compliance Monitoring

Under MTCA, compliance monitoring encompasses the following types of monitoring:

- **Protection monitoring** confirms that human health and the environment are adequately protected during construction and the O&M period of a cleanup action;

[1] The requirements of WAC 173-340-740(6)(f) are paraphrased here; refer to the MTCA regulation for the complete language.

- **Performance monitoring** confirms that the cleanup action has attained cleanup levels and/or other performance standards such as construction quality control measurements or monitoring necessary to demonstrate compliance with a permit; and
- **Confirmation monitoring** confirms the long-term effectiveness of the cleanup action once cleanup levels and/or other performance standards have been attained.

All three alternatives would provide for compliance monitoring. A site-specific cleanup action health and safety plan would include protective measures and monitoring to ensure protection of human health and the environment during remedy construction. The landfill cap (in Alternatives A3/B3 and A3/B4) or cover features (in Alternative A2/B2) would be periodically inspected, and maintenance would be performed as needed to ensure long-term effectiveness. Periodic groundwater quality and LNAPL layer thickness monitoring would be conducted as necessary to confirm that the extent of water table LNAPL and dissolved contaminant plume are not increasing.

9.4.5 Conclusion Regarding Compliance with Threshold Requirements

Based on the above evaluation, all three Site-wide alternatives would comply with the MTCA threshold criteria. Therefore, all three alternatives are carried forward to the next stage of evaluation.

9.5 Evaluation with Respect to Reasonable Restoration Time Frame

A cleanup action is considered to have achieved restoration once cleanup standards have been met. As discussed in Section 9.4.2, all three alternatives would meet soil cleanup standards upon completion of remedy construction, development of compliance monitoring plans, and recording of environmental covenants. Alternative A2/B2 has no construction component, and it is expected that compliance monitoring plans would be developed and environmental covenants recorded within 1 year. Design and implementation of *in situ* treatment of water table LNAPL and landfill capping in Alternative A3/B3 is estimated to take 2 to 3 years. The much more extensive *in situ* treatment in Alternative A3/B4 (of impacted groundwater and vadose zone soils as well as water table LNAPL) is estimated to require an additional year (i.e., 3 to 4 years total) to complete.

As discussed in Section 9.4.2, there are two requirements for meeting groundwater cleanup standards:

1. Achieving groundwater cleanup levels at the established point of compliance; and
2. Removing soil with NAPL exceeding residual saturation.

A conditional point of compliance near the School property boundary would be established in Alternatives A2/B2 and A3/B3, and groundwater monitoring results indicate that cleanup levels are currently achieved at that point. In Alternative A3/B4, this requirement would be satisfied upon completion of remedy construction either by achieving cleanup levels throughout the aquifer of by establishing a conditional point of compliance near the School property boundary.

In situ treatment of water table LNAPL in Alternatives A3/B3 and A3/B4 is expected to satisfy the requirement to remove soil with NAPL exceeding residual saturation upon completion of remedy construction. In Alternative A2/B2, this requirement is considered to be satisfied once the rate at which LNAPL enters existing wells is reduced to the point that further periodic LNAPL removal from the wells is impracticable. For purposes of comparatively evaluating the three alternatives with respect to this criterion, it is assumed that this point will be reached in 5 years.

Therefore, based on the above considerations and assumptions, Alternatives A2/B2, A3/B3, and A3/B4 have estimated restoration time frames of 5 years, 2 to 3 years, and 3 to 4 years, respectively.

WAC173-340-360(4)(b) provides a list of factors to be considered to determine whether a cleanup action provides for a reasonable restoration time frame. Table 8 presents an evaluation of the Site-wide remedial alternatives with respect to these factors. Based on that evaluation, all three alternatives are expected to provide for a reasonable restoration time frame.

9.6 Disproportionate Cost Analysis

As described in Section 9.1.3, a DCA is performed to evaluate whether a cleanup action uses permanent solutions to the maximum extent practicable. The DCA quantifies the environmental benefits of each remedial alternative, and then compares alternative benefits versus costs. Costs are disproportionate to benefits if the incremental cost of a more permanent alternative over that of a lower-cost alternative exceeds the incremental benefits achieved by the alternative over that of the lower-cost alternative. Alternatives that exhibit disproportionate costs are considered “impracticable” under MTCA.

The DCA is performed in the following sections and summarized in Table 9. Environmental benefit is quantified by first rating the alternatives with respect to each of the six criteria discussed in Section 9.1.3. Rating values are assigned on a scale of 1 to 10, where 1 indicates the criterion is satisfied to a very low degree, and 10 indicates the criterion is satisfied to a very high degree. Since Ecology does not consider the criteria to be of equal importance, each criterion is assigned a “weighting factor.” Weighting factors are assigned as follows:

- Overall protectiveness: 30 percent;
- Permanence: 20 percent;
- Long-term effectiveness: 20 percent;
- Short-term effectiveness: 10 percent;
- Implementability: 10 percent; and
- Consideration of public concerns: 10 percent.

A MTCA benefits ranking is then obtained for each alternative by multiplying the six rating values by their corresponding weighting factors, and summing the weighted values. Finally, the benefits ranking of each alternative is divided by the alternative's estimated cost to obtain a benefit/cost ratio, which is a relative measure of the cost effectiveness of the alternative.

9.6.1 Overall Protectiveness

The Site-Wide remedial alternatives would all be protective of human health and the environment, but vary in the technologies used to achieve that protectiveness. Alternatives A3/B3 and A3/B4 would address the human direct contact and terrestrial ecological exposure pathways through construction of a cap meeting Washington State standards for closure of a solid waste landfill. Alternative A2/B2, on the other hand, would rely on the existing clean soil and hard surface cover features. Periodic inspection/maintenance and institutional controls would be required in all cases to maintain the integrity of the cover/cap and restrict invasive work in landfill areas.

There is no evidence that LNAPL or groundwater contamination extends beyond the property boundaries, or that contaminant plumes are advancing. Periodic groundwater monitoring and institutional controls prohibiting activities that could result in exposure to groundwater contamination would be required in Alternatives A2/B2 and A3/B3, but would not be needed in Alternative A3/B4 if *in situ* treatment is effective. Therefore, Alternative A3/B4 is considered to be more protective with respect to this potential exposure pathway.

Based on the above considerations, Alternatives A2/B2, A3/B3, and A3/B4 were given ratings of 4, 7, and 8, respectively, for overall protectiveness.

9.6.2 Permanence

Alternative A3/B4 is considered the most permanent alternative because all contaminated media beneath landfilled materials in the north landfill area would be aggressively treated. Alternative A3/B3 would target only a small portion of the contaminant mass beneath the north landfill area (i.e., LNAPL at the water table). In addition, construction of a cap meeting Washington State standards for closure of a solid waste landfill would reduce leaching of contaminants from the north landfill area in those two alternatives. Periodic LNAPL removal from existing wells would not significantly reduce contaminant mass in Alternative A2/B2. However, natural attenuation of TPH in groundwater, which is apparent beneath the north landfill area, would continue to limit expansion of the TPH plume.

Based on the above considerations, Alternatives A2/B2, A3/B3, and A3/B4 were given ratings of 2, 5, and 8, respectively, for permanence.

9.6.3 Long-Term Effectiveness

Alternative A2/B2 would rely on periodic inspection/maintenance and institutional controls to ensure the long-term integrity of the existing cover features. Long-term effectiveness would be marginally increased in Alternatives A3/B3 and A3/B4 due to the more robust cap. However, dependence on periodic inspection/maintenance and institutional controls would remain. *In situ* treatment of LNAPL in Alternatives A3/B3 and A3/B4 would be technically challenging due to its depth and location beneath landfilled materials. Even if LNAPL treatment were highly effective, long-term groundwater monitoring and associated institutional controls would be needed in

Alternative A3/B3 to address residual groundwater contamination. Aggressive *in situ* treatment of groundwater in Alternative A3/B4 may eliminate the need for long-term groundwater monitoring and institutional controls (although this is not a certainty). For this reason, the long-term effectiveness of Alternative A3/B4 is considered to be somewhat greater than that of Alternative A3/B3.

Based on the above considerations, Alternatives A2/B2, A3/B3, and A3/B4 were given ratings of 5, 6, and 8, respectively, for long-term effectiveness.

9.6.4 Short-Term Risk Management

In general, short-term impacts correlate directly with construction duration and the quantities of contaminated materials removed or handled. Although many impacts can be adequately managed through standard construction practices such as health and safety programs and best management practices (BMPs), the potential for worker injuries, exposures, community impacts, and releases to the environment would increase with longer construction periods and greater volumes of contaminated materials handled.

With no construction component, there would be little or no short-term risk to workers, the local community, or the environment in Alternative A2/B2. In Alternative A3/B3, construction of the cap and *in situ* treatment infrastructure would impact the local community (traffic, noise, air emissions, etc.), and workers drilling through landfilled materials would face exposure risks. Short-term impacts associated with *in situ* treatment would be more significant in Alternative A3/B4 since the scale and duration of treatment would be much greater.

Based on the above considerations, Alternatives A2/B2, A3/B3, and A3/B4 were given ratings of 10, 6, and 4, respectively, for short-term risk management.

9.6.5 Implementability

In general, implementability decreases with increased complexity of the alternative. Alternative A2/B2 would be highly implementable since it has no construction component and no significant technical challenges. Use of electrical resistance heating (ERH), a specialized technology, for *in situ* treatment in Alternative A3/B3 would involve significant technical challenges, including accessing the water table LNAPL beneath the landfilled materials. The challenges would be much greater in Alternative A3/B4 due to the much larger scale of treatment. Cap construction around the existing School building in Alternatives A3/B3 and A3/B4 would also present technical challenges. In addition, most construction would need to take place during the summer break period, which would also impact project implementability.

Based on the above considerations, Alternatives A2/B2, A3/B3, and A3/B4 were given ratings of 10, 5, and 2, respectively, for implementability.

9.6.6 Consideration of Public Concerns

Ecology considers and responds to all public comments received on the Draft FS and Draft CAP documents as part of the cleanup process under MTCA. Therefore, for the purposes of this FS, all three alternatives were given a rating of 10 for consideration of public concerns.

9.6.7 Benefits Rankings, Estimated Costs, and Benefit/Cost Ratios

The MTCA benefits rankings, estimated costs, and benefit/cost ratios for the three Site-wide remedial alternatives are presented at the bottom of Table 9 and graphically on Figure 6. As previously noted, the MTCA benefits ranking is obtained for each alternative by multiplying the rating values assigned for the six evaluation criteria by their corresponding weighting factors, and summing the weighted values. The benefit rankings range from a low of 5.6 for Alternative A2/B2 to a high of 7.2 for Alternative A3/B4.

Estimated costs range from $830,000 (Alternative A2/B2) to $21 million (Alternative A3/B4). The cap construction cost, which is a component of Alternatives A3/B3 and A3/B4, is estimated at approximately $2 million.

The benefit/cost ratio, which is a relative measure of cost effectiveness, is obtained by dividing each alternative's benefits ranking by its estimated cost (in $million). Alternative A2/B2 has the highest benefit/cost ratio (6.75), followed by Alternative A3/B3 (0.89), and then Alternative A3/B4 (0.34).

9.6.8 Disproportionate Cost Analysis Conclusion

Based on the results of the DCA presented above, Alternative A2/B2 is the most cost effective of the three Site-wide remedial alternatives evaluated in this FS. Therefore, under MTCA, Alternative A2/B2 is identified as the alternative that is permanent to the maximum extent practicable.

10 Summary and Conclusions

The Site RI (Aspect, 2013) defined physical characteristics, source areas, the nature and extent of impacted media, and potential contaminant migration pathways. Information from the RI was used in this FS to develop area/media-specific remedial alternatives, including three alternatives addressing landfilled materials and near-surface impacted soils, and four alternatives addressing deep petroleum hydrocarbon and groundwater impacts. Following preliminary screening with respect to the MTCA threshold criteria, the area/media-specific alternatives were combined into three Site-wide alternatives. These Site-wide alternatives were evaluated with respect to MTCA criteria, including a comparative analysis to determine the relative benefits of each and an evaluation of benefits versus estimated costs to determine the most permanent solution to the maximum extent practicable. This section presents the preferred alternative based on these evaluations.

10.1 Preferred Alternative

Alternative A2/B2 was identified in the DCA (Section 9.6) as the remedial alternative that is permanent to the maximum extent practicable for the Crownhill Elementary School site, and is therefore the preferred alternative. The preferred alternative consists of the following elements:

- The interim actions completed in spring 2012 and summer 2013;

- Periodic removal of LNAPL from existing monitoring wells;
- Periodic inspection and maintenance of the existing cover components (soil/sod cover or hard surfaces such as asphalt pavement) over landfilled materials and impacted soils in the north and south landfill areas;
- Requirements to run the HVAC system during the school day and to periodically test sub-slab vapor and/or indoor air, to reconfirm that vapor intrusion is not a concern;
- Periodic groundwater quality monitoring and LNAPL layer thickness monitoring, with provision for contingency actions in the event that LNAPL or contaminated groundwater migration closer to the current property boundary is observed;
- Environmental covenants prohibiting or restricting activities on the School and Church properties that would interfere with the integrity of the existing cover or continued protection of human health. Specific restrictions and requirements for Site use may include:
  - A requirement to use only personnel with health and safety training for any invasive work performed in the north and south landfill areas, and to notify such personnel of subsurface conditions;
  - Prohibition of invasive activities such as drinking water well installation that may result in exposure to LNAPL and groundwater contamination;
  - A requirement to evaluate vapor intrusion potential and/or incorporate vapor controls into future buildings constructed in the immediate vicinity of the north or south landfill areas; and
  - A requirement to monitor the integrity of the existing cover features that provide protection against direct contact exposures, and provide reports to Ecology.

It is assumed that Ecology would establish conditional points of compliance for LNAPL migration and for achieving groundwater cleanup levels. Existing monitoring wells MW-6 and MW-10, respectively, are proposed for this purpose. If LNAPL is detected in MW-6 during periodic monitoring, more aggressive measures to prevent further LNAPL migration would need to be considered. Similarly, exceedance of a groundwater cleanup level for arsenic, lead, TCE, or TPH at MW-10 (Table 1) during periodic monitoring would trigger consideration of active measures to prevent further migration of the dissolved contaminant plume.

The total estimated cost for the preferred alternative, including the cost of completed interim actions, is $830,000.

References

Aspect, 2010a, Soil Vapor Intrusion Assessment August Sub-Slab Sampling, Crownhill Elementary School, Bremerton, Washington, Prepared for Bremerton School District, dated October 18, 2010.

Aspect, 2010b, Soil Vapor Intrusion Assessment November Sub-Slab Sampling, Crownhill Elementary School, Bremerton, Washington, Prepared for Bremerton School District, dated December 22, 2010.

Aspect, 2010c, Soil Vapor Intrusion Assessment Work Plan, Crownhill Elementary School, Bremerton, Washington, Prepared for Bremerton School District, dated July 21, 2010.

Aspect, 2013, Remedial Investigation, Crownhill Elementary School, Prepared for Bremerton School District, dated November 2014.

Ecology, 2011, Crownhill Elementary School Site, Agreed Order #DE 7916, Soil and Groundwater Quality Results/Spring 2011 Investigation Program, Comment letter addressed to Bremerton School District, dated November 9, 2011.

NFESC, 2007, Technical Report TR-2279-ENV, Final Report – Cost and Performance Review of Electrical Resistance Heating (ERH) for Source Treatment, Prepared for Naval Facilities Engineering Service Center, dated March 2007.

Limitations

Work for this project was performed and this report prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This report does not represent a legal opinion. No other warranty, expressed or implied, is made.

All reports prepared by Aspect Consulting are intended solely for the Client and apply only to the services described in the Agreement with Client. Any use or reuse by Client for purposes outside of the scope of Client's Agreement is at the sole risk of Client and without liability to Aspect Consulting. Aspect Consulting shall not be liable for any third parties' use of the deliverables provided by Aspect Consulting. Aspect Consulting's original files/reports shall govern in the event of any dispute regarding the content of electronic documents furnished to others.

TABLES

Table 1 - Proposed Groundwater Cleanup Levels

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Constituent (by Group)[1]	Concentration in Micrograms per Liter (µg/L)			
	Maximum Detected Value during RI	MTCA Method A, Table Value	MTCA Method B, Table Value, Direct Contact[2]	**Proposed Groundwater Cleanup Level**
Total Petroleum Hydrocarbon (TPH)				
Diesel Range	43,000	500		**500**
Motor Oil Range	39,000	500		**500**
Metals				
Arsenic	24.9	5	0.058	**5** [3]
Lead	53.1	15		**15**
Volatile Organic Compounds (VOCs)				
Trichloroethene (TCE)	11	5	0.49	**5** [4]

MTCA Model Toxics Control Act

RI Remedial Investigation

Notes:

1) This table includes those constituents that were identified in the RI report as constituents of potential concern (COPCs) in groundwater.

2) The MTCA Method B Direct Contact values shown are the more restrictive of the carcinogenic and non-carcinogenic values presented in Ecology's CLARC database.

3) MTCA Method A cleanup level is proposed, which is based on background arsenic concentrations for state of Washington.

4) MTCA Method A cleanup level is proposed, which is protective at 10^{-5} risk.

Table 2 - Proposed Soil Cleanup Levels

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Constituent (by Group)[1]	Concentration in Milligrams per Kilogram (mg/kg)				
	Maximum Detected Value during RI	MTCA Method A, Unrestricted Land Use, Table Value	MTCA Method B, Table Value, Direct Contact[2]	MTCA Method B, Groundwater Protection[3]	**Proposed Soil Cleanup Level[4]**
Total Petroleum Hydrocarbon (TPH)					
Diesel Range	27000	2000			**2000**
Motor Oil Range	72000	2000			**2000**
Metals					
Antimony	544		32	5.4	**5.4**
Arsenic	63.1	20[5]	0.67		**20[5]**
Chromium III[6]	1710	2000	120000	1000	**1000**
Copper	6820		3000	260	**260**
Lead	26300	250		3000	**250**
Zinc	14600		24000	6000	**6000**
Volatile Organic Compounds (VOCs)					
Trichloroethene (TCE)	0.1	0.03	11	0.0032	**0.03[7]**
Polycyclic Aromatic Hydrocarbons (PAHs)					
cPAHs TEF	26		0.14[8]		**0.14[8]**

cPAH carcinogenic PAH
MTCA Model Toxics Control Act
RI Remedial Investigation
TEF toxicity equivalency factor

Notes

1) This table includes those constituents that were identified in the RI report as constituents of potential concern (COPCs) in soil.
2) The MTCA Method B Direct Contact values shown are the more restrictive of the carcinogenic and non-carcinogenic values presented in Ecology's CLARC database.
3) Values were calculated as per WAC 173-340-747 using default input parameters.
4) Unless otherwise noted, the most restrictive cleanup level is selected as the screening level.
5) Concentration based on direct contact using Equation 740-2 and protection of groundwater for drinking water use, using the procedures in WAC 173-340-747(4), adjusted for natural background for soil.
6) Since hexavalent chromium was not detected in any sample, total chromium results are attributed to the trivalent state.
7) MTCA Method A cleanup level is proposed, which is protective at 10^{-5} risk.
8) The cPAHs TEF is calculated from the concentrations of seven carcinogenic PAHs, using the method described in WAC 173-340-708.

Table 3 - Proposed Air Cleanup Levels

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Constituent of Potential Concern (2)	Proposed Air Cleanup Level (3)
Freon 12 (Dichlorodifluoromethane)	91
Vinyl chloride	(Note 4)
1,1-Dichloroethene	91
trans-1,2-Dichloroethene	27
1,1-Dichloroethane	(Note 5)
cis-1,2-Dichloroethene	(Note 5)
Chloroform	0.11
Benzene	0.32
1,2-Dichloroethane	0.096
Trichloroethene	0.37
Tetrachloroethene	9.6
Ethylbenzene	460
Xylenes (total)	46
1,2,4-Trimethylbenzene	3.2
Naphthalene	1.4
Hydrogen sulfide	0.91

Notes:

1) All concentrations are in units of micrograms per cubic meter ($\mu g/m^3$).
2) Constituents of potential concern (COPC's) were identified in consultation with Ecology during development of the site-specific Soil Vapor Intrusion Assessment Work Plan (Aspect, 2010).
3) Based on the more restrictive of the carcinogenic and non-carcinogenic MTCA Method B values presented in Ecology's CLARC database.
4) Carcinogenic value not currently provided in CLARC database. Instead, a link is provided to "additional information"
5) No value provided in CLARC database ("not researched" or "researched - no data").

Table 4 - LNAPL Thickness Measurements and Removal Log

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Well ID	Date	LNAPL Thickness in ft (1)	LNAPL Removal Volumes/Notes
MW-8	10/26/12	0.2	(Well installed on 12/20/11.)
	11/21/12		Less than 5 ml LNAPL removed; unable to measure thickness.
	01/31/13	0.1	
	05/03/13	0.03	
	08/07/13	0.23	
	12/17/13	0.86	
MW-13	11/01/12	1.46	(Well installed on 10/25/12.)
	11/21/12	0.99	After this thickness was measured, approx. 900 ml LNAPL was bailed over a 2-hour test period(2). Unable to measure thickness at conclusion of test, but bailing produced only water.
	01/31/13	0.1	
	05/03/13	0.31	
	08/07/13	0.49	
	12/17/13	4.9	
MW-14	11/01/12	nd	(Well installed on 10/26/12.)
	01/31/13	nd	
	05/03/13	nd	
	08/07/13	0.12	
	12/17/13	0.10	
MW-16	11/01/12	nd	(Well installed on 10/26/12.)
	01/31/13	0.5	
	05/03/13	0.48	
	08/07/13	2.61	
	12/17/13	2.83	

LNAPL light non-aqueous-phase liquid
nd no detectable separate-phase liquid thickness

Notes:
1) The viscous, sticky nature of the LNAPL resulted in inconsistent readings of the interface probe (used to measure depth-to-LNAPL and depth-to-water). Therefore, the reported LNAPL thicknesses can only be regarded as estimates.
2) 900 ml LNAPL removal compares with a measured volume of approx. 618 ml inside the well casing at start of test (based on 0.99 ft thickness in a 2-inch ID well).

Table 5 - Factors Affecting the Need for *In Situ* Treatment of LNAPL

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Desired Benefit	Relative Need for In Situ Treatment of LNAPL	
	More Need	**Less Need**
Reduced potential for LNAPL migration as a separate-phase liquid	Known active migration of LNAPL (e.g., discharge to surface water)	Immobile residual LNAPL
Reduced restoration time frame	Large ongoing site care requirement cost Known impacts to receptors (e.g., surface water or wells) High probability of achieving near-term improvement in water quality	Low site care requirement Low resource value (e.g., natural exceedences of secondary standards) Low probability of achieving meaningful improvements in water quality
Near-term enhanced attentuation of a dissolved plume due to reduced loading from an LNAPL zone	An expanding dissolved-phase plume	Stable or shrinking dissolved-phase plume
Near-term reductions in dissolved-phase loading to receptors	Presence of known or soon-to-be impacted receptors	No plausible impact to receptors

Table 6 - Components of Area/Media-Specific Remedial Alternatives

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Components of Remedial Alternatives for Landfilled Materials and Near-Surface Impacted Soils	Alternative A1	Alternative A2	Alternative A3
Spring 2012 and Summer 2013 interim actions	X	X	X
Periodic inspection and maintenance of cover/cap		X	X
Requirements addressing School indoor air (run HVAC system during the school day and periodically test sub-slab vapor and/or indoor air quality)		X	X
Environmental covenants placing restrictions on invasive work and requiring that future buildings incorporate vapor controls if needed		X	X
Cap meeting Washington State standards for closure of a solid waste landfill			X

Components of Remedial Alternatives for Deep Petroleum Hydrocarbon and Groundwater Impacts	Alternative B1	Alternative B2	Alternative B3	Alternative B4
Environmental covenant prohibiting activities that may result in exposure to LNAPL and groundwater contamination	X	X	X	X(2)
Periodic groundwater quality and LNAPL layer thickness monitoring(1)		X	X	X(2)
Periodic physical removal of mobile LNAPL		X		
In situ treatment of LNAPL at water table			X	X
In situ treatment of impacted vadose zone soils and groundwater				X

Notes:

1) Contingency actions would be implemented in the event that LNAPL or contaminated groundwater migration closer to the current property boundary is observed.

2) This component may not be necessary in Alternative B4, depending on the success of the *in situ* treatment.

Table 7 - Summary of Site-Wide Remedial Alternatives and Evaluation with Respect to Threshold Criteria

Feasibility Study, Crownhill Elementary, Bremerton, Washington

	Alternative A2/B2	Alternative A3/B3	Alternative A3/B4
Elements of Site-Wide Remedial Alternative[1]	● Completed interim actions[2] ● Periodic removal of LNAPL from existing wells ● Periodic inspection and maintenance of existing cover ● Requirements addressing School indoor air[3] ● Periodic groundwater quality and LNAPL layer thickness monitoring.[4] ● Environmental covenants addressing: - restrictions on invasive work in landfill areas - VI assessment/mitigation for future buildings - prohibition of activities that may result in exposure to LNAPL and groundwater contamination - periodic reports to Ecology	● Completed interim actions[2] ● Landfill cap[5] ● *In situ* treatment of LNAPL at water table ● Periodic inspection and maintenance of cap ● Requirements addressing School indoor air[3] ● Periodic groundwater quality and LNAPL layer thickness monitoring.[4] ● Environmental covenants addressing: - restrictions on invasive work in landfill areas - VI assessment/mitigation for future buildings - prohibition of activities that may result in exposure to LNAPL and groundwater contamination - periodic reports to Ecology	● Completed interim actions[2] ● Landfill cap[5] ● *In situ* treatment of impacted vadose zone soils, LNAPL at water table, and groundwater ● Periodic inspection and maintenance of cap ● Requirements addressing School indoor air[3] ● Periodic groundwater quality and LNAPL layer thickness monitoring.[4,6] ● Environmental covenants addressing: - restrictions on invasive work in landfill areas - VI assessment/mitigation for future buildings - prohibition of activities that may result in exposure to LNAPL and groundwater contamination[6] - periodic reports to Ecology

Remedial Alternative Evaluation with Respect to MTCA Threshold Criteria[7]

MTCA Threshold Criteria *(WAC 173-340-360(2)(a))*	**Does Alternative Comply with Threshold Criterion?**		
Protect human health and the environment	Yes	Yes	Yes
Comply with cleanup standards	Yes	Yes	Yes
Comply with applicable state & federal laws	Yes	Yes	Yes
Provide for compliance monitoring	Yes	Yes	Yes
Evaluation Results	**Carried Forward to Detailed Evaluation**	**Carried Forward to Detailed Evaluation**	**Carried Forward to Detailed Evaluation**

LNAPL light non-aqueous-phase liquid VI vapor intrusion WAC Washington Administrative Code

Notes:
1) Refer to Section 8 for detailed descriptions of the remedial alternatives.
2) Interim actions were completed in Spring 2012 and Summer 2013; refer to Section 6.1.
3) Includes requirements to run HVAC system during the school day, and to periodically test sub-slab vapor and/or indoor air quality.
4) Contingency actions would be implemented in the event that LNAPL or contaminated groundwater migration closer to the current property boundary is observed.
5) Cap meeting Washington State standards for closure of a solid waste landfill.
6) This component may not be necessary in Alternative A3/B4, depending on the success of the *in situ* treatment.

Table 8 - Evaluation of Reasonable Restoration Time Frame

Feasibility Study, Crownhill Elementary, Bremerton, Washington

		Alternative A2/B2	Alternative A3/B3	Alternative A3/B4
	Estimated Restoration Time Frame[(1)]	5 years[(2)]	2 - 3 years[(2)]	3 - 4 years[(2)]
Factors Used to Determine Whether the Restoration Time Frame is Reasonable (WAC 173-340-360(4)(b)	*Potential risks posed by the Site to human health and the environment*	Interim risks (until Site is restored) would be low.	Interim risks (until Site is restored) would be low.	Interim risks (until Site is restored) would be low.
	Practicability of achieving shorter restoration time frame	Alternatives A3/B3 and A3/B4 are expected to restore Site in shorter time frames.	This alternative is expected to achieve the shortest restoration time frame.	Alternative A3/B3 is expected to restore Site in a shorter time frame.
	Current and potential future use of Site, surrounding areas, and associated resources that are, or may be, affected by releases from the Site	Current Site uses (elementary school and church) are expected to continue into the foreseeable future. There are no ongoing releases from Site.	Current Site uses (elementary school and church) are expected to continue into the foreseeable future. There are no ongoing releases from Site.	Current Site uses (elementary school and church) are expected to continue into the foreseeable future. There are no ongoing releases from Site.
	Availability of alternate water supplies	Municipal water supply is readily available and would not be affected by Site cleanup.	Municipal water supply is readily available and would not be affected by Site cleanup.	Municipal water supply is readily available and would not be affected by Site cleanup.
	Likely effectiveness and reliability of institutional controls	Site restoration will be achieved when mobile LNAPL is removed to the extent practicable. Institutional controls prohibiting invasive activities will be highly effective and reliable at preventing exposure.	Not applicable, since it is expected that Site restoration will be achieved upon completion of remedy construction (before institutional controls are implemented).	Not applicable, since it is expected that Site restoration will be achieved upon completion of remedy construction (before institutional controls are implemented).
	Ability to control and monitor migration of hazardous substances from the Site	RI results indicate that there is no migration of hazardous substances from the Site.	RI results indicate that there is no migration of hazardous substances from the Site.	RI results indicate that there is no migration of hazardous substances from the Site.
	Toxicity of the hazardous substances at the Site	The hazardous substances at the Site have a relatively low toxicity .	The hazardous substances at the Site have a relatively low toxicity .	The hazardous substances at the Site have a relatively low toxicity .
	Natural processes which reduce concentrations of hazardous substances and have been documented to occur at the Site or under similar Site conditions	TPH in groundwater naturally attenuates. Otherwise, the restoration time frame estimated for this alternative does not rely on natural attenuation of hazardous substances.	TPH in groundwater naturally attenuates. Otherwise, the restoration time frame estimated for this alternative does not rely on natural attenuation of hazardous substances.	The restoration time frame estimated for this alternative does not rely on natural attenuation of hazardous substances.
Conclusion Regarding Reasonableness of Restoration Time Frame		While Site restoration would likely be achieved sooner in Alternatives A3/B3 and A3/B4, the restoration time frame estimated for this alternative is also reasonable.	The restoration time frame estimated for this alternative is reasonable.	While Site restoration would likely be achieved sooner in Alternative A3/B3, the restoration time frame estimated for this alternative is also reasonable.

LNAPL light non-aqueous-phase liquid RI remedial investigation TPH total petroleum hydrocarbon VOC volatile organic compound

Notes:

1) Refer to Section 9.5 discussion of restoration time frame.

2) The estimated restoration time frame includes remedy design and implementation. For Alternative A2/B2, it includes the period of LNAPL removal from existing wells.

Table 9 - Disproportionate Cost Analysis

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Criteria to Evaluate Use of Permanent Solutions to the Maximum Extent Practicable	Weighting Factor	Alternative A2/B2	Alternative A3/B3	Alternative A3/B4
Overall Protectiveness	30%	**4** • Human and terrestrial ecological soil direct contact exposure pathways addressed by existing cover with ICs; • Contingent actions in the event that groundwater and/or LNAPL migration closer to property boundary is indicated; • Confirmation that the vapor intrusion pathway is addressed; • Relies on long-term effectiveness of cover IM&M and ICs.	**7** Compared to Alternative A2/B2, a landfill cap meeting Washington State standards for solid waste landfill closure would reduce soil direct contact exposure risk and leaching of contaminants. Treatment of water table LNAPL would not significantly increase overall protectiveness.	**8** Benefits of Alternative A3/B3, and should not require long-term groundwater monitoring to ensure protectiveness. However, landfilled materials and impacted soils would remain on Site.
Permanence	20%	**2** TPH in groundwater is naturally attenuating. Spring 2012 interim action removed contaminated media within 1 foot of ground surface. LNAPL removal from existing wells would not significantly reduce LNAPL mass.	**5** Increased permanence compared to Alternative A2/B2 due to *in situ* treatment of water table LNAPL and landfill cap (reduced contaminant mobility via leaching).	**8** Increased permanence compared to Alternative A3/B3 due to *in situ* treatment of water table LNAPL and landfill cap (reduced contaminant mobility via leaching).
Long-Term Effectiveness	20%	**5** Long-term effectiveness in addressing direct contact/terrestrial ecological exposure potential would be dependent on IM&M and ICs to ensure the long-term integrity of the existing cover.	**6** Marginal increase in long-term effectiveness compared to Alternative A2/B2 due to more robust landfill cap versus existing cover. However, dependence on IM&M and ICs would remain. Treatment of water table LNAPL would not significantly increase long-term effectiveness.	**8** Marginal increase in long-term effectiveness compared to Alternative A3/B3 because there would likely be no need for long-term groundwater monitoring and associated ICs. Otherwise, treatment of vadose zone soils would not significantly increase long-term effectiveness.
Short-Term Risk Management	10%	**10** Except or periodic LNAPL removal from existing wells, contamination would be managed in-place. With no construction component, there would be little to no short-term risk to workers, the local community, or the environment.	**6** Impacts to local community, including traffic, noise, and air emissions associated with construction of cap and *in situ* treatment infrastructure. Potential health and safety risks associated with drilling multiple borings through landfilled materials to treat water table LNAPL.	**4** Same as Alternative A3/B3 with respect to landfill capping. Significantly greater potential for worker and community impacts associated with *in situ* treatment component compared to Alternative A3/B3 due to much larger scale (many more borings through landfilled materials, longer duration, etc.)
Implementability	10%	**10** No construction component. Highly implementable, with no significant technical challenges.	**5** Construction would need to take place primarily during summer break. Significant technical challenges associated with both *in situ* treatment of water table LNAPL (specialized technology plus difficult access beneath landfilled materials) and cap construction around School building.	**2** Same as Alternative A3/B3 with respect to landfill capping. Technical challenges associated with effectively treating all vadose zone soils (as well as water table LNAPL) would be significantly greater.
Consideration of Public Concerns	10%	**10** (Note 2)	**10** (Note 2)	**10** (Note 2)
MTCA Benefits Ranking(3)		**5.6**	**6.4**	**7.2**
Estimated Cost(4)		**$830,000**	**$7,200,000**	**$21,000,000**
Benefit/Cost Ratio(5)		**6.75**	**0.89**	**0.34**

CAP cleanup action plan; IC institutional control; LNAPL light non-aqueous-phase liquid
DCA disproportionate cost analysis; IM&M inspection, monitoring, and maintenance; MTCA Model Toxics Control Act

Notes:

1) A scale of 1 to 10 is used to rate the alternatives with respect to the criteria, where "1" indicates the criterion is satisfied to a very low degree, and "10" indicates the criterion is satisfied to a very high degree. Rating values are shown in RED.

2) Ecology considers and responds to all public comments received on the Draft FS and Draft CAP documents as part of the cleanup process under MTCA. Therefore, all three alternatives are given a rating of 10 for consideration of public concerns.

3) The MTCA benefits ranking is obtained by multiplying the rating for each criterion by its weighting factor, and summing the results for the five criteria.

4) Net present value costs are estimated in 2013 dollars, and were calculated using a discount factor of 1.6 percent. The costs shown are rounded to two significant figures. Itemized estimates are provided in Appendix B.

5) The benefit/cost ratio is obtained by dividing the alternative's MTCA benefits ranking by its estimated cost (in $million).

FIGURES

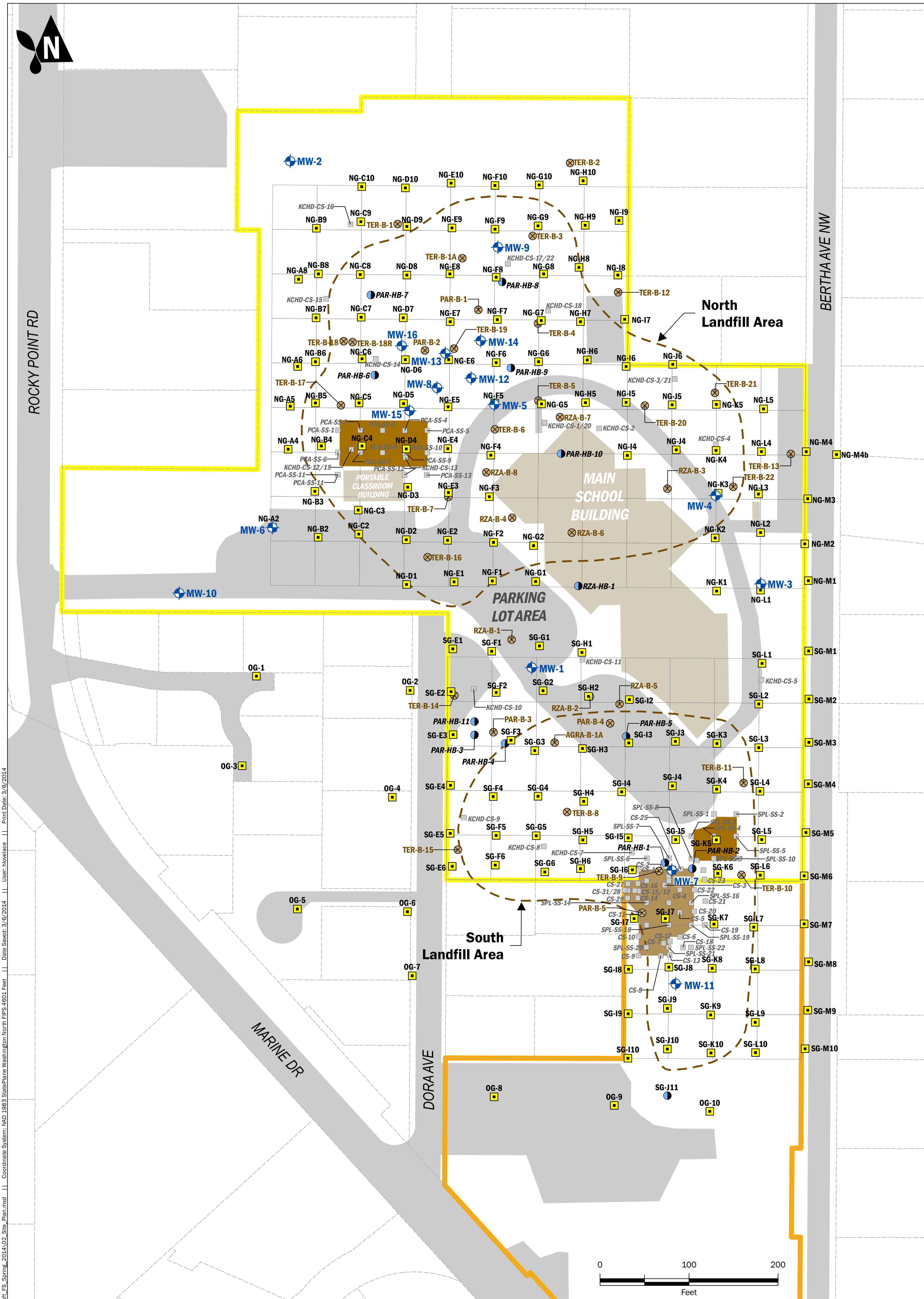
Vicinity Map

Crownhill Elementary FS
Bremerton, Washington

Aspect CONSULTING	NOV-2014	BY: PPW	FIGURE NO. 1
	PROJECT NO. 100094	REV BY: SCC	

Basemap Credits: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

GIS Path: T:\projects_8\CrownhillElementary\Delivered\Draft_FS_Spring_2014\01_VicinityMap.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 3/3/2014 || User: scudd || Print Date: 3/3/2014



Exploration Locations:

- MW-10 Monitoring Well
- NG-A3 Direct Push Probe
- PAR-HB-11 Hand Auger Soil Boring
- TER-B-16 Soil Boring
- SPL-SS-12 Surface Soil Sample

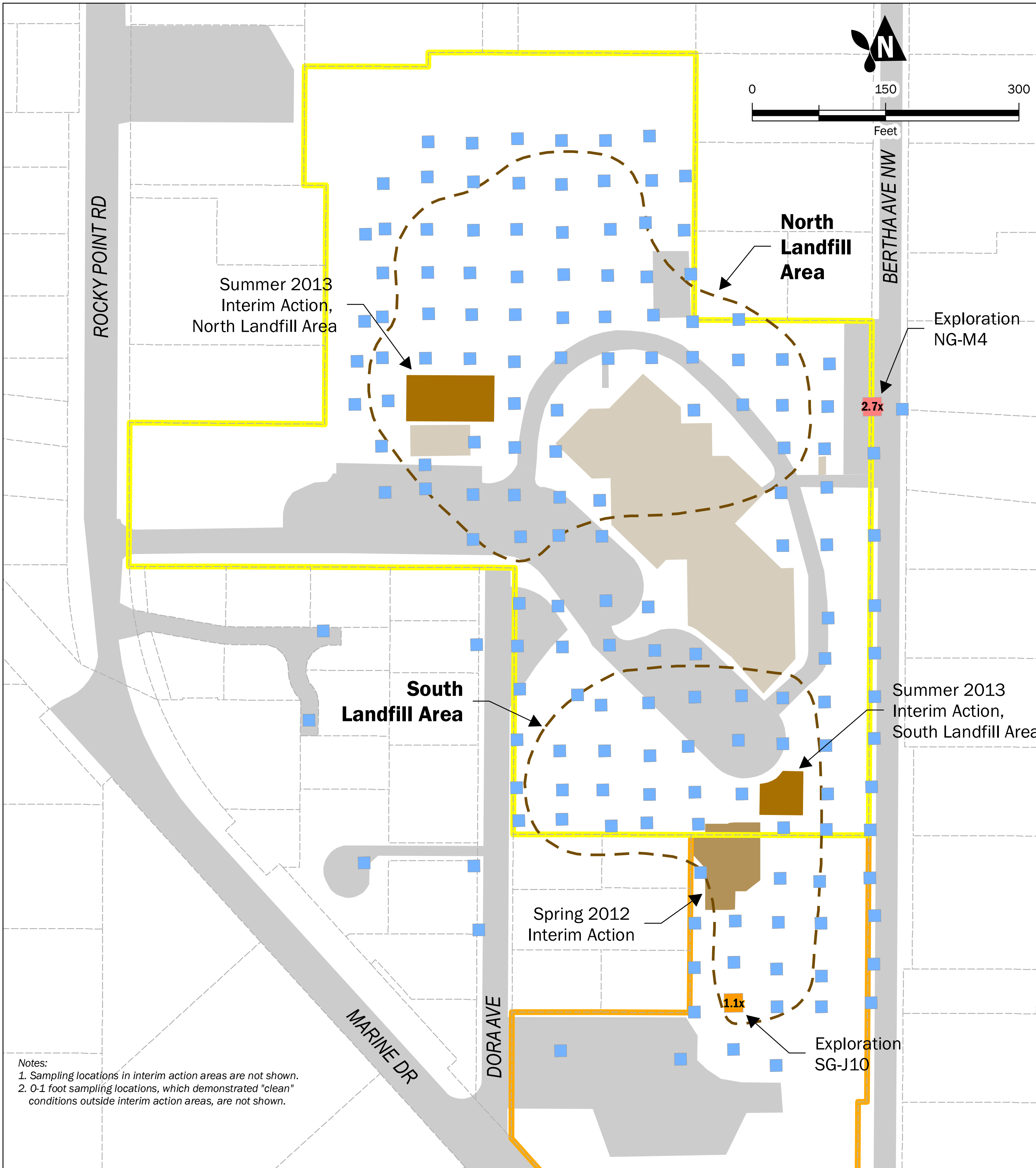
- Bremerton School District (BSD) Property Boundary
- Bremerton United Methodist Church (BUMC) Property Boundary
- Interpreted Extent of Landfill Activity
- Parcel Lines
- Spring 2012 Interim Action
- Summer 2013 Interim Action
- School Building Footprint
- Pavement

Site Plan

Crownhill Elementary FS
Bremerton, Washington

Aspect CONSULTING	NOV-2014	BY: DLH / DLC / PPW	FIGURE NO.
	PROJECT NO. 100094	REV BY: SCC / HRL	2

GIS Path: T:\projects_8\CrownHillElementary\Delivered\Draft_FS_Spring_2014\02_Site_Plan.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 3/6/2014 || User: hlovelace || Print Date: 3/6/2014



Soil Sampling Locations (0-3 foot depth interval)

Cleanup level exceedance factor

2.7x — Lead cleanup level exceedances

1.1x — Arsenic cleanup level exceedances

No cleanup level exceedances

Interpreted Extent of Landfill Activity

Parcel Lines

Bremerton School District Property Boundary

Bremerton United Methodist Church Property Boundary

School Building Footprint

Pavement

Near-Surface Soil Cleanup Level Exceedances

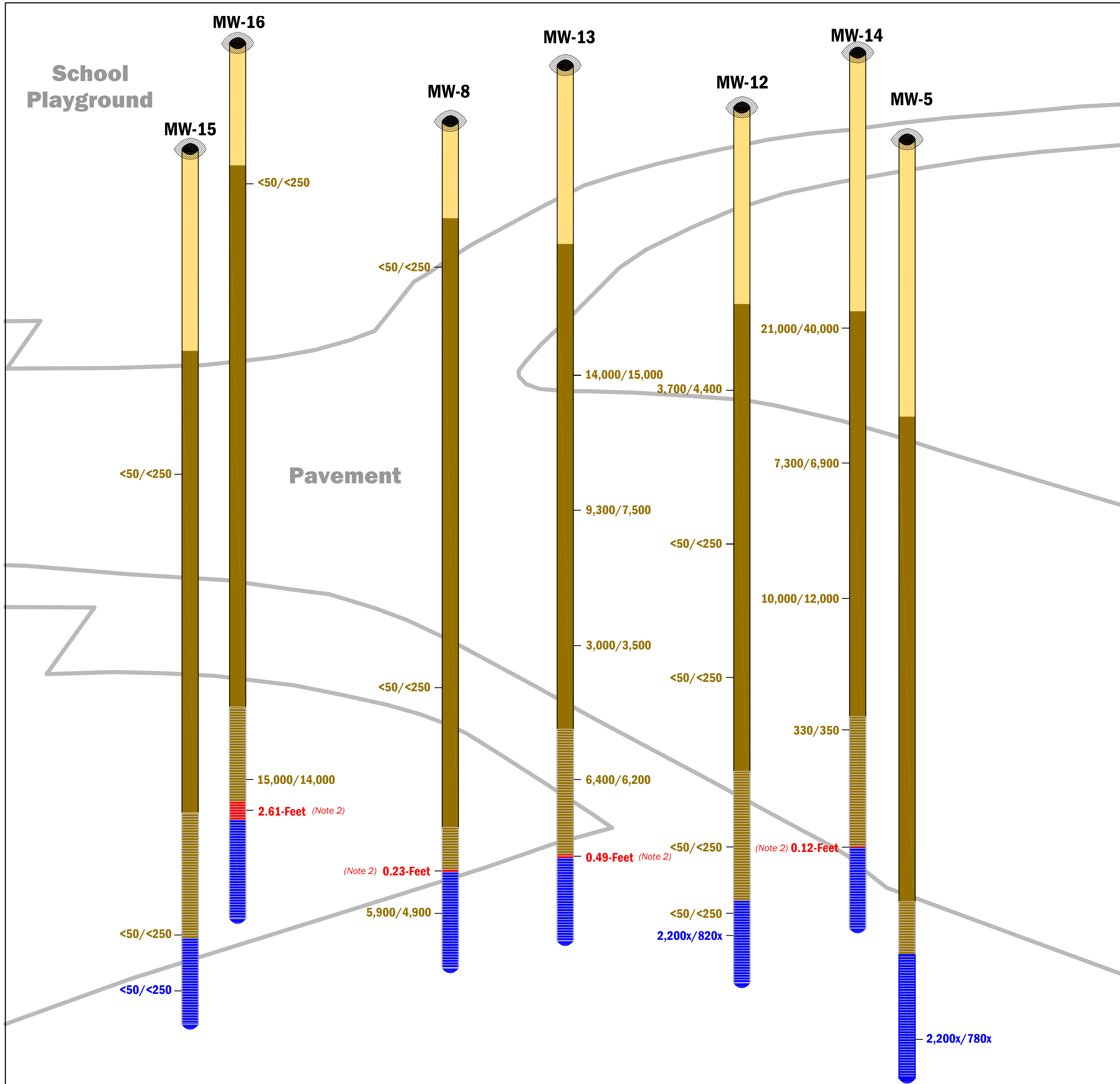
Crownhill Elementary FS

Bremerton, WA

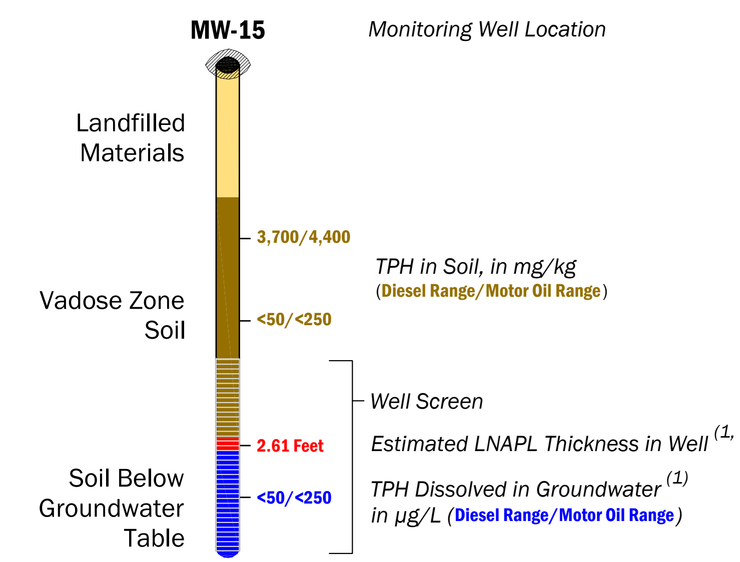
Aspect CONSULTING

NOV-2014	BY: DAH / PPW	FIGURE NO.
PROJECT NO. 100094	REV BY: SCC	3

GIS Path: T:\projects_8\CrownhillElementary\Delivered\Draft_FS_Spring_2014\03_NearSurfaceSoil_CUL_Exceeds.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 3/3/2014 || User: scudd || Print Date: 3/3/2014



LEGEND



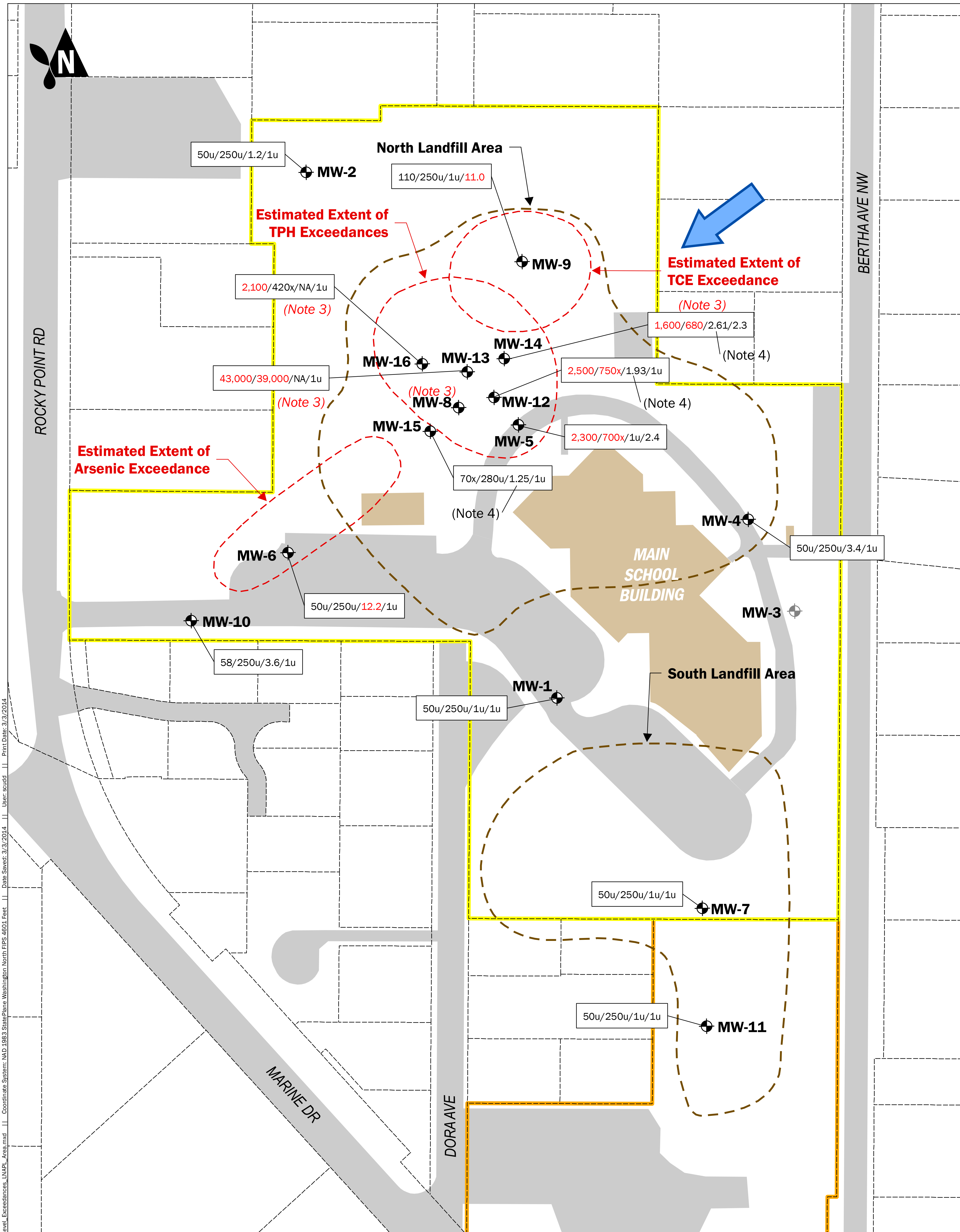
Notes:

(1) TPH in groundwater and LNAPL thickness measured on 8/7/13. These data were used to estimate TPH mass in the subsurface (Appendix A).
(2) As discussed in Section 6.2, LNAPL thickness measurements were highly variable from one monitoring round to the next. Refer to Table 4 for thickness measurements.
(3) Qualifier "x" = The sample chromatographic pattern does not resemble the fuel standard used for quantitation.

Drawing not to scale.
Relative positions are correct.

3-D Visualization of Deep Petroleum Hydrocarbon Impacts
Crownhill Elementary FS
Bremerton, Washington

Aspect CONSULTING	NOV-2014	BY: DAH/PPW/SCC	FIGURE NO.
	PROJECT NO. 100094	REV BY: SCC	4



Well Locations:

- Monitoring Well
- Perched Zone Monitoring Well (Not Sampled)

Fall 2012 Groundwater Monitoring Data:

Diesel-Range TPH / Motor-Oil-Range TPH / Arsenic / TCE

50u/250u/1u/12.2

Other Site Features and Interpretation:

- School Building Footprint
- Parcel boundary
- Pavement
- Interpreted Extent of Landfill Activity
- Bremerton School District Property Boundary
- Bremerton United Methodist Church Property Boundary
- Inferred Direction of Groundwater Flow
- Estimated Extent of Exceedances

Notes:

(1) RED TEXT in chemistry boxes indicates an exceedance of cleanup level. Cleanup levels are 500 ug/L for both diesel-range and motor-oil-range TPH, and 5ug/L for both TCE and arsenic.

(2) "NA" Denotes Not Analyzed;
Qualifier "U" = Non-Detect;
Qualifier "X" = The sample chromatographic pattern does not resemble the fuel standard used for quantification;

(3) LNAPL was detected in Wells MW-8, MW-13, MW-14, and MW-16 on at least one occasion. Refer to Table 4.

(4) The Fall 2012 sample from this well was not analyzed for arsenic. The result shown is for the Winter 2013 sample.

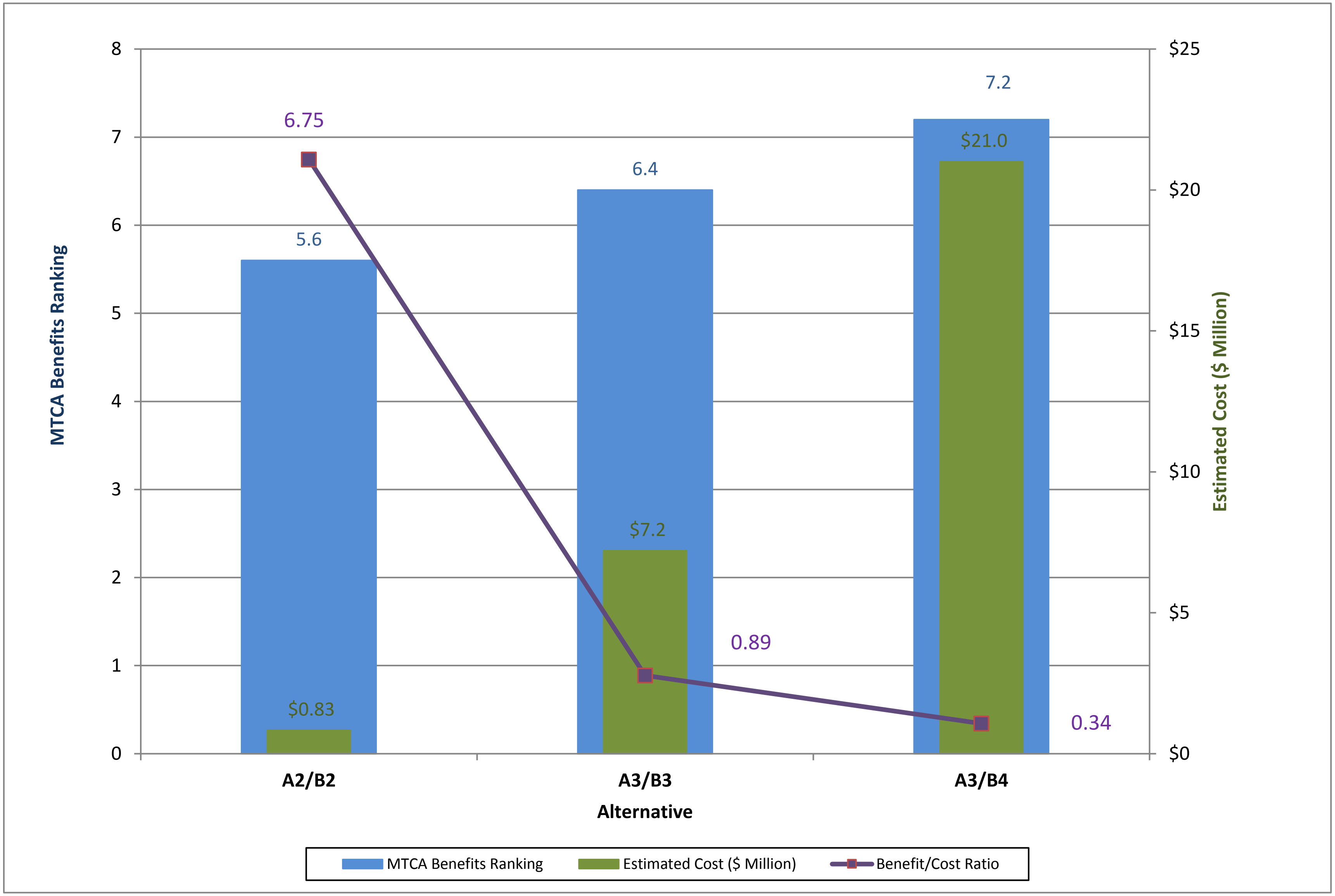
Areal Extent of Groundwater Cleanup Level Exceedances

Crownhill Elementary FS
Bremerton, Washington

Aspect CONSULTING

NOV-2014	BY: DLH / PPW	FIGURE NO.	
PROJECT NO. 100094	REV BY: SCC / HRL	5	

Print Date: 3/3/2014 || User: scudd || Date Saved: 3/3/2014 || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet



Notes:
1) Present worth costs in 2013 dollars, calculated using a discount factor of 1.6%.

Aspect Consulting
11/24/2014
V:\100094 BSD Crownhill Elementary RIFS\Deliverables\FS Report\Final\Combined Tbls_Nov2014.xlsx

Figure 6
Disproportionate Cost Analysis Summary

APPENDIX A

Estimation of TPH Mass at Groundwater Table and in Vadose Zone Soils

Est. TPH Mass as Water Table LNAPL

Note: LNAPL thickness measurements on 8/7/13 were used to provide a conservative estimate, since LNAPL was observed in the largest no. of wells (4) on that date. See attached Fig. 24 markup.

$M_{LNAPL} = A \cdot b \cdot \rho_{LNAPL} \cdot r$, where

M_{LNAPL} = TPH mass floating on water table (kg)

A = est. areal extent on 8/7/13 = 11,800 ft²

b = est. avg. LNAPL thickness on 8/7/13 = 1.0 ft

$\rho_{LNAPL} = 1{,}000 \frac{kg}{m^3} * \left(\frac{1 m^3}{35.315 ft^3}\right) * 0.90 = 25.5 \frac{kg}{ft^3}$

(0.90 = LNAPL specific gravity measured during RI)

r = 0.2 (Assumed portion of volume occupied by LNAPL)

$M_{LNAPL} = 11{,}800\ ft^2 * 1.0\ ft * 25.5 \frac{kg}{ft^3} * 0.2 = 60{,}180\ kg$

⇒ Round to 60,000 kg

ESTIMATED TPH MASS IN VADOSE ZONE SOILS

$$M_{LNAPL(VZ)} = A_{VZ}\, b_{VZ}\, \rho_{soil}\, C_{[TPH]_{total}}$$

where:

$M_{LNAPL(VZ)}$: TPH mass in vadose zone soils

A_{VZ} : Areal extent of TPH impacted vadose zone soils and is assumed to be the same as the LNAPL area on p.1

$$A_{VZ} = 11{,}800\ ft^2 = 1{,}310\ yd^2$$

b_{VZ} : Thickness of the vadose zone

$$b_{VZ} = 76\ feet = 25.3\ yd$$

ρ_{soil} : Bulk density of vadose zone soil

$$\rho_{soil} = 1.6\ tons/yd^3$$

$C_{[TPH]_{total}}$: Average $[TPH]_{total}$ concentrations detected in soil in monitoring wells MW-12, MW-13, MW-14, & MW-16

where $[TPH]_{total} = [TPH]_{diesel} + [TPH]_{motor oil}$

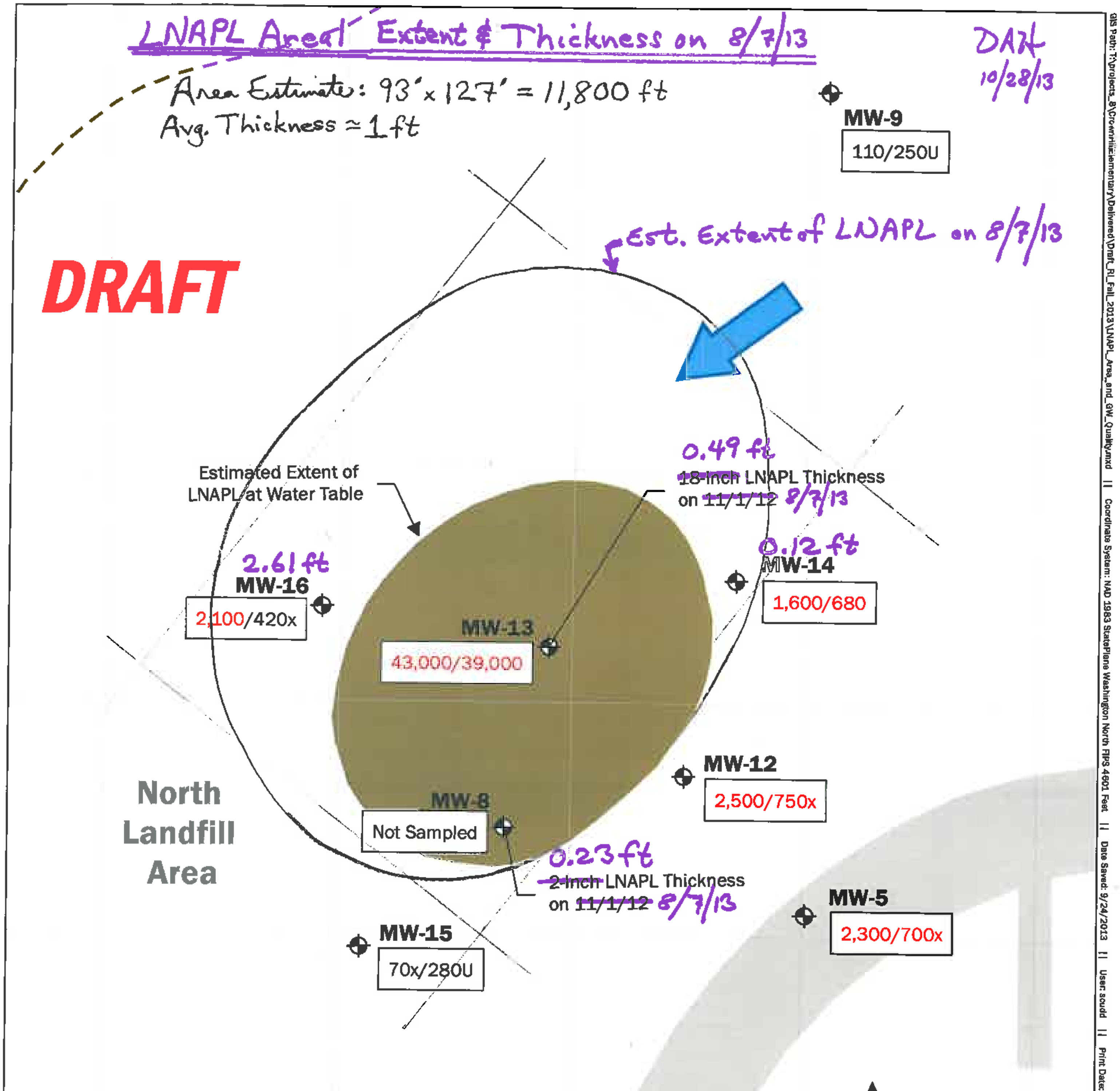
Vadose Zone Depth In Feet	$[TPH]_{total}$ IN mg/kg			
	MW-12	MW-13	MW-14	MW-16
0-19	8,100	29,000	61,000	0
19-39	0	16,800	14,200	0
39-57	0	6,500	22,000	0
57-76	0	12,600	680	29,000
Average	2,025	16,225	24,470	7,250
$C_{[TPH]_{total}}$	Overall Average = 12,493 mg/kg			

= 0.012493 mg/mg

$M_{LNAPL(VZ)} = 1{,}310\,yd^2 * 25.3\,yd * 1.6\,ton/yd^3 * 0.012493\,mg/mg * 907.2\,\frac{kg}{ton}$

= 601,000 kg

⇒ Round to 600,000 kg



Notes:

1. *RED TEXT in chemistry boxes indicates an exceedance of screening level. The screening level for both diesel-range and motor-oil-range TPH is 500 µg/L.*
2. *Qualifier "U" = Non-Detect; Qualifier "X" = The sample chromatographic pattern does not resemble the fuel standard used for quantitation.*

MW-7 Monitoring Well

Inferred Direction of Groundwater Flow

Pavement

Interpreted Extent of Landfill Activity

Fall 2012 Groundwater Monitoring Data:

Diesel-Range TPH — Motor-Oil-Range TPH

70x/280U

Concentrations in µg/L

LNAPL Area and Associated Groundwater Quality, Fall 2012

Crownhill Elementary RI
Bremerton, Washington

Aspect CONSULTING

SEP-2013	BY: DLC / PPW	FIGURE NO.
PROJECT NO. 100094	REV BY: HRL / SCC	24

GIS Path: T:\projects_8\Crownhill\Elementary\Delivered\Draft_RI_Fall_2013\LNAPL_Area_and_GW_Quality.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/24/2013 || User: sould || Print Date: 9/24/2013

APPENDIX B

Remedial Alternative Cost Estimates

Table B.1 - Summary of Cost Estimates for Remedial Alternatives

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Area/Media-Specific Remedial Alternatives	Total Estimated Cost(1)
Alternatives for Landfilled Materials and Near-Surface Impacted Soils	
A1 - No Additional Action	$277,000
A2 - Institutional Controls and Maintenance of Existing Cover	$529,000
A3 - Landfill Cap	$2,620,000
Alternatives for Deep Petroleum Hydrocarbon and Groundwater Impacts	
B1 - No Action	$0
B2 - Physical Removal of LNAPL, Institutional Controls, and Long-Term Monitoring	$296,000
B3 - *In Situ* Treatment of Water Table LNAPL	$4,530,000
B4 - *In Situ* Treatment of LNAPL, Impacted Vadose Zone Soils, and Groundwater	$18,200,000
Site-Wide Remedial Alternatives(3)	
Alternative A2/B2	$825,000
Alternative A3/B3	$7,150,000
Alternative A3/B4	$20,800,000

LNAPL light non-aqueous-phase liquid

Notes:

1) Cost are in 2013 dollars. Costs were estimated using Net Present Value (NPV) analysis, assuming a discount rate of 1.6 percent. Long-term inspection and maintenance (I&M) costs were evaluated over a 30-year period, consistent with EPA guidance. The estimates are order-of-magnitude, with an intended accuracy in the range of -30 to +50 percent.

2) Estimated costs are rounded to three significant figures.

3) Site-wide remedial alternatives are combinations of the area/media-specific alternatives, as indicated by the Site-wide alternative names. The estimated cost of a Site-wide alternative is the sum of the estimates for the two area/media-specific alternatives.

Table B.2 - Alternative A2 Cost Estimate

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Site: Crownhill Elementary
Remedial Action Description: Alternative: A2 Institutional Controls and Maintenance of Existing Cover
Cost Estimate Accuracy: FS Screening Level (+50/-30 percent)

Key Assumptions and Quantities:

CONSTRUCTION COSTS							
Item	**Quantity**	**Unit**	**Unit Cost**		**Total Cost**		**Notes**
Sunk Costs							
Spring 2012 Interim Action	1	LS	$	215,000	$	215,000	
Summer 2013 Interim Action	1	LS	$	62,000	$	62,000	
Subtotal Sunk Costs					*$*	*277,000*	
Soil Cover Systems							
I&M manual for cover systems	1	LS	$	15,000	$	15,000	
Environmental covenants, near surface items	1	LS	$	10,000	$	10,000	
Subtotal Soil Cap Cost					*$*	*25,000*	
Tax	9.5%		$	25,000	$	2,375	
Contingency	20%		$	25,000	$	5,000	
Subtotal					*$*	*7,375*	
Professional Services (as percent of construction and contingency costs)							
Project management	5%				$	1,619	
Subtotal Professional Servies					*$*	*1,619*	
Total Estimated Capital Costs					$	310,994	

IM&M COSTS - Net Present Value								
Item	**Frequency[(1)]**	**Unit Cost**		**Annual Cost**		**NPV Cost**		**Notes**
							1.6%	discount rate for Net Present Value calculation
Periodic IM&M								
Periodic vapor intrusion monitoring & reporting	0.2	$	15,000	$	3,000	$	71,036	sub-slab sampling at 5-year intervals
Periodic inspection and maintenance of cover systems	1	$	5,000	$	5,000	$	118,394	annual inspection/reporting; maintenance as needed
Subtotal Periodic IM&M Cost						*$*	*189,431*	
Professional Services (as percent of Periodic IM&M costs)								
Project management/Reporting		15%				$	28,415	
Total, Periodic IM&M Net Present Value:						**$**	**217,845**	
TOTAL ESTIMATED COST						**$**	**528,839**	

Notes:
1) The frequencies shown are assumed for cost estimating purposes. The actual frequencies at which IM&M items will be conducted, along with other IM&M details, will be developed during remedy design.

Table B.3 - Alternative A3 Cost Estimate

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Site:	Crownhill Elementary				
Remedial Action Description:	Alternative:	A4	Landfill Cap		
Cost Estimate Accuracy:	FS Screening Level (+50/-30 percent)				
Key Assumptions and Quantities:					
	286,592	SF	total landfill cap area		
	36,895	SF	total asphalt area		
	1.6	tons/BCY	soil density		

CONSTRUCTION COSTS

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Sunk Costs					
Spring 2012 Interim Action	1	LS	$ 215,000	$ 215,000	
Summer 2013 Interim Action	1	LS	$ 62,000	$ 62,000	
Subtotal Sunk Costs				*$ 277,000*	
Landfill Cap					
RCRA Subtitle D cover system	6.6	acre	$ 180,000	$ 1,184,266	in accordance with WAC 173-304-460(3)(e)
Asphalt	36,895	SF	$ 3	$ 110,686	remove and replace
I&M manual for landfill cap	1	LS	$ 15,000	$ 15,000	
Environmental covenants, near surface items	1	LS	$ 5,000	$ 5,000	
Subtotal Landfill Cover Cost				*$ 1,314,952*	
Tax	9.5%		$ 1,314,952	$ 124,920	
Contingency	20%		$ 1,314,952	$ 262,990	
Subtotal				*$ 387,911*	
Professional Services (as percent of construction and contingency costs)					
Project management	5%			$ 85,143	
Remedial design	6%			$ 102,172	
Construction management and reporting	6%			$ 102,172	
Subtotal Professional Servies				*$ 289,487*	
Total Estimated Capital Costs				$ 2,269,350	

IM&M COSTS - Net Present Value

Item	Frequency[1]	Unit Cost	Annual Cost	NPV Cost	Notes
				1.6%	discount rate for Net Present Value calculation
Periodic IM&M					
Periodic vapor intrusion monitoring & reporting	0.2	$ 15,000	$ 3,000	$ 71,036	sub-slab sampling at 5-year intervals
Periodic inspection and maintenance of landfill cap	2	$ 5,000	$ 10,000	$ 236,788	semi-annual inspection/reporting; maintenance as needed
Subtotal Periodic IM&M Cost				*$ 307,825*	
Professional Services (as percent of Periodic IM&M costs)					
Project management/Reporting		15%		$ 46,174	
Total, Periodic IM&M Net Present Value:				**$ 353,998**	
TOTAL ESTIMATED COST				**$ 2,623,348**	

Notes:

1) The frequencies shown are assumed for cost estimating purposes. The actual frequencies at which IM&M items will be conducted, along with other IM&M details, will be developed during remedy design.

Table B.4 - Alternative B2 Cost Estimate

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Site:	Crownhill Elementary				
Remedial Action Description:	Alternative: B2	Physical Removal of LNAPL, Institutional Controls, and Long-Term Monitoring			
Cost Estimate Accuracy:	FS Screening Level (+50/-30 percent)				
Key Assumptions and Quantities:					

CONSTRUCTION COSTS

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Environmental covenants, deep items	1	LS	$ 5,000	$ 5,000	
Long term monitoring and contingency plan for LNAPL/GW	1	LS	$ 15,000	$ 15,000	
Subtotal LNAPL Removal Cost				*$ 20,000*	
Contingency	20%		$ 20,000	$ 4,000	
Subtotal				*$ 4,000*	
Professional Services (as percent of construction and contingency costs)					
Project management	5%			$ 1,200	
Subtotal Professional Servies				*$ 1,200*	
Total Estimated Capital Costs				$ 25,200	

IM&M COSTS - Net Present Value

Item	Frequency[1]	Unit Cost	Annual Cost	NPV Cost	Notes
				1.6%	discount rate for Net Present Value calculation
Periodic IM&M					
Periodic GW quality and LNAPL thickness monitoring					
-Years 1&2 monitoring	4	$ 4,000	$ 16,000	$ 31,248	quarterly monitoring
-Years 3-30 monitoring	2	$ 3,500	$ 7,000	$ 152,081	semi-annual monitoring
Periodic physical removal of LNAPL					
-Years 1&2 removal and disposal	6	$ 2,500	$ 15,000	$ 29,295	alternate-month removal
-Years 3-5 removal and disposal	4	$ 2,000	$ 8,000	$ 22,525	quarterly removal
Subtotal Periodic IM&M Cost				*$ 235,149*	
Professional Services (as percent of Periodic IM&M costs)					
Project management/Reporting		15%		$ 35,272	
Total, Periodic IM&M Net Present Value:				**$ 270,422**	
TOTAL ESTIMATED COST				**$ 295,622**	

Notes:

1) The frequencies shown are assumed for cost estimating purposes. The actual frequencies at which IM&M items will be conducted, along with other IM&M details, will be developed during remedy design.

Table B.5 - Alternative B3 Cost Estimate

Feasibility Study, Crownhill Elementary, Bremerton, Washington

Site:	Crownhill Elementary				
Remedial Action Description:	Alternative: B3	In Situ Treatment of Water Table LNAPL			
Cost Estimate Accuracy:	FS Screening Level (+50/-30 percent)				
Key Assumptions and Quantities:					
	141,600	ft3	volume of LNAPL soils to be treated		

CONSTRUCTION COSTS					
Item	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**	**Notes**
In Situ LNAPL Treatment					
ERH treatment	141,600	ft3	$ 20	$ 2,832,000	assume 20% larger aquifer area, 10 foot thick
Environmental covenants, deep items	1	LS	$ 5,000	$ 5,000	
Long term monitoring and contingency plan for LNAPL/GW	1	LS	$ 15,000	$ 15,000	
Subtotal In Situ LNAPL Treatment Cost				$ 2,852,000	
Tax	9.5%		$ 2,852,000	$ 270,940	
Contingency	20%		$ 2,852,000	$ 570,400	
Subtotal				$ 841,340	
Professional Services (as percent of construction and contingency costs)					
Project management	5%			$ 184,667	
Remedial design	6%			$ 221,600	
Construction management and reporting	6%			$ 221,600	
Subtotal Professional Servies				$ 627,868	
Total Estimated Capital Costs				$ 4,321,208	

IM&M COSTS - Net Present Value					
Item	**Frequency[1]**	**Unit Cost**	**Annual Cost**	**NPV Cost**	**Notes**
				1.6%	discount rate for Net Present Value calculation
Periodic IM&M					
Periodic GW quality and LNAPL thickness monitoring					
-Years 1&2 monitoring	4	$ 4,000	$ 16,000	$ 31,248	quarterly monitoring
-Years 3-30 monitoring	2	$ 3,500	$ 7,000	$ 152,081	semi-annual monitoring
Subtotal Periodic IM&M Cost				*$ 183,329*	
Professional Services (as percent of Periodic IM&M costs)					
Project management/Reporting		15%		$ 27,499	
Total, Periodic IM&M Net Present Value:				**$ 210,828**	
TOTAL ESTIMATED COST				**$ 4,532,036**	

Notes:

1) The frequencies shown are assumed for cost estimating purposes. The actual frequencies at which IM&M items will be conducted, along with other IM&M details, will be developed during remedy design.

Table B.6 - Alternative B4 Cost Estimate
Feasibility Study, Crownhill Elementary, Bremerton, Washington

Site:	Crownhill Elementary				
Remedial Action Description:	Alternative: B4	In Situ Treatment of LNAPL, Impacted Vadose Zone Soils, and Groundwater			
Cost Estimate Accuracy:	FS Screening Level (+50/-30 percent)				
Key Assumptions and Quantities:					
	986,480	ft3	volume of vadoze zone soils and LNAPL to be treated		

CONSTRUCTION COSTS

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
In Situ LNAPL and Vadose Zone Treatment					
ERH treatment	986,480	ft3	$ 12	$ 11,837,760	assume 10% larger soil volume
ISCO follow up treatments	2	LS	$ 60,000	$ 120,000	two treatments
Subtotal In Situ LNAPL and Vadose Zone Treatment				$ 11,957,760	
Tax	9.5%		$ 11,957,760	$ 1,135,987	
Contingency	20%		$ 11,957,760	$ 2,391,552	
Subtotal				$ 3,527,539	
Professional Services (as percent of construction and contingency costs)					
Project management	5%			$ 774,265	
Remedial design	6%			$ 929,118	
Construction management and reporting	6%			$ 929,118	
Subtotal Professional Servies				$ 2,632,501	
Total Estimated Capital Costs				$ 18,117,800	

IM&M COSTS - Net Present Value

Item	Frequency[(1)]	Unit Cost	Annual Cost	NPV Cost	Notes
				1.6%	discount rate for Net Present Value calculation
Periodic IM&M					
Periodic GW quality and LNAPL thickness monitoring					
-Years 1&2 monitoring	4	$ 4,000	$ 16,000	$ 31,248	quarterly monitoring
Subtotal Periodic IM&M Cost				*$ 31,248*	
Professional Services (as percent of Periodic IM&M costs)					
Project management/Reporting		15%		$ 4,687	
Total, Periodic IM&M Net Present Value:				**$ 35,935**	
TOTAL ESTIMATED COST				**$ 18,153,735**	

Notes:
1) The frequencies shown are assumed for cost estimating purposes. The actual frequencies at which IM&M items will be conducted, along with other IM&M details, will be developed during remedy design.