1.0 INTRODUCTION

This document presents the Remedial Investigation/Feasibility Study (RI/FS) for Site –wide groundwater issues and is defined as Remedial Action Unit 2C (RAU 2C) at the former Camp Bonneville Military Reservation (CBMR) in Clark County, Washington (**Figures 1.1 and 1.2**). This RI/FS has been prepared for and is submitted by the Bonneville Conservation Restoration and Renewal Team, LLC (BCRRT), the current owner of the CBMR. The RI/FS is based on previously approved remedial investigations, no-further-action determinations, ongoing groundwater monitoring at LF4/DA1 and Lacamas Creek wells, and direction given by Washington Department of Ecology (Ecology). This submittal is part of an ongoing dialogue between the Ecology and the BCRRT regarding the applicable requirements of the Prospective Purchaser Consent Decree (PPCD; Ecology, 2006) as it relates to the RAU 2C, which addresses groundwater quality concerns..

This RI/FS will include a summary of the remedial investigations to date, describe cleanup standards, risk evaluations for each area (where compounds exceeded MTCA default cleanup levels), and identify:

- preliminary cleanup action components,
- areas of the CBMR that may need cleanup,
- remedial objectives,
- response actions,
- specific cleanup technologies, and
- preferred cleanup actions.

This RI/FS meets the specifications of regulations promulgated under the Washington State Model Toxics Control Act (MTCA) as set forth in Title 173-340 of the Washington Administrative Code (WAC) Section 350 – Remedial Investigation and Feasibility Study [WAC 173-340-350], the requirements of WAC 173-340-360 concerning the evaluation of cleanup action alternatives.

1.1 Project Authorization and Status

The investigation of groundwater on-site began with Parsons Infrastructure & Technology Group (Parsons) was awarded Delivery Order No. 0017, Contract No. DACA87-00-D-0038 from the U.S. Army Engineering Support Center, Huntsville (USAESCH) in October 2001. The contract was awarded to conduct an Engineering Evaluation / Cost Analysis (EE/CA) at Camp Bonneville, Vancouver, Washington. Subsequently, the Army agreed to work cooperatively with Ecology and perform a Remedial Investigation/Feasibility Study (RI/FS) consistent with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Washington State Model Toxics Control Act requirements (MTCA). This RI/FS Report was prepared consistent with the USAESCH scope of work (SOW), revised December 2002 and the Washington State MTCA Chapter 173-340 Washington Administrative Code (WAC).

On July 28, 2006, the DA and Clark County entered into an Environmental Services Cooperative Agreement (ESCA) concerning Camp Bonneville. The ESCA (Agreement No. W9128F-06-2-0160) defines the funding, obligations and technical requirements for the early transfer of Camp Bonneville from DA to Clark County.

In August 2006, the U. S. Department of the Army (DA) issued a "Finding of Suitability for Early Transfer (FOSET) – Camp Bonneville" (U.S. Army 2006). In the FOSET, the DA concludes that "all DoD requirements to reach a Finding of Suitability for Early Transfer of the Property to the Clark County have been met. The proposed uses of the Property (i.e. Camp Bonneville) by the Grantee for the uses intended herein are consistent with the protection of human health and the environment, subject to inclusion of the covenants and notifications of this document, and the PPCD."

In the FOSET, the DA requests that the Governor of Washington agree to defer the federal government's covenant requirements under CERCLA (42 USC 9620(h)(3)(C)) until completion of the remediation of hazardous substances at Camp Bonneville are complete. When the federal government transfers federal property to non-federal entities, the deed must contain a covenant warranting that all hazardous substance remedial actions are complete prior to transfer. CERCLA allows for the Governor of the state in which a facility is located to defer the covenant and allow the early transfer of the property if certain findings are made. Once all required hazardous substance remedial actions are completed for a given RAU (described in Section 1.2) by the new property owner and are approved of by Ecology, the DA will grant the CERCLA covenant for that RAU. On October 2, 2006 The Governor of Washington approved the covenant deferral.

On October 3, 2006 the title of the former Camp Bonneville Military Reservation was transferred from the DA to Clark County. Immediately following that transfer, title was then transferred from Clark County to its Conservation Partner, the Bonneville Conservation Restoration and Renewal Team, LLC (BCRRT), a conservation not-for-profit organization. The BCRRT will hold title to Camp Bonneville while all required hazardous substance remedial actions are completed.

On October 13, 2006, Clark County and BCRRT entered into a PPCD No. 06-2-05390-4 (Ecology, 2006) with the Ecology concerning Camp Bonneville. The PPCD details the mutual objectives of Ecology, Clark County and BCRRT to provide for remedial action of releases or threatened releases of hazardous substances at Camp Bonneville. The PPCD also broadly describes required remedial actions, required documentation and the schedule by which remedial actions are to be completed. Since the transfer of the property to BCRRT, the PPCD required RAU 2C actions [***includes those parts of the PPCD that refers to "RAU 3 soil" or "RAU 3 groundwater"***] actions have been performed:

1) A Supplemental Groundwater Remedial Investigation Work Plan (BCRRT, 2006) was submitted, approved, and implemented at the Landfill 4/Demolition Area 1 (LF4/DA1) and Site-Wide Groundwater locations as detailed in Quarterly Groundwater Sampling and Analysis reports (BCRRT, 2006 to 2009).

2) A Supplemental Soil Remedial Investigation Work Plan [and Report] (Sampling and Analysis Plan for the Preliminary Assessment of Artillery Firing Points, Impact Areas and "Pop-up" Pond, BCRRT, 2007) was submitted, approved, and implemented, as documented in the Report of Soil and Sediment Investigations at Artillery/Mortar Firing Points, Artillery/Mortar Impact Areas, and "Pop-up" Pond, BCRRT, 2008).

3) The Conceptual Work Plan attached to the PPCD already called for 25 years of monitoring:

- The eleven LF4/DA1 wells were to be sampled quarterly until a clear and consistent decreasing trend of all contaminants of interest (which we a say are limited to perchlorate and RDX) for 4 quarters. Once this is reached, the sampling would be reduced to semi-annual for 3 years. If the decreasing trend continues, then sampling would be reduced to annual sampling until MTCA cleanup levels are achieved.

- The Sentinel wells will be sampled annually for 10 years (*the Demo 3 wells were also included but have since been discontinued per the RAU2B approval by Ecology*). If a decreasing trend of all COCs continues at the LF4 wells and no COC is detected at the Sentinel Wells, then the sampling could be reduced to once every 5 years until MCTA compliance is achieved.

- A Long-Term Monitoring and Contingency Plan that takes into account the current groundwater conditions and the remote possibility that increasing contaminant levels must be developed and approved by Ecology.

One of the requirements of the PPCD is that BCRRT is required to produce a Draft Final RI/FS for RAU 2C (***and includes those part of the PPCD that refers to "Site-Wide" or RAU 3 groundwater"***). This document has been produced to fulfill this requirement.

1.2 Purpose and Scope

For administrative reasons, the Camp Bonneville site is divided into three Remedial Action Units. The Remedial Action Units established at Camp Bonneville include the following:

- RAU 1: Consists of twenty discrete areas where hazardous substances have been encountered; RAU1 remedial actions have been completed for all of the areas and Ecology has issued a No Further Action letter.

- RAU 2A: Consists twenty-one small arms ranges to address the residual lead associated with these ranges; a final Corrective Action Plan (CAP) has been approved by the Ecology and it is being actively implemented at the time of this writing.

  RAU 2B: Consists of two former open burning/demolition areas, Demolition Areas 2 & 3; remedial actions have been completed at both areas. RAU 2B remedial actions have been completed for all of the areas, and Ecology has issued a No Further Action letter.

- RAU 2C: Consists of the Site-Wide groundwater evaluation, with special emphasis on the groundwater plume at the Landfill 4/Demolition Area.

- RAU 3: Consists of the entire site where munitions and explosive of concern (MEC) may be found.

The purpose of this Camp Bonneville RI/FS for RAU 2C is to document and present:

- Address groundwater contamination arising from anthropogenic activities and determine the nature and extent of groundwater contamination at CBMR;

- Collect sufficient data to meet the Model Toxics Control Act (MTCA) requirements for site characterization (WAC 173-340) and other applicable groundwater monitoring guidelines published by Ecology (Ecology 1995, 2001, 2004, 2005a, 2005b and Cruz 2005).

- Provide Data needed to determine whether actions are required based on surficial soil sampling of Artillery/Mortar Firing Points, and Artillery/Mortar target areas for the likelihood of explosive constituents impacting site groundwater;

- Development of appropriate risk assessment methods and results;

- Development of remediation levels;

- Identification and screening of various cleanup actions; and

- Rationale for selection of proposed cleanup action(s).

1.3 General Site Information

This section contains the following general facility information:

Project title: Remedial Investigation/Feasibility Study RI/FS for Site-Wide Groundwater - Remedial Action Unit 2C

Project coordinator: Name: Michael Gage
Address: Bonneville Conservation Restoration and Renewal Team, LLC
23201 Northeast Pluss Road
Vancouver, WA 98682
Phone number: (360)566-6990

Facility location: LF4/DA1 is within the boundaries of Camp Bonneville which is located in southwestern Washington; approximately 5 miles east of the Vancouver City limits in Clark County (see **Figure 1.1**).

Dimensions of facility: Camp Bonneville consists of approximately 3,840 acres. The Explosives Residue Target and Firing Points included about 30 acres, and LF4/DA1 consists of an approximately 1.82 acres located about 1,800 feet north of the Central Valley Floor and 2.5 miles northeast of where Lacamas Creek exits Camp Bonneville.

Present owner and operator: Camp Bonneville are owned and operated by the by BCRRT, LLC.

Chronological listing of past owners and operators and operational history: Since the early 1900's, the Department of the Army has owned and operated the Camp Bonneville site. In October 2006, the Army transferred ownership of the property to the County, which subsequently transferred the land to the BCRRT. BCRRT will hold the deed of the property during investigation and clean-up activities at the site. After the property is cleaned to Ecology standards the BCCRT will transfer the property back to the County

1.4 Site Location and Current Land Use

The 3,840-acre Camp Bonneville site is located northeast of Vancouver, Washington, in the southeastern region of Clark County (**Figure 1.1**). The property is approximately five miles from Vancouver, Washington and approximately seven miles north of the Columbia River. Camp Bonneville is located along the western foothills of the Cascade Mountain Range, with Camp Hill and Little Elkhorn Mountain to the northwest, Munsell Hill to the west, and Little Baldy Mountain to the south.

Vehicular access to Camp Bonneville is restricted to a single entrance. The entrance is located on SE 232nd Ave. and enters the site from the west at the Camp Killpack cantonment. The entrance is gated and monitored. Most recently, the facility had been used for weekend and summer training by the U.S. Army Reserve and Navy Reserve units from Southern Washington and Northern Oregon and was a sub-installation of Fort Lewis. Other Reserve and National Guard components, as well as the Federal Bureau of Investigation (FBI) and local law enforcement units, have also used the site. Operations at the facility seized in 1995 when CBMR was selected for closure under the 1995 Base Realignment and Closure (BRAC) process. From 1995 through 2008, the FBI and other law enforcement agencies continued to use the firing range known as the FBI Range. Currently, there is no military or law enforcement use of Camp Bonneville (grants for use of the site were cancelled beginning in November 1996). Camp Bonneville is mostly undeveloped, forested hillsides and creek side drainages. Former military barracks and training facilities are concentrated at Camp Killpack and Camp Bonneville cantonment areas. Other developed areas include firing ranges, a paved two-lane road connecting the main gate with the two cantonment areas, and a network of unpaved roads.

Camp Bonneville is more particularly described in U.S. Public Land Survey terminology as follows:

- The site is located in Range 3 East relative to the Willamette Primary Meridian. It includes the following parcels in Township 2 North:
  - Section 1 – all (640± acres) – owned
  - Section 2 – all (640± acres) – owned
  - Section 3 – all [except for two parcels along the western boundary of Section 3] (618± acres) – owned
  - Section 10 – North ½ (320± acres) – owned
  - Section 11 – Northwest ¼ [except for the southeast triangular ½ of southeast ¼ of this ¼ and the northwest ¼ of northeast ¼] (175± acres) – in process to transfer from the Washington State Department of Natural Resources to Clark County

- The following parcels are located in Township 3 North:
  - Section 34 – Southeast ¼ (160± acres) – owned
  - Section 35 – all (640± acres) – owned
  - Section 36 – all (640± acres) – in process to transfer from the Washington State Department of Natural Resources to Clark County

Between 1910 and 1995, the Army used Camp Bonneville for live fire of small arms, assault weapons, artillery, and field and air defense artillery. In the early 1950s, the Department of Defense arranged to lease an additional 840 acres from the State of Washington to expand training possibilities off of the post.

Since the Camp was officially closed, investigations have been conducted by the Army and its consultants in order to characterize the nature and extent of contamination at the site and to develop a plan for potentially transferring ownership. Clark County (County) expressed interest in the site and began the process for obtaining the property by developing a Reuse Plan. The Reuse Plan developed called for the majority of Camp Bonneville to be transferred to the County for the public benefit – education, law enforcement, and parks, with no financial gain to the County. Over the intervening years, several unsuccessful attempts were made to transfer Camp Bonneville from the Army to Clark County.

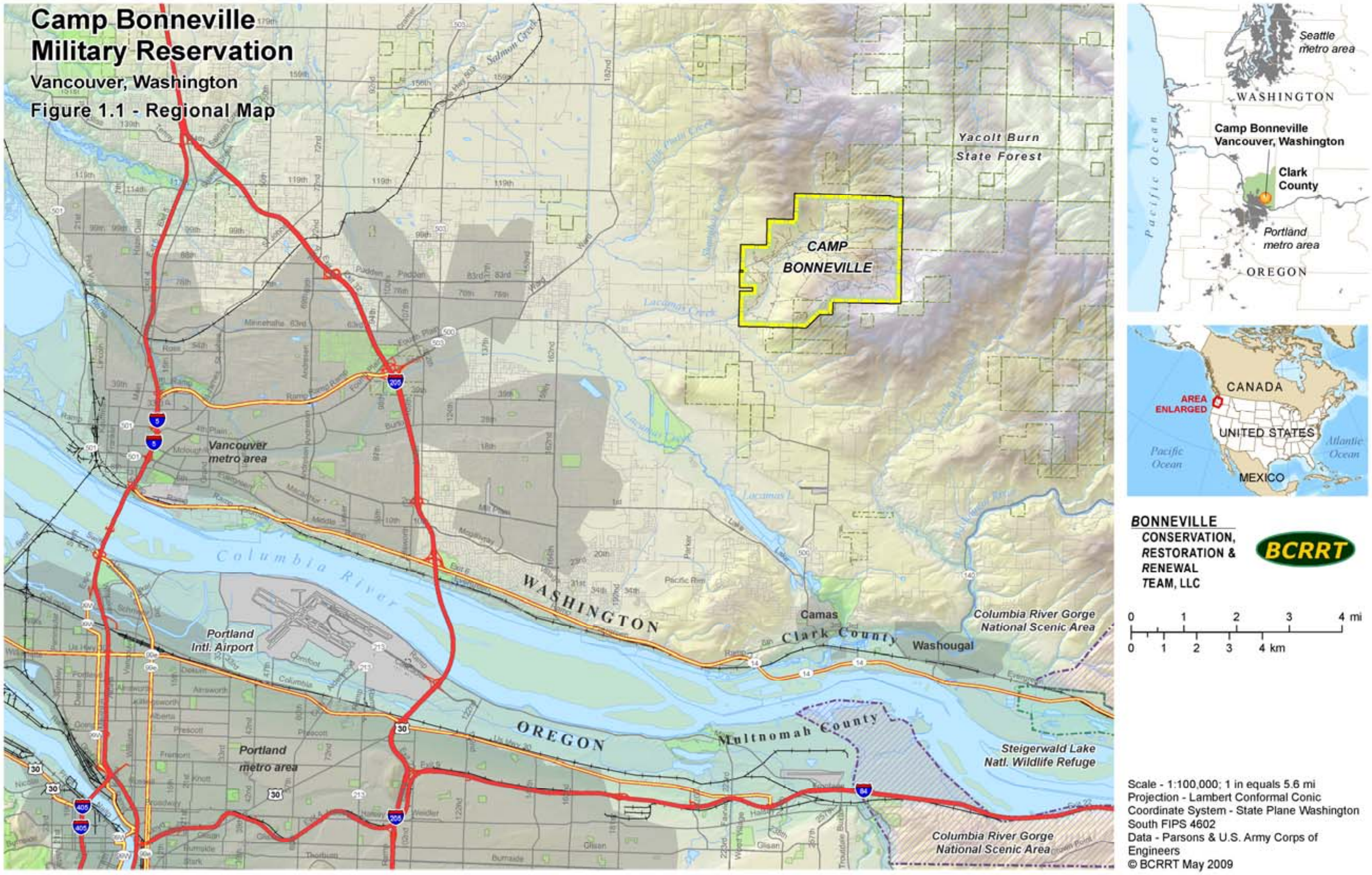
In October 2006, the Army transferred ownership of the property to the County which immediately transferred the land to the BCRRT. BCRRT will hold the deed of the property during investigation and clean-up activities at the site. After the property is cleaned to Ecology standards, BCCRT will transfer the property back to the County. The County will then begin implementing the Reuse Plan.

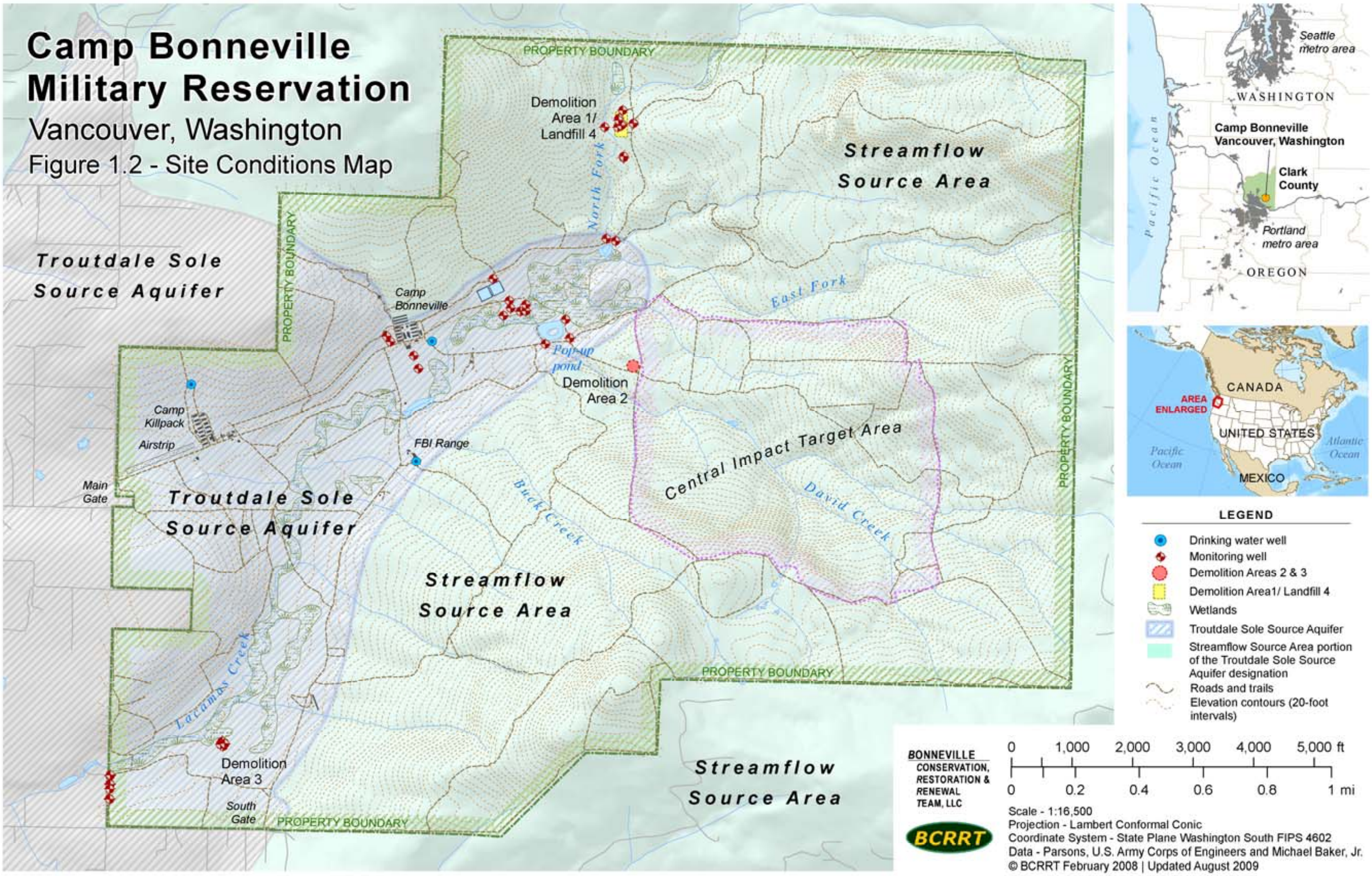
1.5 Report Organization

This Camp Bonneville RI/FS for RAU 2C is organized to meet the format requirements of, and contain the appropriate and applicable information identified in Washington State MTCA, Chapter 173-340 WAC. **Table 1-1** outlines the Sections and Appendices included in this document.

TABLE 1-1
CONTENTS – SITE-WIDE GROUNDWATER RI/FS REPORT

Section	Content
Section 1	Introduction
Section 2	Site Conditions
Section 3	Site Characterization
Section 4	Conceptual Site Model/Risk Assessment
Section 5	Cleanup Standards
Section 6	Identification of Cleanup Technologies
Section 7	Cleanup Action Alternative Evaluation
Section 8	References
Appendix A	No Further Action Letters
Appendix B	BCRRT Groundwater Monitoring Workplans and Reports
Appendix C	Draft Report of Soil and Sediment (Firing and Target Areas)
Appendix D	Perchlorate Evaluation Reports
Appendix E	Groundwater Modeling Outputs


Camp Bonneville
Military Reservation
Vancouver, Washington
Figure 1.1 - Regional Map
Yacolt Burn
State Forest
CAMP
BONNEVILLE
Vancouver
metro area
Columbia River
WASHINGTON
Portland
Intl. Airport
Camas
Clark County
Washougal
Columbia River Gorge
National Scenic Area
OREGON
Multnomah County
Steigerwald Lake
Natl. Wildlife Refuge
Portland
metro area
Columbia River Gorge
National Scenic Area
Seattle
metro area
WASHINGTON
Camp Bonneville
Vancouver, Washington
Clark
County
Portland
metro area
OREGON
Pacific Ocean
CANADA
AREA
ENLARGED
UNITED STATES
Pacific
Ocean
Atlantic
Ocean
MEXICO
BONNEVILLE
CONSERVATION,
RESTORATION &
RENEWAL
TEAM, LLC
0 1 2 3 4 mi
0 1 2 3 4 km
Scale - 1:100,000; 1 in equals 5.6 mi
Projection - Lambert Conformal Conic
Coordinate System - State Plane Washington
South FIPS 4602
Data - Parsons & U.S. Army Corps of
Engineers
© BCRRT May 2009


Camp Bonneville
Military Reservation
Vancouver, Washington
Figure 1.2 - Site Conditions Map
PROPERTY BOUNDARY
Demolition Area 1/ Landfill 4
North Fork
Streamflow Source Area
Troutdale Sole Source Aquifer
Camp Bonneville
East Fork
Pop-up pond
Demolition Area 2
Camp Killpack
Airstrip
FBI Range
Central Impact Target Area
Main Gate
Buck Creek
David Creek
Lacamas Creek
Demolition Area 3
South Gate
Seattle metro area
WASHINGTON
Camp Bonneville Vancouver, Washington
Clark County
Portland metro area
OREGON
Pacific Ocean
CANADA
AREA ENLARGED
UNITED STATES
Atlantic Ocean
MEXICO
LEGEND
Drinking water well
Monitoring well
Demolition Areas 2 & 3
Demolition Area1/ Landfill 4
Wetlands
Troutdale Sole Source Aquifer
Streamflow Source Area portion of the Troutdale Sole Source Aquifer designation
Roads and trails
Elevation contours (20-foot intervals)
BONNEVILLE CONSERVATION, RESTORATION & RENEWAL TEAM, LLC
BCRRT
0 1,000 2,000 3,000 4,000 5,000 ft
0 0.2 0.4 0.6 0.8 1 mi
Scale - 1:16,500
Projection - Lambert Conformal Conic
Coordinate System - State Plane Washington South FIPS 4602
Data - Parsons, U.S. Army Corps of Engineers and Michael Baker, Jr.
© BCRRT February 2008 | Updated August 2009

2.0 SITE CONDITIONS

This section presents an update of our understanding of the site conditions at the CBMR, based upon previous investigation reports, site reconnaissance/observations, recently discovered public literature and maps (specifically the 2006 detailed mapping of the geology of the Lacamas Creek by the U.S. Geological Survey, Evarts, Russell C., 2006).

2.1 General Location and Topography

The area surrounding Camp Bonneville is sparsely populated with scattered private residences and is used primarily for agriculture and livestock grazing. The nearest town is Proebstel, an unincorporated community about two and one-half miles to the southwest of the western entrance to the Camp.

Lacamas Creek (also identified on some historic maps as "La Camas Creek") flows southwestward from the confluence of North Fork and East Fork in the north-central part of Camp Bonneville in the flat to moderately sloped area known as the Central Valley, to the southwestern corner of the property (see **Figure 1.2**). Lacamas Creek also is fed by David Creek and Buck Creek, which drain the southeastern part of the property. From the southwestern property boundary, Lacamas Creek flows southwestward to Proebstel, where it turns toward the southeast and continues to its confluence with the Columbia River at the town of Camas.

The two cantonments, Camp Killpack and Camp Bonneville, are located in the Lacamas Creek Valley. The remainder of the property consists of moderately steep, heavily vegetated slopes that were used for military training activities prior to conveyance of the site to BCRRT in 2006. The Central Valley floor is primarily a relatively narrow floodplain. Elevations at Camp Bonneville which range from an about 290 feet above sea level [referenced as the National Geodetic Vertical Datum of 1929 (NGVD)] on the western end of the property to about 360 feet on the east. The adjoining slopes rise to moderately steeply up to elevations of between 1,000 and 1,500 feet along ridge tops within the property boundaries.

The two cantonments are accessible by a paved roadway through the western entrance of Camp Bonneville. Access within the Camp is limited to a few all-season gravel roads, most of which are on the valley floor, and seasonal dirt roads leading into perimeter areas in the northern, southern, and western portions of the facility. Access to the Camp is restricted to project personnel and others on official business. Because of the potential hazards associated with Munitions and Explosives of Concern (MEC), access to the facility outside of the cantonment areas where MEC clearance has not been completed is not allowed without an escort trained in ordnance recognition and avoidance.

Future land use planning for Camp Bonneville facility proposes development of the Central Valley and western third of the property as a regional park. Use of the remaining portions of the site will be limited to wildlife management. In terms of groundwater concerns, the Landfill 4/Demolition Area 1 (LF4/DA1) site. will be outside of the park limits and in the Wildlife Management Area. LF4/DA1 consists of an approximately 1.82 acres located about 1,800 feet north of the Central Valley Floor and 2.5 miles northeast of where Lacamas Creek exits Camp Bonneville.

2.2 Climate

The Camp Bonneville area has mild, wet winters and moderately warm, dry summers. January is the coldest month, with an average temperature of about 38 degrees Fahrenheit (°F). July and August are the warmest months, with an average temperature of about 69°F. On the average, only 26 days a year experience temperatures below freezing, and seven days have temperatures of 90°F or more.

Most of the precipitation in the area is caused by the passage of low-pressure zones along a path from the North Pacific Ocean eastward over the region during the winter and spring. The rainy season usually begins in the later part of September/October, and continues through March/April. On average, there are 154 days a year with measurable amounts of rainfall, and the average annual precipitation is approximately 47 inches. Annual snowfall in the Vancouver area averages about 8.4 inches. The average snow depth is typically only 2 or 3 inches, with continuous snow cover lasting one to three days at a time. Heavy fog occurs frequently during the fall and winter.

2.3 Surface Water Hydrology

Camp Bonneville is located in the Lacamas Creek Watershed (see **Figure 2.1**). This watershed is about 67 square miles that includes forest, farm, residential, commercial and industrial land uses. Lacamas Creek flows about 12.5 miles from relatively undisturbed headwaters (that extend beyond Camp Bonneville) into Lacamas and Round Lakes dropping through a series of waterfalls into the Washougal River and then into the Columbia River at Camas, Washington.

The principal surface water feature on-site is Lacamas Creek, which flows southwest from the confluence of two branch streams (North and East Forks) in the Central Valley, exiting the installation at its southwest corner. From the southwestern property boundary, Lacamas Creek flows southwestward to Proebstel, where it turns toward the southeast and continues to its confluence with the Columbia River at the town of Camas. Numerous minor tributaries drain adjacent uplands and flow into Lacamas Creek. Buck Creek and David Creek (see **Figure 1.2**), the largest of these tributary streams, drain the southeastern hills of Camp Bonneville.

2.4 Geology

In 2006, a newly detailed mapping of the geology of the Lacamas Creek 7.5 minute quadrangle was published by the U.S. Geological Survey (Evarts, 2006). Because Evarts' geologic mapping has important ramifications regarding the fate and transport of groundwater contaminants at the CBMR, this publication is relied upon heavily in the following discussion.

2.4.1 Physiography and Regional Geologic History

The Cascade Mountains divide Washington into two distinct parts, a wet western side with moderate temperatures and a semi-arid eastern side that experiences greater temperature extremes. The peaks and ridges of the range are at about 6,000 to 8,000 feet in elevation with some volcanic peaks over 10,000 feet. The southern Cascade Range that borders the site to the east consists of Tertiary age volcanic and sedimentary rocks.

Camp Bonneville is situated between the western foothills of the southern Cascade Range and the Portland Basin physiographic provinces. **Figure 2.2** presents the most recent geologic mapping for the Camp Bonneville area (Evarts, 2006). The Portland Basin and surrounding area has an eventful geologic history and are characterized by low topographic relief with exposures of Oligocene [24 to 34 million years ago (Ma)] volcanic basalt flows of the Elkhorn Mountain (~26.5 Ma) at the eastern edges of the basin. Volcanism and uplift of the young Cascade Range in the east caused the basin to fill with relatively low-energy sediments (i.e., the Sandy River Mudstone) via the ancestral Columbia River. In the Miocene period (5-24 Ma), more abrupt changes in relief resulted in higher energy sediments of the Troutdale Formation to accumulate in the basin from the sources in the east. An abrupt lifting of the Cascade Range in late Miocene or early Pliocene (~5 Ma), resulted in a further increase in sedimentation in the Columbia Valley, which caused much of the previously-existing Troutdale Formation in the Portland Basin to be eroded. This left Troutdale Formation remnants mainly on the western foothills of the Cascades.

This series of uplifting events in the Cascade Range continued from the late Miocene into the Pliocene (2 to 5 Ma). The northwest-to-southeast trending graben-type faulting beneath the southwest part of the Lacamas Creek quadrangle caused the Portland Basin to sink more than 200 ft (60 m). Another period of volcanism in the late Pliocene in the Cascades, resulted in two separate depositions of the characteristically hyaloclastic conglomerate sediments [i.e., containing glassy (vitric) clasts of lava cooled quickly in river water].

Beginning in the late Pliocene (~2.5 Ma), volcanic activity spread westward from the Cascade Range into the Portland Basin to form the Boring Volcanic Field (Mundorff, 1984; Evarts, 2006). The Lacamas Creek quadrangle is near the northern edge of the volcanic field and contains three volcanoes that erupted between 650 and 600 thousand years ago (ka), one at Green Mountain and two in the Brunner Hill-Matney Creek area. The Brunner Hill and Matney Creek vents produced chemically similar lava flows that are probably products of a single magmatic system, and may have erupted more or less simultaneously.

The Lacamas Creek quadrangle lies beyond the limits of Pleistocene (2 million to 10,000 years ago) glaciers emanating from the southern Washington Cascade Range (Mundorff, 1984; Evarts, 2006). However, elevations below about 400 ft (120 m) were periodically inundated by the latest Pleistocene glacier-outburst floods from Glacial Lake Missoula (Mundorff, 1984; Evarts, 2006). About 40 episodes of catastrophic ice dam breakage and flooding caused water exiting the Columbia River Gorge to spread out into the Portland Basin, and to erode the trough now occupied by Lacamas Lake.

2.4.2 <u>Local Geology</u>

Given the thin covering of soil (overburden) in the upland portions of CBMR and the deeper, orogenic source of alluvial soils in the Central Valley, the underlying bedrock can have a significant effect on the physical and chemical factors involved in contaminant fate and transport, surface and groundwater migration, as well as hyrdogology/aquifer properties.

According to Evarts' nomenclature (Evarts, 2006), five geologic formations are present at Camp Bonneville (see **Figure 2.2**) and are, from oldest to youngest:

1) Basaltic (volcanic) Andesite of Elkhorn Mountain (referred to as: Tbem)
2) Sandy River Mudstone (Tsr)
3) Lower (Conglomerate) Member of the Troutdale Formation (Ttfc, Ttfh)
4) Landslide Deposits (Qls)
5) Alluvial Sediments (Qa)

The andesite bedrock occurs at the surface over much of the mountainous eastern half of Camp Bonneville while the sedimentary deposits occur in the Central Valley and, importantly, in the North Fork of Lacamas Creek.

2.4.2.1 Basaltic Andesite of the Elkhorn Mountain (Tbem)

Bedrock in the Lacamas Creek quadrangle consists of a sequence of tholeiitic (olivine-poor) basaltic andesite and basalt surface flows informally named the basaltic andesite of Elkhorn Mountain. This series of lava flows has a maximum thickness of at least 2,800 ft (800 m) and extends from near Amboy, about 19 km north of Hockinson, to Camas, about 5 km south of the southern edge of the quadrangle area (Evarts, 2005; R.C. Evarts, unpublished mapping). Individual flows are typically 14 to 35 ft (4 to 10 m) thick but locally reach 240 ft (70 m) thick.

The lava flows are characterized by blocky, platy, or columnar-jointed interiors that commonly grade into upper and lower flow breccia zones. The upper zones typically contain abundant zeolite-, quartz-, and clay-filled vesicles and have been oxidized to reddish-orange during cooling. All flows were apparently at land surface; many rest on red paleosols (ancient soils) developed on previously emplaced flows or on thin sedimentary intervals, with no pillow lavas or other indications of subaqueous environments.

Structural attitudes of basement rocks in the map area are difficult to ascertain mainly because the unit lacks mappable sedimentary interbeds. However, the distribution of individual flows can be mapped locally and indicates the bedrock surface dips generally to the southwest at less than a 5° slope. The buried surface of the basaltic andesite (Tbem) bedrock slopes irregularly westward within the Lacamas Creek quadrangle and is deeper than 1,000 ft (305 m) below sea level in the southwest corner of the map.

The thick sequence of lava flows probably represents part of a large mafic (magnesium and iron rich) shield volcano centered east of the Lacamas Creek quadrangle. Lava flows in the Elkhorn Mountain unit range from aphanitic to highly porphyritic. Plagioclase phenocrysts in these rocks are larger than 5 mm and commonly larger than 1 cm across. Groundmass textures indicate the basalts cooled rapidly; their coarse-grained appearance reflects pre-eruptive accumulation and concentration of feldspar crystals in a sub-volcanic magma chamber rather than slow cooling at depth.

The lava flows of the Elkhorn Mountain unit vary from basalt to mafic andesite, but most are basaltic andesite; they are uniformly tholeiitic (olivine-poor), with low to medium potassium contents and exceptionally high Al2O3 contents (as high as 21 wt percent). Rocks with more than about 18 percent Al2O3 almost certainly accumulated plagioclase crystals prior to eruption. The Elkhorn Mountain flows are also unusually rich in iron (Fe) (about 9.3 to 12.5 wt percent) and poor in strontium (generally less than 320 ppm). Incremental-heating with argon (Ar) via 40Ar/39Ar age determinations in the adjacent Yacolt quadrangle (Evarts, 2006) indicate that the basaltic andesite of Elkhorn Mountain is about 26 to 27 million years old.

The basaltic andesite of the Elkhorn Mountain unit (Tbem) has been subjected to zeolite-facies metamorphism on a regional scale, the general character of which is similar to that described from other areas in the southern Washington Cascade Range (Fiske and others, 1963; Wise, 1970; Evarts and others, 1987; Evarts and Swanson, 1994). This region-wide metamorphism reflects burial of the early Oligocene rocks by younger volcanic rocks within the relatively high-heat-flow environment of an active volcanic arc. The primary effect of very-low-grade metamorphism in the mafic flows of the basaltic andesite of Elkhorn Mountain is the nearly universal development of clay minerals and zeolites replacing interstitial glass, filling vesicles, and deposited on joint surfaces. Feldspar phenocrysts typically display partial alteration to clay minerals and (or) zeolites along fractures and cleavage planes.

According to the logs of borings from several investigations at the Base, the uppermost bedrock is severely weathered. This weathered bedrock tends to form clay-rich surface soils, which contain increasing amounts of angular, basaltic gravel with depth. This weathering end product is consistent with the process started by the regional metamorphism and wide-scale alteration of parent bedrock to clay and zeolite minerals as described above.

2.4.2.2 Sandy River Mudstone (Tsr)

Hundreds of water-well logs record clayey siltstone and fine-grained sandstone of the Sandy River Mudstone (Tsr) atop the volcanic bedrock surface throughout the map area west of the Cascade foothills. Well logs indicate that this formation is present at the surface at Camp Killpack and east of Brunner Hill, although exposures are absent in those areas. These deposits thicken to the west and locally exceed 1,000 ft (300 m) thick. Outcrops in areas to the northwest of the Lacamas Creek quadrangle show that the formation consists of well-bedded sandstone, siltstone, and mudstone that typically display graded bedding, planar and trough crossbeds, and cut and fill structures indicative of a fluvial depositional setting (Mundorff, 1964; Howard, 2002; Evarts, 2004a, c). The upper contact with the Troutdale Formation is generally abrupt and probably disconformable.

The Sandy River Mudstone is fine-grained, low permeability siltstone deposit that also has very little permeability. The Sandy River Mudstone occurs only between the Camp Bonneville and Killpack cantonments (see **Figure 2.2**) in the small valley between Camp Hill/Munsell Hill along the north side of Lacamas Creek as it exits CBMR southwest; this unit does not occur at LF4/DA1.

2.4.2.3 Troutdale Formation (Ttfc, Ttfh)

The Troutdale Formation in the Lacamas Creek quadrangle is characterized as two lithologically distinct informal members that are separated by an unconformity (significant break in age of the rock). The older member (Ttfc) consists of quartzite-bearing conglomerate and arkosic sandstone. The younger member (Ttfh) is composed largely of hyaloclastic (volcanic glass-containing) basaltic debris. Only the older member (Ttfc) occurs at Camp Bonneville and will be discussed further.

The older member of the Troutdale Formation (Ttfc) underlies a flat to gently southwest-sloping and dissected surface, mostly below 600 ft (180 m) in elevation, between Hockinson and Camp Bonneville that Mundorff (1964) called the Troutdale bench. It consists chiefly of deeply weathered conglomerate that overlies the Sandy River Mudstone (Tsr). Similar gravelly deposits are present at Green Mountain and east of Brunner Hill. In the map area, the conglomerate member (Ttfc) is generally less than 280 ft (80 m) thick, although Swanson and others (1993) infer a thickness greater than 420 ft (120) m at Green Mountain. Good exposures of the lower conglomerate member of the Troutdale Formation are uncommon owing to intense weathering; in many locations only residual quartzite clasts remain. Well rounded quartzite clasts are widely distributed atop the basaltic andesite bedrock (Tbem) near and south of Camp Bonneville indicating that the Troutdale Formation originally buried all of the terrain below about 700 ft (200 m) elevation.

Scattered exposures show that the Troutdale Formation conglomerate member (Ttfc) consists of weakly to moderately cemented pebble and cobble conglomerate and lenses of coarse sandstone. Well-rounded pebbles and cobbles eroded from the Columbia River Basalt Group are the most abundant constituent of the conglomerate; the remainder includes light-colored granitic and quartzo-feldspathic metamorphic rocks, iron oxide-stained quartzite, and minor amounts of volcanic rocks eroded from the Cascade Range. The interbedded sandstone ranges in composition from basaltic to muscovite-bearing arkosic and quartzose, and is lithologically similar to the sandy matrix of the conglomerate. Significantly, the conglomerate member of the Troutdale Formation (Ttfc) lacks clasts of Pliocene and younger basalts like those that dominate the basaltic hyaloclastic sandstone member (Ttfh). Characteristics of the conglomerate, such as the massive to crudely stratified beds, clast-support, moderate to good sorting, and clast imbrication, are consistent with deposition during flood stage in a gravelly braided river system (Miall, 1977, 1996; Rust, 1978).

2.4.2.4 Recent Alluvium and Landslide Deposits (Qa, Qls)

A veneer of recent alluvial deposits of unconsolidated silt, sand, and gravel (Qa) underlies the floodplains along Lacamas, Shanghai, Fifth Plain, and Morgan Creeks as well as the Little Washougal River. Well-rounded quartzite pebbles eroded from the Troutdale Formation are abundant in all of these deposits.

Several large landslide complexes mantle the steep bedrock terrain of the eastern part of the Lacamas Creek quadrangle. These slides appear to be generated by failure of weathered, clay-rich, flow-breccia zones or thin volcaniclastic interbeds. Small slides, including some too small to map, are widespread along steep slopes underlain by weakly consolidated parts of the Troutdale Formation.

2.5 Hydrogeology

2.5.1 Hydrogeology of the Basaltic Andesite of the Elkhorn Mountain (Tbem)

The andesite bedrock has little to no primary permeability due to the following three factors:

1) The volcanic origins of the andesite,

2) Large-scale metamorphism of the Elkhorn Mountain unit to clay and zeolite minerals as mentioned above, and

3) Extreme weathering of near-surface rock strata and ensuing filling of resulting open spaces in the rock strata with clay intrusions in response to increasing geostatic pressure with depth.

Accordingly, the andesite bedrock present at Camp Bonneville is not considered to be a productive aquifer.

However, several wells in the Camp Bonneville area have been used for potable water supplies since these wells were installed deep enough (350 to 600 ft) to encounter enough open, water-bearing fractures for an adequate supply (secondary permeable zones/fractures). One water supply well at Camp Bonneville was drilled to a depth of 364 feet in 1978 and initially produced 77 gallons per minute (gpm) (see **Appendix D**). However, the cement grout seal of the well extended only to 129 ft, leaving the well screen open to a four-foot thick layer of saturated gravel at 133 feet atop the weathered rock. Competent rock was not reached until 207 feet. Therefore, it is impossible to determine if the water was coming from the gravel, from the weathered bedrock, from fractures in the competent rock, or from a combination thereof.

From recovery test data recorded by the driller on that well log, an estimate of hydraulic conductivity was made using a dual-permeability model (Moench, 1984), in which the fracture conductivity was 5.5 ft/d (1.9e-3 cm/sec) and that of the bedrock matrix was 5e-7 ft/d (1.8e-10 cm/sec).

These conductivity estimates illustrate the impermeable nature of the unweathered andesite bedrock and that unless fractures are present and interconnected, groundwater will tend to stay in the more permeable overburden.

2.5.2 Hydrogeology of the Troutdale Sole-Source Aquifer System

Portions of the Western Slopes and Central Valley Areas of CBMR overlies the Troutdale Sole-Source Aquifer System. The Troutdale Streamflow Source Area generally covers the remainder of the CBR east/upslope of the Central Valley (see **Figure**

2.3). The USEPA defines a Sole-Source Aquifer as “an aquifer or aquifer system which supplies at least 50% of the drinking water consumed in the area overlying the aquifer, and for which there is no alternative source or combination of alternative drinking water sources which could physically, legally and economically supply those dependent upon the aquifer.” The Troutdale Sole-Source Aquifer System is a highly productive aquifer and includes not only the Troutdale Formation, but all of the productive, hydraulically interconnected water-bearing sedimentary units overlying it within the entire Portland Basin, namely the unnamed conglomerate (Qtc), cataclysmic flood deposits (Qfg) and alluvium (Qa) (USEPA 2006, using the nomenclature of Evarts, 2006).

The USEPA defines the Streamflow Source Area as “the upstream headwaters area of streams that flow into the recharge area of the aquifer.” According to the USEPA, groundwater pumping in the Streamflow Source Area (east of the Sole Source Area) has lowered the groundwater levels in the Lacamas Creek Watershed causing water in the rivers to recharge the aquifer system (USEPA 2006).

2.5.3 General Hydrogeology at Camp Bonneville

Groundwater flow within Camp Bonneville generally follows topography from precipitation recharging groundwater in the uplands and flowing downhill through the shallow, weathered zones of bedrock into the Central Valley to enter the alluvium of the floodplain (see **Figure 2.3**). Because Lacamas Creek and its tributaries represent the lowest pressure head in the area, groundwater typically discharges to these surface water bodies. Groundwater deep in the Central Valley alluvium that does not discharge to the steams will generally flow parallel to the valley, toward the southwest. Groundwater exits Camp Bonneville where Lacamas Creek crosses the southwestern corner of the Base and is monitored at this boundary crossing by wells LC-MW-1S, 1D, 2S, 2D, 3S, 3D, 4S & 4D (URS, 2003).

2.6 Air

Hazardous substances related to groundwater at the CBMR are not of concern with respect to impacts to air quality. As shown in the **Section 4.0 Risk Assessment**, the contaminants of concern are present in groundwater in very limited portions of the site and usually at considerable depth. Because of the non-volatile nature of the contaminants in the groundwater, it is unlikely that contaminants would affect the air at the CBMR.

Camp Bonneville Military Reservation, Vancouver, Washington

Figure 2.1 - Lacamas Creek Watershed

China Ditch

China Ditch is in the northwest corner of Lacamas Creek watershed. The area is largely comprised of fields and pastures with some rural residential development. Much of China Ditch drainage is marshy and not well suited to suburban or urban development.

China Ditch has a very poor stream health rating based on poor water quality and very poor harmful bacteria ratings. Manmade channels designed to drain wetlands created most of the drainage system. Such systems usually have very poor health because they lack wooded areas to shade them, have a dirt channel bottom, and stagnant water conditions during summer months.

Management objectives for China Ditch

- Identifying and removing bacteria sources
- Establishing shade along the ditches
- Ensure implementation of flood control methods

Upper Lacamas Creek

Upper Lacamas Creek is the easternmost part of Lacamas Creek watershed and includes Camp Bonneville Military Reservation. It is predominantly forest with some suburban development on large lots and is expected to remain mostly forested because Camp Bonneville is a restricted area.

Data show Upper Lacamas Creek to be in good health. Some headwater areas may be in excellent health.

Management objectives for Upper Lacamas Creek

- Protecting good to excellent condition by limiting forest clearing
- Minimizing the amount of runoff from new homes and roads
- Retaining open spaces

Dwyer Creek

Dwyer Creek drains north to Lacamas Creek from the northwest part of Camas and eastern Vancouver.

The Dwyer Creek area is rapidly converting from a rural area to an urban area of housing subdivisions and extensive industrial and commercial development. Significant areas of forested wetlands remain along the stream channel.

Dwyer Creek is in poor health based on samples of stream insects. Its headwaters are in residential subdivisions and some parts of the creek are channeled.

Most of the developing area that drains directly to the creek is inside the city of Camas. The western part of Dwyer Creek's mapped drainage area is underlain by coarse gravelly soils that allow stormwater runoff to be infiltrated instead of piped to the stream. These types of soils are common in other parts of southwest Clark County but are rare in Lacamas Creek watershed.

Management objectives for Dwyer Creek

- Preventing further degradation due to urbanization

Lacamas Creek Watershed
Stream Health 2003

Stream Health Ratings	Description
Excellent	Pristine, superior, or unsurpassed condition; minimal human disturbance
Good	Healthy enough to support aquatic life and recreation
Fair	Degraded but may support aquatic life and recreation
Poor	Inferior health, poorly suited for aquatic life and recreation
Very Poor	Severely degraded health; unsuitable for aquatic life or recreation
Unassessed	No data collected
Probable	Predicted stream health

Land Cover Key
Forest
Grass/Shrubs
Residential/ Recently cleared land
Commercial/ Industrial

This figure is from the report "Monitoring Report: Lacamas Lake Annual Data Summary for 2005".

Matney Creek

The headwaters of Matney Creek begin in the Cascade Foothills and join Lacamas Creek just below Camp Bonneville. The area draining to Matney Creek is rural and includes forest and large lot residential at the headwaters and small farms and rural suburban areas in the lower areas.

Matney Creek ranges from good health in its forested headwaters to poor in the lower areas. Where we have test results, harmful bacteria cause a poor rating for water quality. Matney Creek is at risk of further degradation due to forest loss and increasing development.

Management objectives for Matney Creek

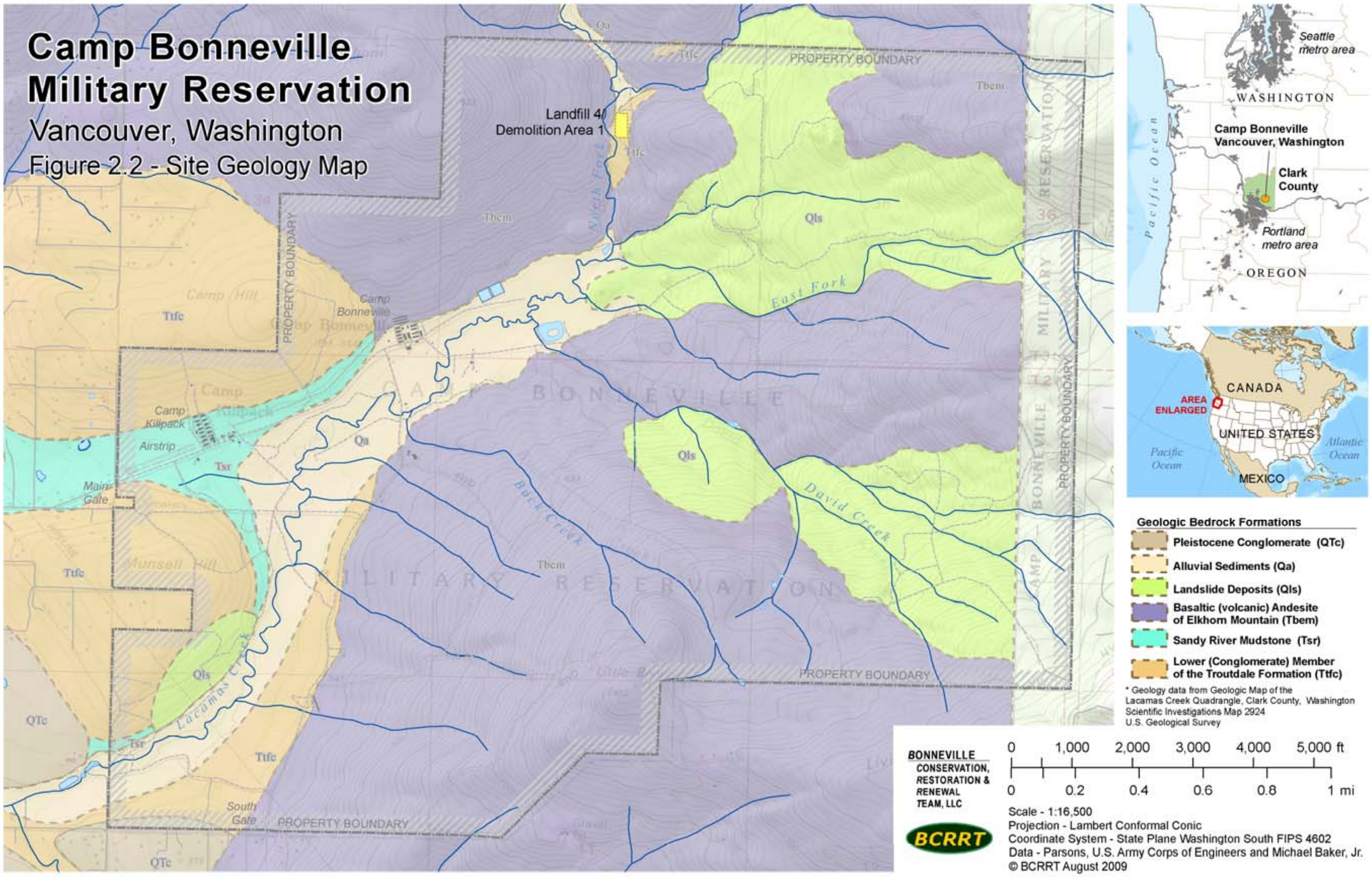
- Preventing further degradation for Matney Creek
- Preserving forests and using development methods that limit the amount of stormwater runoff created
- Establishing plants/trees along stream banks to shade the creek (better temperature control)

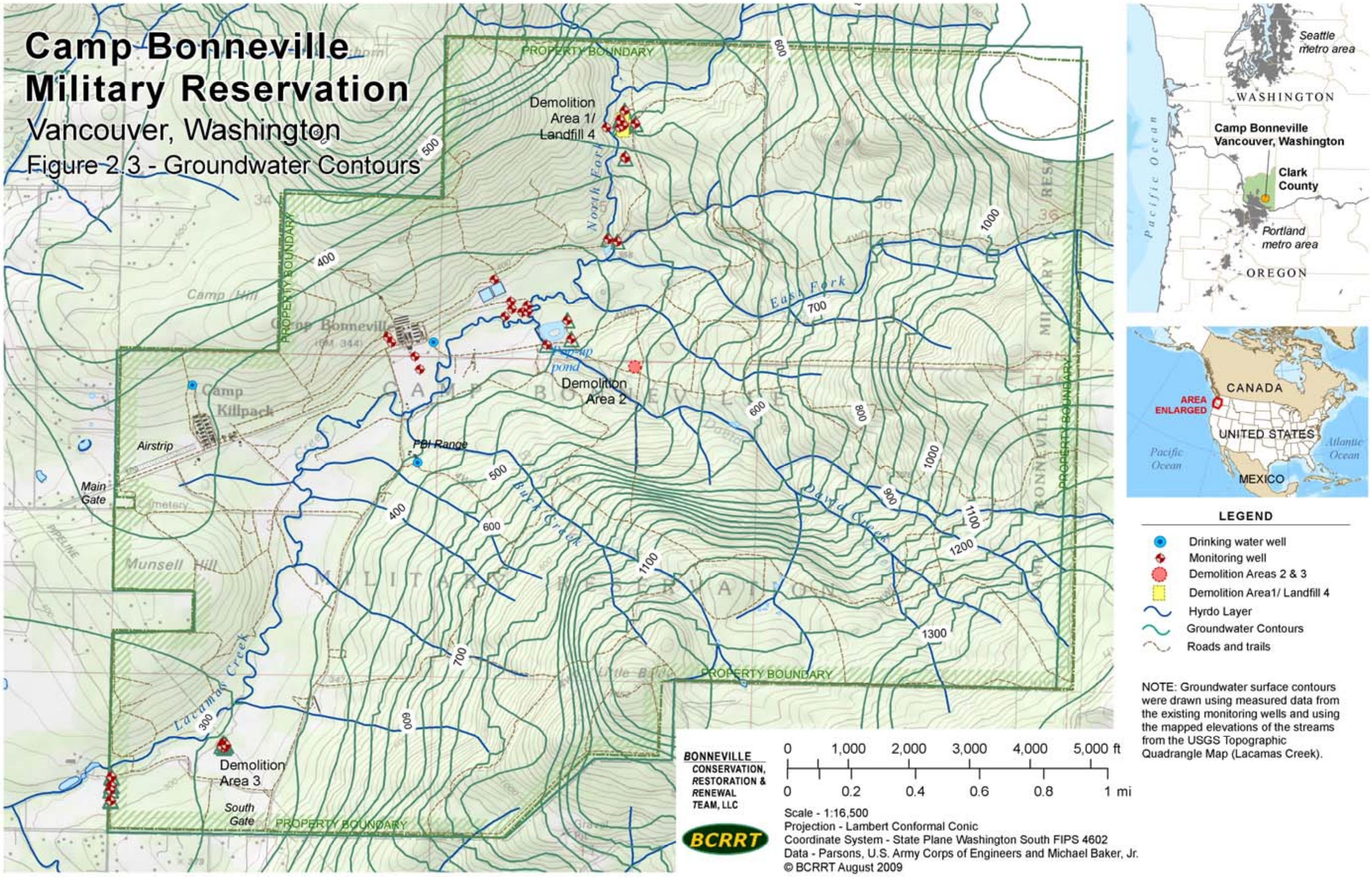
Lacamas Lake

Most of the Lacamas Creek watershed drains to Lacamas Lake. Any sediment and pollutants carried by the creek enter and may become trapped in the lake.

The health of Lacamas Lake suffers due to warm water and low dissolved oxygen during the summer. This is largely caused by eroded soil and nutrients carried to the lake by Lacamas Creek. Boat wakes disturb sediment causing it to resuspend. Dissolved oxygen is very low during the summer, stressing aquatic life.

Lacamas Lake supports fishing, boating and swimming, as well as hiking and birding along its shores. While the current programs have stabilized lake health, it is unlikely that there will be major improvements. One proposed option is to build a system to aerate the lake, similar to a giant fish aquarium.


Camp Bonneville
Military Reservation
Vancouver, Washington
Figure 2.2 - Site Geology Map
Landfill 4/
Demolition Area 1
PROPERTY BOUNDARY
East Fork
David Creek
Buck Creek
Lacamas Creek
North Fork
Camp Bonneville
Camp Hill
Camp Kilpack
Airstrip
Main Gate
South Gate
Munsell Hill
Qa
Qls
Tbem
Ttfc
Tsr
QTc
BONNEVILLE MILITARY RESERVATION
Seattle metro area
WASHINGTON
Camp Bonneville
Vancouver, Washington
Clark County
Portland metro area
OREGON
Pacific Ocean
CANADA
AREA ENLARGED
UNITED STATES
MEXICO
Atlantic Ocean
Geologic Bedrock Formations
Pleistocene Conglomerate (QTc)
Alluvial Sediments (Qa)
Landslide Deposits (Qls)
Basaltic (volcanic) Andesite of Elkhorn Mountain (Tbem)
Sandy River Mudstone (Tsr)
Lower (Conglomerate) Member of the Troutdale Formation (Ttfc)
* Geology data from Geologic Map of the Lacamas Creek Quadrangle, Clark County, Washington Scientific Investigations Map 2924 U.S. Geological Survey
BONNEVILLE CONSERVATION, RESTORATION & RENEWAL TEAM, LLC
0 1,000 2,000 3,000 4,000 5,000 ft
0 0.2 0.4 0.6 0.8 1 mi
Scale - 1:16,500
Projection - Lambert Conformal Conic
Coordinate System - State Plane Washington South FIPS 4602
Data - Parsons, U.S. Army Corps of Engineers and Michael Baker, Jr.
© BCRRT August 2009


Camp Bonneville
Military Reservation
Vancouver, Washington
Figure 2.3 - Groundwater Contours
PROPERTY BOUNDARY
Demolition Area 1/ Landfill 4
Demolition Area 2
Demolition Area 3
PBI Range
Airstrip
Main Gate
South Gate
Camp Killpack
Camp Hill
Munsell Hill
North Fork
East Fork
Buck Creek
David Creek
Lacamas Creek
Seattle metro area
WASHINGTON
Camp Bonneville Vancouver, Washington
Clark County
Portland metro area
OREGON
Pacific Ocean
CANADA
AREA ENLARGED
UNITED STATES
Atlantic Ocean
MEXICO
LEGEND
Drinking water well
Monitoring well
Demolition Areas 2 & 3
Demolition Area1/ Landfill 4
Hyrdo Layer
Groundwater Contours
Roads and trails
NOTE: Groundwater surface contours were drawn using measured data from the existing monitoring wells and using the mapped elevations of the streams from the USGS Topographic Quadrangle Map (Lacamas Creek).
BONNEVILLE CONSERVATION, RESTORATION & RENEWAL TEAM, LLC
0 1,000 2,000 3,000 4,000 5,000 ft
0 0.2 0.4 0.6 0.8 1 mi
Scale - 1:16,500
Projection - Lambert Conformal Conic
Coordinate System - State Plane Washington South FIPS 4602
Data - Parsons, U.S. Army Corps of Engineers and Michael Baker, Jr.
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3.0 SITE CHARACTERIZATION

The Site-Wide Groundwater RI/FS is based on the previously approved remedial investigations, no-further-action determinations, ongoing groundwater monitoring at LF4/DA1 and Site-Wide Groundwater Sentinel wells, and direction given by Ecology. This Section reviews the remedial investigations to date, status of Ecology approval, and whether there are outstanding groundwater issues that require further evaluation (where compounds exceeded MTCA Method A or B Cleanup Levels).

There have been numerous investigations have been performed at the CBMR related to potential soil and groundwater impacts. Investigations of the following areas had included groundwater-related components, but have been addressed separately from RAU 2C - Site-Wide Groundwater:

- RAU 1 - Hazardous waste impact at 20 locations (remediated pre-transfer),
- RAU 2A – 21 Small Arms Ranges where lead or other contaminants may be of concern,
- RAU2B – Open Burn/Open Demolition Areas (OB/OD) 2 and 3, and
- Newly Discovered OB/OD Areas.

These areas are in included in following **Sections 3.1, 3.2, 3.3 and 3.6** and include a brief summary, their status under Ecology review/approval, and whether there are outstanding groundwater issues that require evaluation under RAU 2C.

There are no locations on the property where site activities are known to have affected the quality of surface water (Hart Crowser, 2000), and as such are not part of the RAU 2C evaluation.

Sections 3.4, 3.5, and 3.7 address the Site-Wide Groundwater for CBMR per the PPCD:

- Site-Wide Groundwater Sentinel Wells
- Explosives Residue at Firing Points and Target Areas, and
- Landfill 4 /Demolition Area 1.

3.1 RAU 1

The hazardous waste impact at 20 locations (remediated pre-transfer) located near/at the Bonneville and Killpack Cantonment areas were addressed as RAU 1 (see **Figure 3.1)**.

3.1.1 Previous Investigations

Previous remedial investigations were conducted at the RAU 1 locations:

- Shannon & Wilson, July, 1999. Final Report Volume 1 Multi-Sites Investigations, Camp Bonneville, Washington. Contract No. DACA 67-94-D-1014.

- Hart Crowser September, 1996. Petroleum Contaminated Soil Investigation, Former Tank no.7-CMBPN, Building no. 4475, Camp Bonneville Washington. Contract No. DACA67-93-D-1004.

- September 2000. Final Report for Landfills 1, 2, and 3; Former Burn Area; Buildings 1962 and 1963; Grease Pits at the Camp Bonneville and Camp Killpack Cantonments; Former Sewage Pond, and Hazardous Materials Accumulation Point, URS.

- URS May 2002. BRAC HTRW Closure Report for Drum Disposal Area, Paint Solvent Disposal Area, Washracks 1 and 2, Maintenance Pit, Pesticide Mixing/Storage Building, (Bldg 1864), Aboveground Storage Tanks, CS Gas Training Area, Pesticide Storage Building (Bldg 4126), and Ammunition Storage Bunkers (#2953, #5951, and #2950).

- BCRRT February 2007. Request for No Further Action Determination.

- Ecology January 2008. No Further Action Determination, Ecology (see **Appendix A**).

3.1.2 Status Summary

The RAU 1 investigations and remedial actions have been completed for all of the Bonneville and Killpack Cantonment Areas. The reports concluded that remedial actions were complete and did not identify the potential for impacts to groundwater. Responses to the RAU 1 areas of concern are complete and will not be part of this RAU-2C RI/FS evaluation.

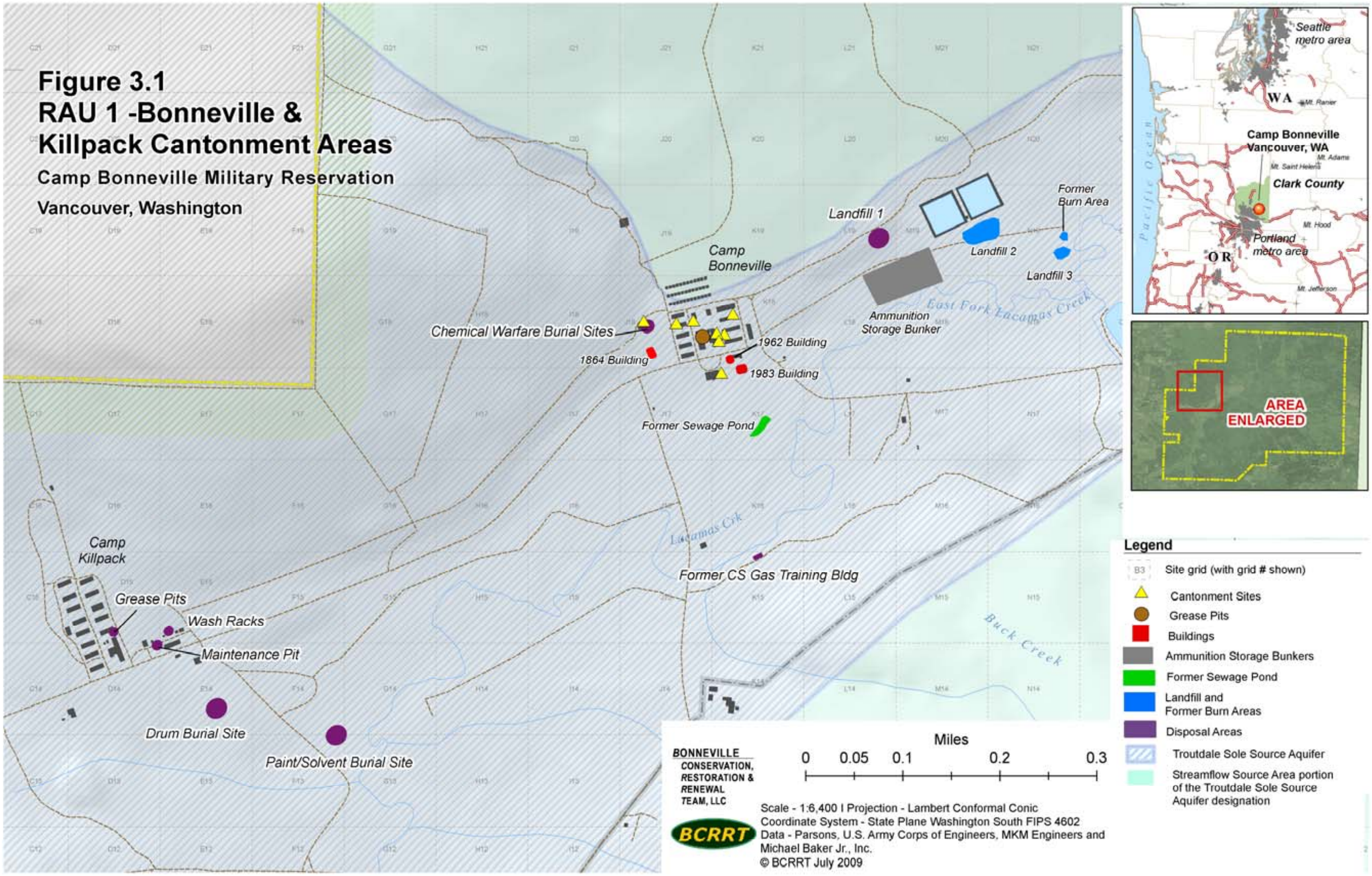
Figure 3.1
RAU 1 -Bonneville &
Killpack Cantonment Areas
Camp Bonneville Military Reservation
Vancouver, Washington
Landfill 1
Former Burn Area
Landfill 2
Landfill 3
Camp Bonneville
Ammunition Storage Bunker
East Fork Lacamas Creek
Chemical Warfare Burial Sites
1864 Building
1962 Building
1983 Building
Former Sewage Pond
Lacamas Crk
Former CS Gas Training Bldg
Camp Killpack
Grease Pits
Wash Racks
Maintenance Pit
Drum Burial Site
Paint/Solvent Burial Site
Buck Creek
Seattle metro area
WA
Camp Bonneville Vancouver, WA
Clark County
Portland metro area
OR
Pacific Ocean
AREA ENLARGED
Legend
Site grid (with grid # shown)
Cantonment Sites
Grease Pits
Buildings
Ammunition Storage Bunkers
Former Sewage Pond
Landfill and Former Burn Areas
Disposal Areas
Troutdale Sole Source Aquifer
Streamflow Source Area portion of the Troutdale Sole Source Aquifer designation
Miles
0 0.05 0.1 0.2 0.3
BONNEVILLE CONSERVATION, RESTORATION & RENEWAL TEAM, LLC
BCRRT
Scale - 1:6,400 I Projection - Lambert Conformal Conic
Coordinate System - State Plane Washington South FIPS 4602
Data - Parsons, U.S. Army Corps of Engineers, MKM Engineers and Michael Baker Jr., Inc.
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3.2 RAU 2A Small Arms Ranges

RAU 2A includes approximately 25 Small Arms Ranges were tentatively identified within the boundaries of CBMR from maps dating back to 1958. The firing ranges were used for small arms, large-caliber machine guns, rifles, grenades, light antitank weapon rockets, and sub-caliber weapons. Of the 25 potential ranges, it was determined during the RAU 2A RI/FS that eight were redundant or double counts from the same range location having different names historically (AEM, 2005 and BCRRT, 207b).

A final total of 17 firing ranges were confirmed and identified for investigation during the RAU 2A RI/FS of the Small Arms Ranges (see **Figure 3.2**):

- Close Combat Range
- 25 Meter M60 Range/Pistol Range
- Sub Machine Gun Range
- TF Range
- Rifle Ranges 1 & 2
- Field Fire Rifle Ranges 1 & 2
- Infiltration Course North
- Field Firing Ranges 1 & 2 & Pistol Range
- Undocumented Pistol Range
- 1,000 Foot Range, Machine Gun & Moving Target Range
- Combat Pistol Range
- Machine Gun Range North
- Machine Gun Range South
- M31 Sub-Caliber Ranges 1 & 2
- 25 Meter and Machine Gun Range
- Infiltration Course South
- 25 M Record Fire Field/Field Firing Range

3.2.1 Previous Investigations

The final RAU 2A RI/FS and Corrective Action Plan (CAP) have been approved by Ecology and those firing ranges having significant lead impact are currently undergoing active implementation. To understand the nature and extent of lead impact at these firing ranges, the following studies and investigations were conducted.

- Atlanta Environmental Management (AEM), 2003. Work Plan for Soil Sampling in Firing Ranges and Demolition Areas 2 and 3, Sampling and Analysis Plan – Soil, Quality Assurance Project Plan, Site Safety and Health Plan, Data Management Plan, and Waste Management and Minimization Plan. Prepared for U.S. Army Engineering District Norfolk, Norfolk, Virginia. February 2003.

- AEM, 2003. Draft Site Investigation Report, Small Arms Ranges and Demolition Areas 2 and 3. Camp Bonneville, Vancouver, Washington. Prepared for U.S. Army. April 2003.

- CALIBRE, 2005 Draft Final Work Plan for Interim Actions at Small Arms Range Berms and Fire Support Areas.

- BCRRT, 2007, Final Remedial Investigation/Feasibility Study RI/FS Report for RAU-2A. August 2007.

- BCRRT.2008. Final Cleanup Action Plan, Small Arms Ranges (RAU 2A), Camp Bonneville, Vancouver, Washington. January 2008.

3.2.2 Data Analysis

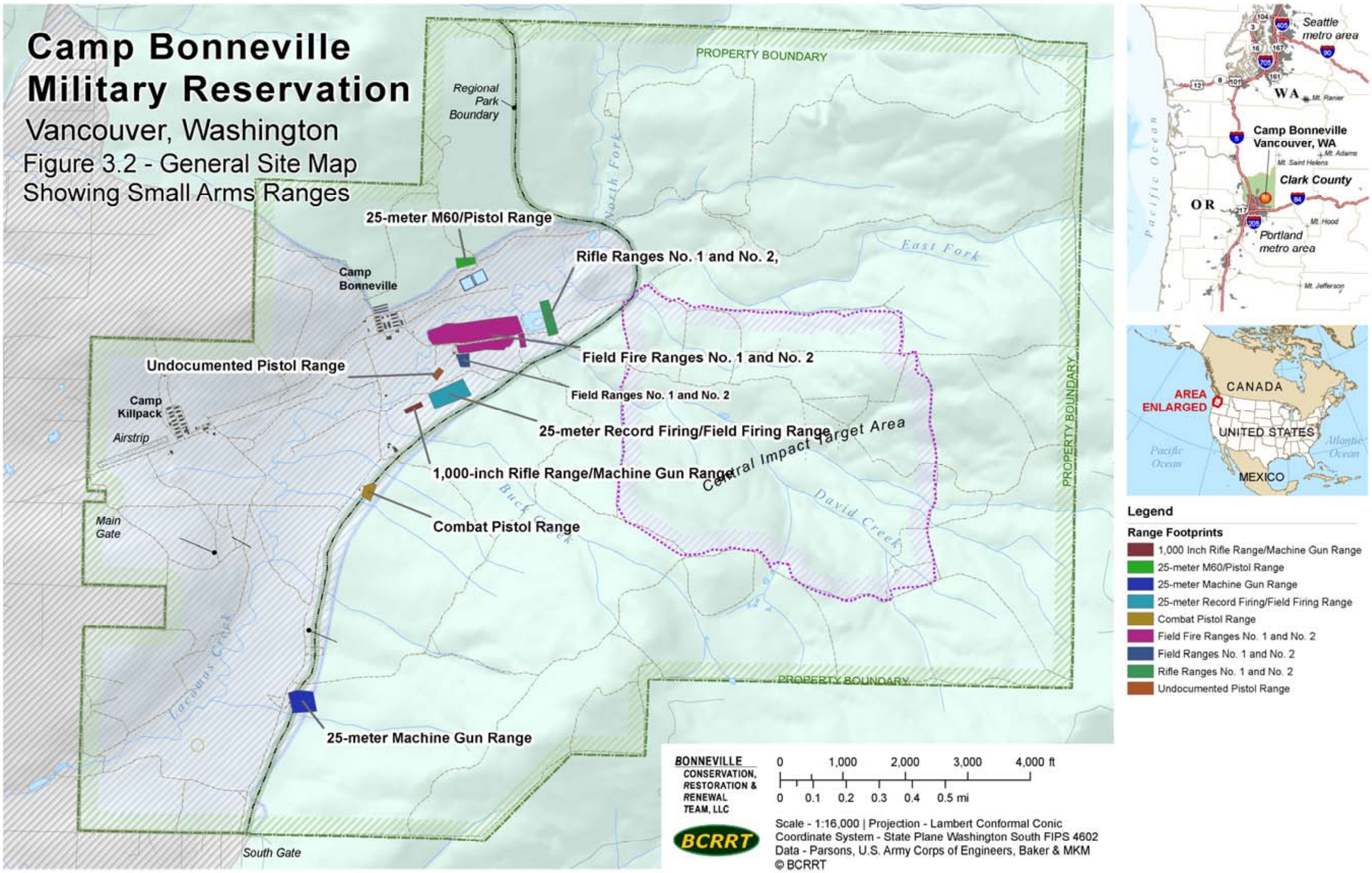
In developing the MTCA cleanup levels for unrestricted land use for the Small Arms Ranges, the MTCA [(WAC 173-340-740 (2)] lead cleanup level was determined based upon:

- Concentrations in MTCA Table 740-1 and compliance with the corresponding footnotes (this table specifies a lead cleanup level of 250 mg/kg for unrestricted land use); concentrations established under applicable state and federal laws;
- Concentrations that result in no significant adverse effects on the protection and propagation of terrestrial ecological receptors using the procedures specified in WAC 173-340-7490 through 7493 (tables in this section specify ecological indicator soil lead concentrations for plants, soil biota, and wildlife at 50, 500, and 118 mg/kg, respectively).
- Concentrations that are protective of groundwater [Method A cleanup levels were designed to be protective of groundwater, that is, lead concentrations in soil less than 3,000 mg/kg (Ecology, 2001).

Therefore, upon successful implementation of the RAU 2A CAP, groundwater associated with the Small Arms Ranges will have been addressed.

3.2.3 Status Summary

Potential lead impact on groundwater at Camp Bonneville stemming from the Small Arms Ranges was addressed during development of the RAU 2A CAP and will not be addressed further as part of the RAU 2C RI/FS evaluation.


Camp Bonneville Military Reservation
Vancouver, Washington
Figure 3.2 - General Site Map Showing Small Arms Ranges
PROPERTY BOUNDARY
Regional Park Boundary
25-meter M60/Pistol Range
Rifle Ranges No. 1 and No. 2,
Camp Bonneville
Field Fire Ranges No. 1 and No. 2
Undocumented Pistol Range
Field Ranges No. 1 and No. 2
Camp Killpack
Airstrip
25-meter Record Firing/Field Firing Range
1,000-inch Rifle Range/Machine Gun Range
Central Impact Target Area
Combat Pistol Range
Main Gate
25-meter Machine Gun Range
South Gate
East Fork
North Fork
Buck Creek
David Creek
Lacamas Creek
Seattle metro area
WA
Camp Bonneville Vancouver, WA
Clark County
OR
Portland metro area
Pacific Ocean
CANADA
AREA ENLARGED
UNITED STATES
MEXICO
Atlantic Ocean
Legend
Range Footprints
1,000 Inch Rifle Range/Machine Gun Range
25-meter M60/Pistol Range
25-meter Machine Gun Range
25-meter Record Firing/Field Firing Range
Combat Pistol Range
Field Fire Ranges No. 1 and No. 2
Field Ranges No. 1 and No. 2
Rifle Ranges No. 1 and No. 2
Undocumented Pistol Range
BONNEVILLE CONSERVATION, RESTORATION & RENEWAL TEAM, LLC
BCRRT
0 1,000 2,000 3,000 4,000 ft
0 0.1 0.2 0.3 0.4 0.5 mi
Scale - 1:16,000 | Projection - Lambert Conformal Conic
Coordinate System - State Plane Washington South FIPS 4602
Data - Parsons, U.S. Army Corps of Engineers, Baker & MKM
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3.3 RAU 2B Open Burning / Open Detonation Areas 2 and 3

Monitoring of groundwater at Open Burning / Open Detonation Areas 2 and 3 (OB/OD Areas 2 and 3), and at the point where groundwater associated with Lacamas Creek leaves the first began in 2003. The locations of groundwater monitoring wells at OB/OD Area 2 are shown in **Figure 3.3.** Monitoring well locations at OB/OD Area 3 and the CBMR perimeter (often referred to as the perimeter or sentinel wells) are presented in **Figure 3.4.**

3.3.1 Previous Investigations Summary

The final RAU 2B RI has been finalized and approved by Ecology No further investigation or study was deemed necessary for the contaminants of concern (e.g., explosive chemical residuals) at these locations. Data gained during these activities and the contaminants encountered did not identify the potential for an impact to groundwater. To understand the nature and extent of potential chemical impact at these OB/OD areas, the following studies and investigations were conducted:

- AEM, 2003. Draft Site Investigation Report, Small Arms Ranges and Demolition Areas 2 and 3, Camp Bonneville, Vancouver, Washington, prepared for U.S. Army. April 2003.
- BCRRT, 2007. Final Remedial Investigation Report Demolition Areas 2 & 3 (RAU 2B), Camp Bonneville, Vancouver, Washington. June 2007.
- BCRRT, 2007. Request for No Further Action Determination. December 2007.
- Ecology, 2009. No Further Action Determination. March 2009 (see **Appendix A**).

3.3.2 Data Analysis

Eight quarters of groundwater monitoring have determined there are no chemicals of concern present in groundwater above regulatory limits at the locations of OB/OD Areas 2 and 3. Further, there is no evidence that soil contamination exists that could leach to groundwater in the future.

Based on applicable Ecology guidance documents related to groundwater monitoring and the sampling results, Ecology approved discontinuation of groundwater sampling at both OB/OD Areas 2 and 3 (Ecology 2006).

3.3.3 Status Summary

Responses to the RAU 2B areas of concern are complete. Groundwater data obtained during the 2-years of monitoring at these OB/OD Areas was used as part of the overall groundwater evaluation detailed in this report.

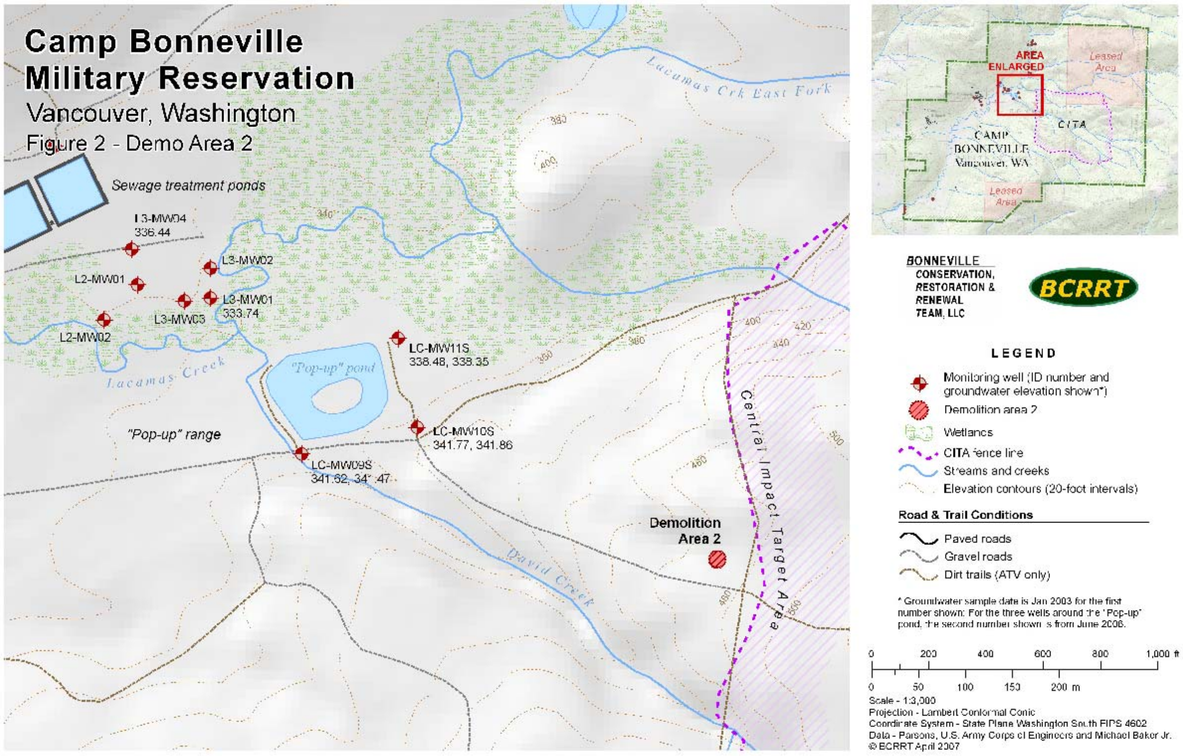

Figure 3.3

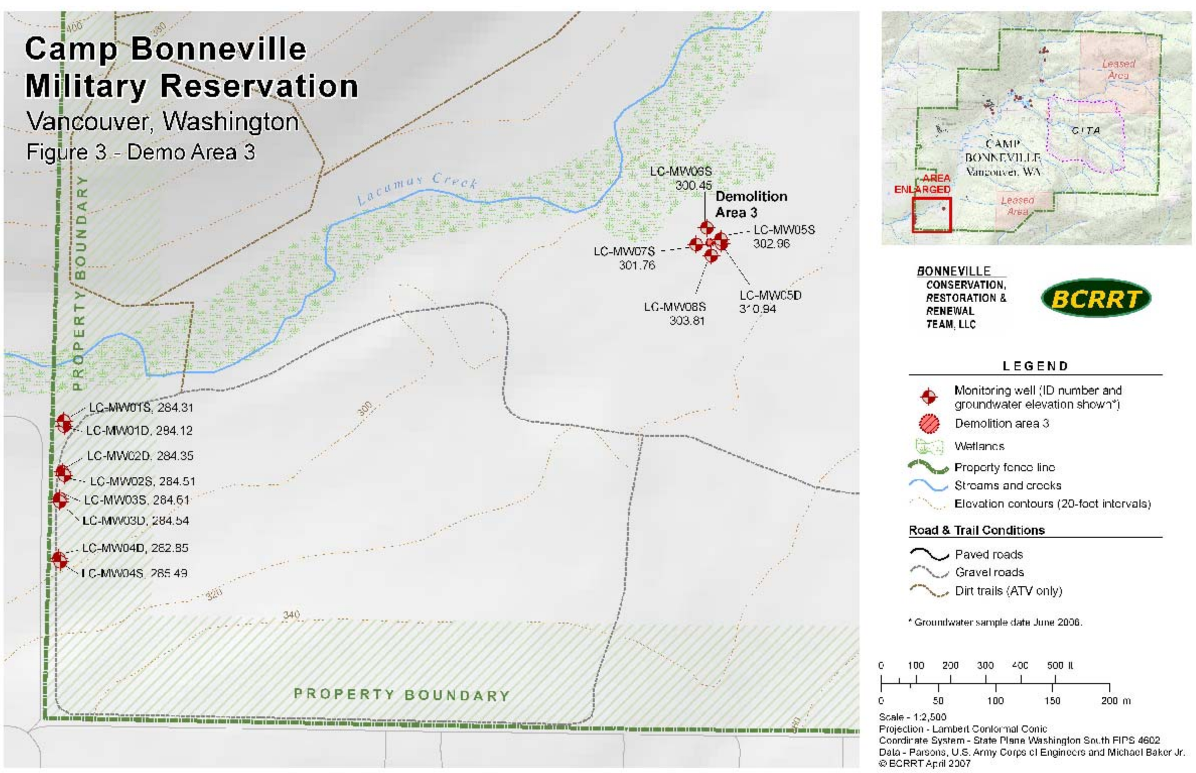

Figure 3.4

3.4 Sentinel Wells

A series of eight groundwater monitoring wells were installed along the valley floor at the western boundary of the CBMR. Included were: shallow wells (top of the aquifer) LCMW01S, LCMW02S, LCMW03S and LCMW04S; and deep wells (bottom of the aquifer) LCMW01D, LCMW02D, LCMW03D and LCMW04D (see **Figure 3.5**). These Sentinel Wells were constructed for the express purpose of determining whether contaminants, regardless of source, were flowing off of the CBMR at this location.

3.4.1 Previous Investigations

Historical CBMR Quarterly Groundwater Monitoring Reports and Workplans include:

- PBS Engineering and Environmental (PBS), 2003. Groundwater Sampling and Analysis Plan – Camp Bonneville, Washington. Prepared for the Department of the Army – Base Realignment and Closure Office. Fort McPherson, GA. December 2003.

- PBS, 2003. Quality Assurance Project Plan - Groundwater Sampling and Analysis – Camp Bonneville, Washington. December, 2003.

- PBS, 2004. Groundwater Sampling and Analysis Report – 4th Quarter 2003 – Camp Bonneville, Washington. February 2004.

- PBS, 2004. Monitoring Well Installation Report Landfill 4/ Lacamas Creek, Camp Bonneville, Vancouver, Washington. August 2004.

- PBS, 2004. Groundwater Sampling and Analysis Report – 1st Quarter 2004 – Camp Bonneville, Washington. January 2004

- PBS, 2004. Groundwater Sampling and Analysis Report – 2nd Quarter 2004 – Camp Bonneville, Washington. January 2005

- PBS, 2005. Groundwater Sampling and Analysis Report – 3rd Quarter 2004 – Camp Bonneville, Washington. January 2005.

- PBS, 2005. Groundwater Sampling and Analysis Report – 4th Quarter 2004 – Camp Bonneville, Washington. July 2005.

- PBS, July 2005. Groundwater Sampling and Analysis Report – 1st Quarter 2005 – Camp Bonneville, Washington. July 2005.

- PBS, 2005. Groundwater Sampling and Analysis Report – 2nd Quarter 2005 – Camp Bonneville, Washington. December 2005.

- PBS, 2005. Groundwater Sampling and Analysis Report – 3rd Quarter 2005 – Camp Bonneville, Washington. December 2005.

- PBS, 2006. Groundwater Sampling and Analysis Report – 4th Quarter 2005 – Camp Bonneville, Washington. April 2006.
- PBS, 2006. Groundwater Sampling and Analysis Report – 1st Quarter 2006 – Camp Bonneville, Washington. May 2006.
- PBS, 2006. Groundwater Sampling and Analysis Report – 2nd Quarter 2006 – Camp Bonneville, Washington. October 2006.
- BCRRT, 2006. Draft Supplemental Ground Water Remedial Investigation Work Plan, Camp Bonneville, Vancouver, Washington. November 2006.
- BCRRT, 2007. Draft Groundwater Sampling and Analysis Report 4th Quarter 2006, Camp Bonneville Military Reservation, Vancouver, Washington. March 2007.
- BCRRT, 2007. Draft Groundwater Sampling and Analysis Report 1st Quarter 2007, Camp Bonneville Military Reservation, Vancouver, Washington. June 2007.
- BCRRT, 2007. Draft Groundwater Sampling and Analysis Report 2nd Quarter 2007, Camp Bonneville Military Reservation, Vancouver, Washington. August 2007.
- BCRRT, 2007. Draft Groundwater Sampling and Analysis Report 3rd Quarter 2007, Camp Bonneville Military Reservation, Vancouver, Washington. November 2007.
- BCRRT, 2008. Draft Groundwater Sampling and Analysis Report 4th Quarter 2007, Camp Bonneville, Vancouver, Washington. February 2008.
- BCRRT, 2008. Draft Groundwater Sampling and Analysis Report 1st Quarter 2008, Camp Bonneville Military Reservation, Vancouver, Washington. April 2008.
- BCRRT, 2008. Draft Groundwater Sampling and Analysis Report 2nd Quarter 2008, Camp Bonneville Military Reservation, Vancouver, Washington. July 2008.
- BCRRT, 2008. Draft Groundwater Sampling and Analysis Report 3rd Quarter 2008, Camp Bonneville Military Reservation, Vancouver, Washington. October 2008.
- BCRRT, 2008. Draft Groundwater Sampling and Analysis Report 4th Quarter 2008, Camp Bonneville Military Reservation, Vancouver, Washington. February 2008
- BCRRT, 2009. Draft Groundwater Sampling and Analysis Report 1st Quarter 2009, Camp Bonneville Military Reservation, Vancouver, Washington. April 2009.
- BCRRT, 2009. Draft Groundwater Sampling and Analysis Report 2nd Quarter 2009, Camp Bonneville Military Reservation, Vancouver, Washington. August 2009.

3.4.2 Groundwater Flow

The shallow sets of Sentinel well have exhibited water level measurements that indicate a water table measured at these locations that is representative of the water table of the valley floor. The surface of the shallow aquifer is sloped from the south to the bank of Lacamas Creek, showing that water recharged on the sides of the basin flows downward into the valley where it likely turns and flows westward in parallel with the creek. Some exceptions occurred in 2004 and 2005, when the well nearest Lacamas Creek, LCMW01S suggests under certain conditions, Lacamas Creek is a losing stream in this area and is recharging local groundwater. Hence, there is a small mounding affect beneath and approximate to the creek that diminishes in a relatively short distance due to the steep slope of the terrain.

Depending on the season, groundwater and the Creek maybe contributing to each other along the southwestern portion of the CBMR. A comparison of water levels measured in the paired shallow Sentinel wells indicates that Lacamas Creek is a losing stream in this portion of the creek during limited periods of time. Groundwater discharges to Lacamas Creek at other times such as in December 2003 and 2004 when the deeper well (LCMW01D) has a higher water level than the shallow well (LCMW01S). The further monitoring wells are from Lacamas Creek, the more frequently they display downward gradients indicative of active recharge zones. The exceptions occur in wetter months (April and December) when some wells display upward gradients indicative of water flowing from the basin walls and surging upwards as it approaches the valley floor. This may indicate a finite thickness for water flow that may create surface seeps during wet weather.

In summary, groundwater flows from the sides of the basin down into the valley floor just as surface runoff would flow. Using the water level data from the OB/OD Area 3 wells in conjunction within the Sentinel Wells it is clear that groundwater flows from the east to the west, draining the sub-surface basin just as Lacamas Creek drains the topographic basin. Moreover, comparison of water levels from all 27 monitoring wells installed at CBMR confirm the conceptual model that groundwater flow is analogous to the flow of surface water in Lacamas Creek and its tributaries. Water flows down from the basin walls and out the valley, leaving the site at the point where Lacamas Creek crosses the site boundary.

3.4.3 Data Analysis

Groundwater samples were collected from the Sentinel Wells -- four two-well pairs (for a total of eight wells) located near the western boundary of Camp Bonneville where Lacamas Creek exits the site to the west (Site-Wide Groundwater Sentinel Wells, labeled as LC wells). Recent sampling results are summarized as follows:

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- With the use of dedicated pumps and low flow purging/sampling techniques (which are designed to obtain water samples with lower turbidity), the reported total and dissolved metals concentrations have decreased significantly. All of the total and dissolved metals detections in groundwater from these wells are were below MTCA Method A and B regulatory screening levels with the exception of results for beryllium, which have consistently been reported as estimated values (i.e., groundwater sample concentrations of beryllium detected above the Method Detection Limit (MDL) but below the Minimum Reporting Limit (MRL) of the laboratory analytical equipment and whose accuracy is limited).

- Petroleum hydrocarbons have not been detected in any of the Sentinel Wells throughout the monitoring period of over seven years except for an isolated detection of diesel range petroleum hydrocarbons in LCMW02DW at 0.15 mg/L in January 2006.

- Perchlorate and explosive constituents have never been detected at any of the Sentinel Wells during seven years of groundwater monitoring..

The groundwater samples collected and analyzed to date display no reliable evidence of any contaminant in site groundwater being present at or near the site boundary or leaving the CBMR. All explosive compounds and total petroleum hydrocarbons were below the limits of detection.

Perchlorate had been detected near or at the MRL of 1 ug/L it an individual well on occasion (2004, 2005, 2008 and 2009). However, these data were found to result from laboratory errors (i.e. false positives) based on one or more of the following factors: non-detectable duplicate sample, rejection by third-party independent validator, laboratory process audit, or confirmation sampling.

Naturally occurring levels of inorganic elements were observed in the parts per billion ranges in both shallow and deep wells. The highest observed concentrations are generally associated with groundwater samples that had a high level of suspended solids in them. The comparable filtered sample for many of the metals displayed lower concentrations, indicating the elevated reading was the result of the acid preservative dissolving materials from the soil particles suspended in the sample. In any event, none of the metal concentrations (total or dissolved) from Sentinel Wells exceeded MTCA Method A or Method B criteria.

3.4.4 Status Summary

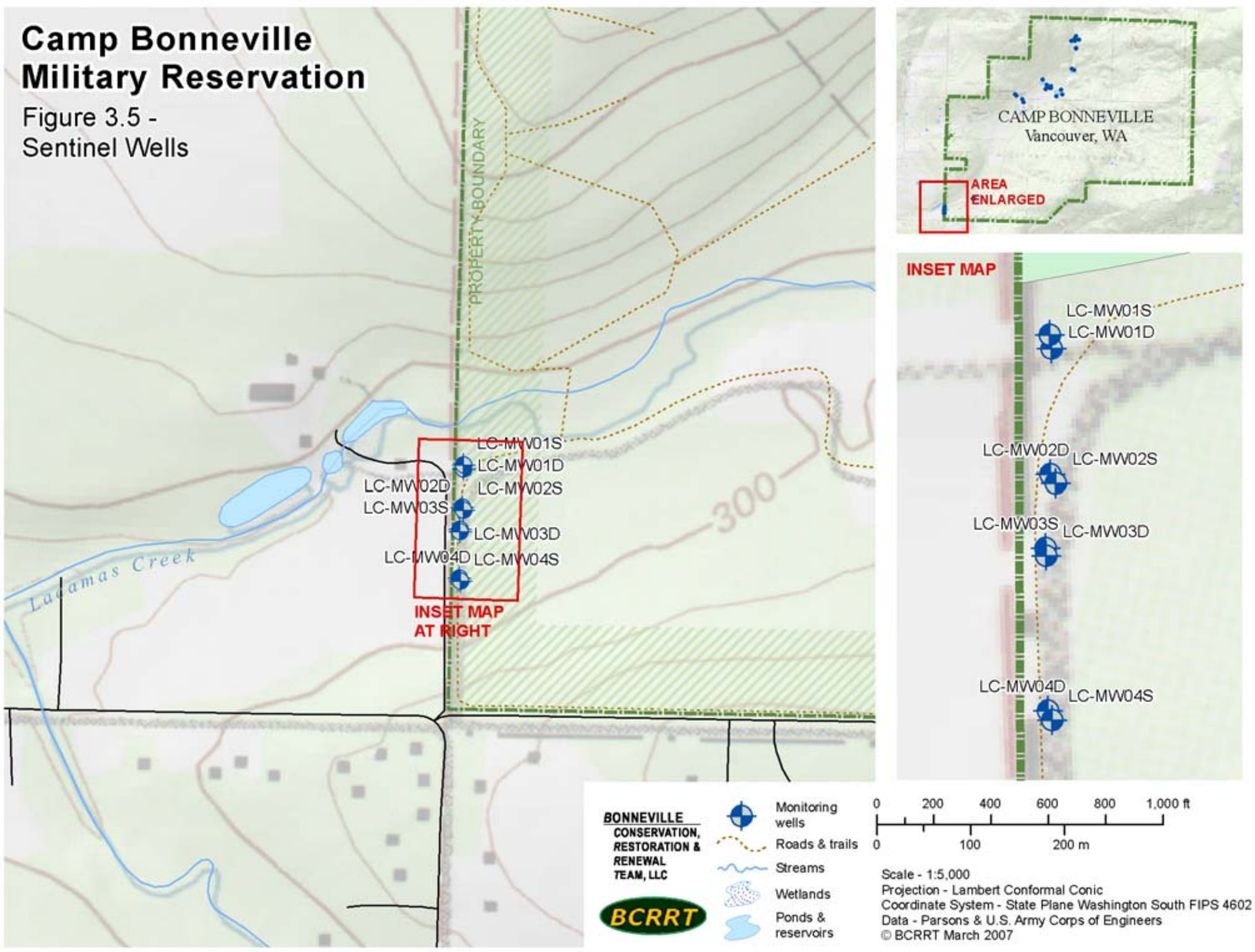
Given the extensive groundwater monitoring that has been conducted at the Sentinel Wells (located across the Lacamas Creek valley) and the lack of contaminant findings over this extended period of time, Ecology adjustments groundwater monitoring.

- There are no chemicals of concern in groundwater at the Sentinel wells. No explosive, propellants, petroleum hydrocarbons, metals, SVOCs, or VOCs (except common laboratory contaminants) have been detected at levels of concern. .

- Four of the wells are cross-gradient and higher in elevation than the nested wells MW01S, MW01D, MW02S, and MW02D. If any groundwater contaminant plume migrates via a cross-gradient pathway (note that none have ever been detected at the CBMR boundary or the upgradient area near OB/OD Area 3) any potential contamination would be detected in these wells closer to Lacamas Creek rather than the nested wells MW03S, MW03D, MW04S and MW04D.

- Chemical analyses for VOCs, SVOCs, petroleum hydrocarbons (gas, diesel and oil range), and total/dissolved metals in groundwater samples from the Sentinel wells has been stopped as these analytes have never been detected in any of the sampling events conducted over more than six years..

  While no constituents of concern have been detected, the Sentinel Wells will continue to be monitored per the Long-Term Monitoring Obligations in the PPCD.



3.5 Potential Explosives Residuals at Firing Points and Target Areas

Due to the concern that artillery and mortar firing points could prove to be a source of contamination (i.e., weapons firing at these locations could release residual explosive constituents that could build up in soil after repeated use of a specific area) that could subsequently migrate into groundwater, a plan to investigate the presence of explosive residuals in surface soils at these locations was developed. In October 2007, Baker implemented the Ecology-approved plan (Baker 2007) by conducting soil sampling at 30 areas of concern (AOCs) and sediment sampling at one AOC within Camp Bonneville (see **Figure 3.6)**. The sampling program was focused on those areas that were considered as having the highest likelihood for explosives residues at the CBMR, other than OB/OD and landfill areas which have been addressed individually. This information was used to evaluate the potential impact of any explosive residuals encountered on Site-Wide Groundwater.

3.5.1 Explosive Residuals Investigation

A total of fifteen firing points had surface soil samples collected and analyzed for explosive residuals as part of this investigation. These firing point areas encompass a total of 19-acres and consisted of six mortar firing points, seven artillery firing points, one rifle grenade firing point, and one 3.5-inch rocket firing point (see **Appendix C**).

Additionally, total of fifteen target areas located in the Central Target Impact Area (CITA) were sampled as part of this investigation.. The CITA covers 465 acres and the specific target areas within the CITA consist of four undifferentiated targets, seven individual car targets and four refrigerator targets. Sediments were sampled at the remaining AOC, the “Pop-Up” Pond. The results of this investigation were reported in the following reports:

- BCRRT, 2007. Preliminary Assessment of Artillery Firing Points, Impact Areas and “Pop-Up” Pond Sediments Draft Report on Soil and Sediment Investigations at Artillery/Mortar Firing Points, Artillery/Mortar Impact Areas and “Pop-up” Pond, Camp Bonneville, Vancouver, Washington, August 2007.

- BCRRT, 2008. Report on Soil and Sediment Investigations at Artillery/Mortar Firing Points, Artillery/Mortar Impact Areas and “Pop-up” Pond, Camp Bonneville, Vancouver, Washington, February 2008.

3.5.2 Data Analysis

Following completion of the soil and sediment sampling, documentation, laboratory analysis, quality assurance/quality control assessment for the 448 primary samples collected in this sampling effort, the 31 AOCs were classified based on whether residual explosive constituents were detected for any of the samples collected within a given AOC:

- **AOCs with No Detected Residual Explosive Constituents,** Analytical results did not detect any residual explosive constituents in the soil samples from 25 of the AOCs investigated. Based on these analytical results, a finding of "No Further Action" is warranted for these AOCs:

Firing Points

- 2-B Rifle Grenade
- 26-B 14.5 mm
- 34-A Mortar Position 1
- 35-A Mortar Position 2
- 36-A Mortar Position 3
- 37-A Mortar Position 4
- 38-A Mortar Position 5
- 39-A Mortar Position 6
- 43-A Artillery Position 5
- 45-A Artillery Position 7

Targets Areas

- 4-A Car Target
- 4-B Car Target
- 5-A Car Target
- 5-B Car Target
- 5-C Car Target
- 5-D Car Target
- 5-E Car Target
- 5-F Refrigerator Target
- 5-G Refrigerator Target
- 5-H Refrigerator Target
- 8 Undifferentiated Target
- 18 Undifferentiated Target
- 20 Undifferentiated Target
- 21 Undifferentiated Target

- **AOCs with Detected Residual Explosive Constituents – 2, 4-Dinitrotoluene**

The residual explosive constituent, 2, 4-Dinitrotoluene (2,4-DNT) was detected in one or more soil samples from five AOCs.. The highest reported concentration was 5.3 mg/kg detected reported in sample 1B-12 from AOC 1-B, the 3.5-inch rocket range firing point. The residue 2,4-DNT was detected at ethe following five firing points:

- 1-B 3.5-inch Rocket
- 40-A Artillery Position 1&2
- 41-A Artillery Position 3
- 42-A Artillery Position
- 44-A Artillery Position

While there is no listed MTCA cleanup level for 2,4-DNT, the USEPA Region 3 has established a Risk-Based Concentration (RBC) for residential properties of 160 mg/kg for 2,4-DNT.

The use of the USEPA Region 3 Residential RBC is considered conservative since this site is not to be used for residential purposes. Agreements made at the time of the property transfer preclude its' future use as residential property.. Future use of Camp Bonneville is limited to conservation and recreational use. In fact, only the western third of the property will be used for recreation as a regional park with the remainder of the site for conservation, or wildlife management purposes.. Therfore, the use of the residential RBC for 2,4-DNT as the cleanup standard at Camp Bonneville given the planned future use of the site and the deed restriction against residential development.

Given that all of soil samples where 2,4-DNT was detected, the concentrations were significantly below the USEPA Region 3 Residential RBC, no further action is warranted for these firing points.

- **AOCs with Detected Residual Explosive Constituent- 1,3-Dinitirobenene**

Sample analysis results from one AOC (41-A Artillery Position 3) included the residual explosive constituent, 1,3-Dinitirobenene (1,3- DNB). This constituent was detected in one sample from 41-A Artillery Position 3 and was the only residual explosive constituent detected at this firing point.. The concentration of 1,3,-DNB in soil was at 0.23 mg/kg. This analytical result was qualified during data validation by an independent third party validator as being a tentative identification A tentative identification may require special methods to confirm the constituent's presence or absence in the sample.) While a cleanup level for 1,3- DNB is not listed in the MTCA Regulations, the USEPA Region 3 has established an RBC for residential properties of 7.8 mg/kg for this COPC. Since the only tentative identification of 1,3-DNB on-site was well below this RBC, no further action is warranted for 41-A Artillery Position 3 (41-A) AOC.

- **AOCs with Detected Constituents - Lead**

Lead was detected in the sediment samples from ten of the "Pop-Up" Pond samples locations. These reported lead concentrations ranged from 4.50 mg/kg to 50 mg/kg, with an average concentration of 17.27 mg/kg.

MTCA lists the Soil, Method A, Unrestricted Land Use Value of 250 mg/kg lead for human health and an Ecological Indicator Soil Concentrations for the Protection of Terrestrial Plants and Animals (MTCA - Table 749-3) for lead of 50 mg/kg for plants, 500 mg/kg for soil biota, and 118 mg/kg for wildlife.

Appreciable sediment was not encountered at any of the locations in the "Pop-Up" Pond, possibly due to the relatively young age of this man-made pond. The samples were predominantly collected from the underlying soil (clay) encountered within the pond. The clayey quality of these soils and sediments is known to promote the trapping of heavy metals and to potentially influence the homogeneity of the samples.

The analytical result for only one of the "Pop-Up" Pond samples equaled the most conservative MTCA soil concentration for lead (50 mg/kg for protection of plants) while all of the remaining samples were significantly below this MTCA cleanup standard. Therefore, lead does not pose threat to ecological receptors at this AOC and no further action is warranted for the "Pop-Up" Pond.

3.5.2 Status Summary

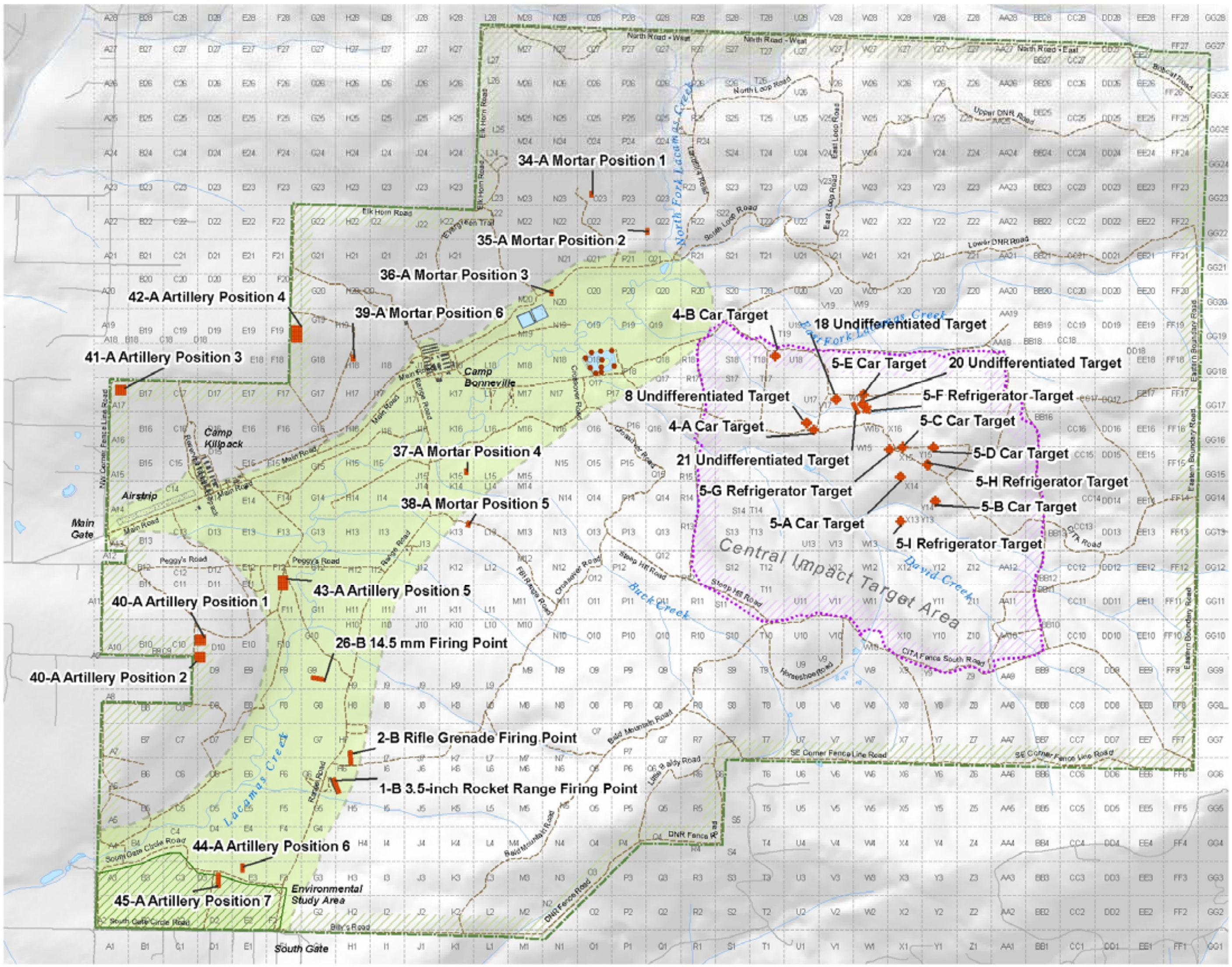
Numerous soils samples were collected from 30 different firing points, target areas and the "Pop-Up" Pond; AOCs widely spaced across Camp Bonneville. Analysis of these samples revealed few detectable concentrations of residual explosive constituents at locations used for a variety weapons (artillery, mortar, rifle grenade, rockets) and uses (firing and target). When considered as a whole, this data set makes a strong statement that the weapons training activities conducted at these AOCs did not result in appreciable explosive constituent impact to soils. Other key conclusions of this study include:

- None of the 448 primary samples collected from the 31 AOCs exceeded MTCA cleanup criteria and the vast majority of the samples were non-detectable for any residual explosive constituent.

- The samples were collected using composite sampling of nine aliquots per sample (for a total of 4,032 aliquots) which reduced the potential for "missing" heterogeneous distribution of contamination at a specific location..

- The sampling program was focused on those areas that were considered as having the highest likelihood for explosives residues at the CBMR,

<u>Given all of the above, it is our conclusion that explosive residuals from firing points and target areas have not impacted on site-wide groundwater and does not require further evaluation in this RI/FS.</u>



Camp Bonneville Military Reservation
Vancouver, Washington

Figure 3.6-
Potential Explosives Residue at Firing Points & Target Areas

LEGEND
- Site grid (with grid # shown)
- Roads and trails
- Streams and creeks
- Ponds
- Soil sample grids
- Environmental Study Area
- Central Valley

BONNEVILLE CONSERVATION, RESTORATION & RENEWAL TEAM, LLC

0 990 1,980 2,970 ft
0 0.1 0.2 0.3 0.4 0.5 mi

Scale - 1:16,000 I Projection - Lambert Conformal Conic | Coordinate System - State Plane Washington South FIPS 4602
Data - Parsons, U.S. Army Corps of Engineers, MKM Engineers and Michael Baker Jr., Inc.

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3.6 Newly Discovered Disposal Areas

During the implementation of an Interim Action for MEC Surface Clearance in the Central Valley Floor, two previously unknown ordance disposal areas were discovered (see **Figure 3.7**).

- **Newly Discovered MEC Disposal Area (Burial Pit)**

  This MEC disposal pit is located within a flat-lying open field in the central portion of the CVF, west of Lacamas Creek. Several layers of grenade spoons, rocket parts (some can be identified as HE rocket parts), and miscellaneous munitions-related debris were identified. The pit has not been investigated vertically, but has been defined laterally. Lateral delineation of burial pit defines it as a 50 ft x 50 ft area. Vertical excavation limits will be based upon the actual depth of MEC/MD encountered in the excavation.

- **Newly Discovered Open Burn/Open Disposal (OB/OD) Area**

  Ths OB/OD area is located in the southern part of the CVF on its eastern border and just north of the ESA. This newly identified demolition area covers approximately 16.33 acres and was discovered during the CVF clearance action. Several inert 5 in. rocket warheads were identified on the surface as well as aluminum rocket slag from a thermite burn. The recent findings show the area has several subsurface anomalies indicative of additional potential MEC or MD. In addition, the area has several demolition craters indicative of past surface demolition activities. The majority of the area is located within an open flat area of the CVF. Recent MEC and MD findings include 2.36 in. rockets (one fired, fuzed), 3" Stokes mortars (fired, unfuzed), a 5" rocket warhead, a 37 mm HE (unfired and unfuzed), and other miscellaneous items.

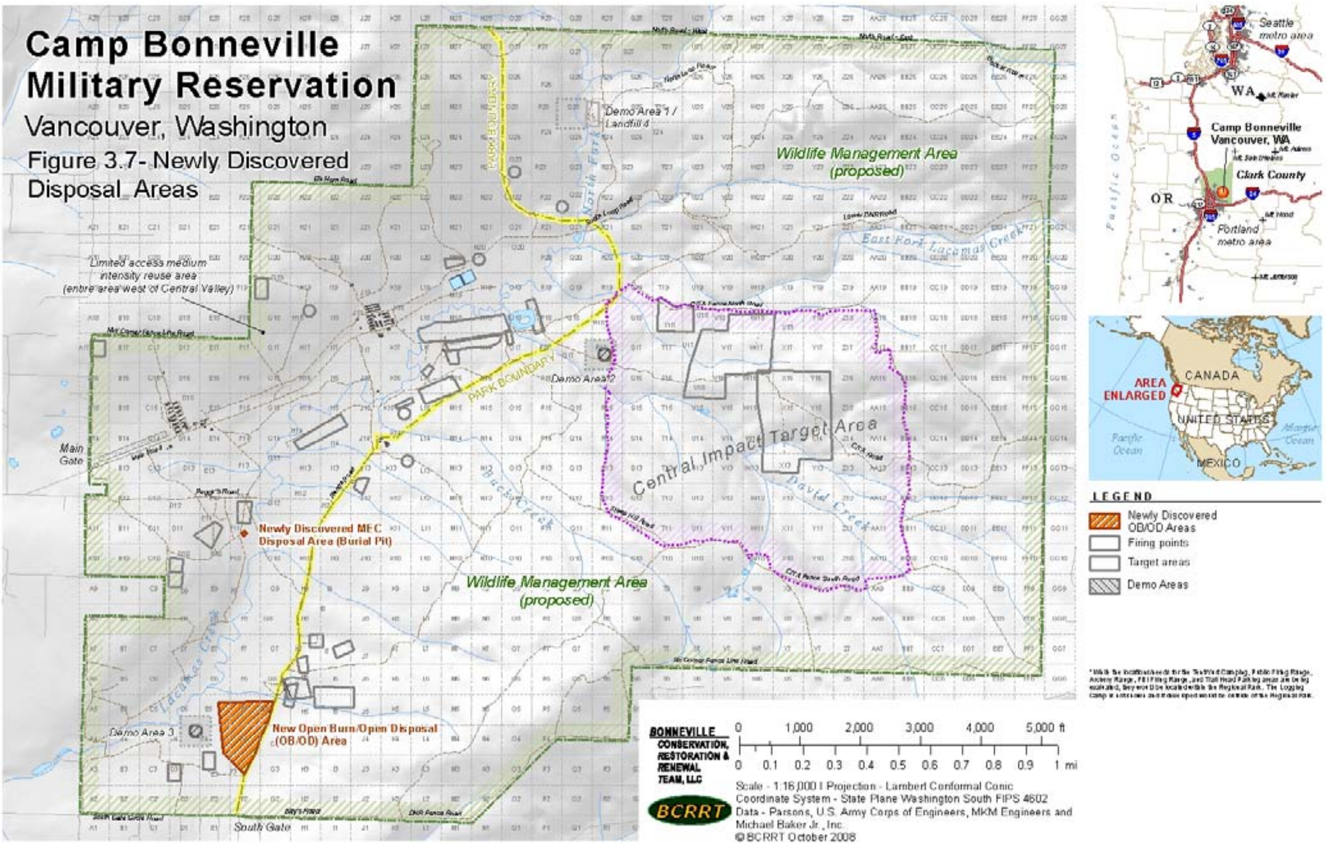
3.6.1 Investigations Summary/Data Analysis

No investigations or data analysis are available for either area at this time.

Soil and Groundwater Sampling Programs will be implemented for the burial and OB/OD areas to address potential explosives residues from historic OB/OD activities following the completion of MEC subsurface clearance activities. The sampling will be conducted per site specific Work Plans that focus on the potential for groundwater impacts related to the OB/OD operations/material explosive residuals and will be prepared as a separate document. The Sampling Program will be conducted in a phased approach based upon the results of the Recommended Cleanup Action, field observations, and analytical sample results.

3.6.2 Status Summary

The two areas will be addressed under separate investigations and are being considered as separate from the remainder of RAU 2C per discussions with Ecology and as referenced in the draft final RAU 3 CAP.


Camp Bonneville
Military Reservation
Vancouver, Washington
Figure 3.7- Newly Discovered
Disposal Areas
Wildlife Management Area
(proposed)
Demo Area 1 /
Landfill 4
Limited access medium
intensity reuse area
(entire area west of Central Valley)
PARK BOUNDARY
Demo Area 2
Central Impact Target Area
Main
Gate
Newly Discovered MEC
Disposal Area (Burial Pit)
Wildlife Management Area
(proposed)
Demo Area 3
New Open Burn/Open Disposal
(OB/OD) Area
South Gate
Seattle
metro area
WA
Camp Bonneville
Vancouver, WA
Clark County
OR
Portland
metro area
Pacific Ocean
AREA
ENLARGED
CANADA
UNITED STATES
MEXICO
LEGEND
Newly Discovered
OB/OD Areas
Firing points
Target areas
Demo Areas
BONNEVILLE
CONSERVATION,
RESTORATION &
RENEWAL
TEAM, LLC
0 1,000 2,000 3,000 4,000 5,000 ft
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 mi
Scale - 1:16,000 I Projection - Lambert Conformal Conic
Coordinate System - State Plane Washington South FIPS 4602
Data - Parsons, U.S. Army Corps of Engineers, MKM Engineers and
Michael Baker Jr., Inc.
©BCRRT October 2008

3.7 Landfill 4/Demolition Area 1

Landfill 4/Demolition Area 1 (LF4/DA1) is located about 5,000 feet northeast of the Camp Bonneville Cantonment; the landfill underlies Demolition Area 1 (see **Figure 1.2**). Vancouver Barracks reportedly used the site for the disposal of building demolition debris during the mid-1960's. According to the Environmental Baseline Survey (EBS, Woodword Clyde 1999), the former CBMR facility manager reported that firearms and ammunition were also disposed at this location. Identified potential contaminants at the CBMR included building demolition debris, explosive and propellant residue, and debris from historic onsite ordnance demolition activities, total petroleum hydrocarbons (TPH), semi-volatile organic compounds (SVOCs), volatile organic compounds (VOCs), organochlorine insecticides and herbicides, and metals. According to the Supplemental Archive Search Report (SASR, URS 1999), historic activities at CBMR included training and disposal of unserviceable ammunition. In addition, the site had been used by a number of groups and agencies, including the Army, Portland Air National Guard (PANG), local Fire Departments, and law enforcement for training and disposal operations. For example, the Bureau of Alcohol Tobacco and Firearms brought explosive and firearms to this location for disposal by open detonation.

3.7.1 Previous Investigations Summary

Site investigations (SI) were conducted to evaluate the potential for contamination resulting from past uses of the LF4/DA1. The investigation was directed primarily at evaluating potential environmental impacts from waste disposal within the landfill, but also took into account potential impacts from activities related to use of the site as an OB/OD ordnance demolition area. The primary objectives of the investigation were to evaluate whether the site poses a potential risk to human health or the environment, and to provide recommendations for additional actions (where appropriate), either for site remediation or to conduct additional investigations to better evaluate the need for and extent of remediation. The LF4/DA1 SI consisted of UXO avoidance, geophysical surveying, surface soil sampling, drilling and subsurface soil sampling, monitoring well installation and development, and groundwater sampling (URS 2003).

An area of buried debris disposal was identified to be approximately 120 by 200 feet during the geophysical survey. Other than a ground-penetrating radar (GPR) survey, no other types of testing were performed to delineate the actual presence of chemical constituents. The depth of the landfill material could not be determined through the use of geophysics; based on GPR profiles, it appeared to extend more than 11 feet bgs. During January 1999, groundwater was encountered at a depth of 10.4 feet below ground surface in monitoring well L4MW01 (upgradient well) and at 18.8 feet bgs in well L4MW02 (downgradient well). The report suggested that some of the landfill material could be in contact with groundwater, at least seasonally (URS 2003).

During the 2003 SI, the only constituents detected in soil (both near-surface and subsurface) at concentrations exceeding a MTCA Method B criteria were barium, copper, and possibly chromium. Total chromium was analyzed; however, the lowest screening criterion (which was exceeded) is based on chromium+6 (VI). Elevated barium and copper concentrations were detected in both upgradient and downgradient soil-boring samples. Arsenic, beryllium, and nickel were detected in soil samples at concentrations above MTCA Method B criteria for groundwater protections but below background levels for Clark County. Low levels of one or more SVOCs, insecticides and herbicides, and VOCs were detected in some samples; however, concentrations of these constituents did not exceed the screening criteria, and several were suspected to be laboratory contaminants. Two surface soil samples were collected at RAU 2C, and 15 deeper soil samples were obtained from five borings drilled outside of the landfill area (URS 2003).

Initially, the only constituent detected in groundwater at a concentration exceeding a screening level was Royal Demolition Explosive (RDX, aka, cyclotrimethylene-trinitramine or hexahydro-1,3,5-trinitro-1,3,5-triazine). This compound was detected only in the presumed downgradient well (L4MW02). RDX may be associated with surface or near-surface ordnance demolition activities, rather than with deeper buried building demolition debris. Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) was also detected in L4MW02 *(A)*, but at a concentration below the screening criteria. Low levels of three VOCs were detected in one or both wells; however, the concentrations detected were below the screening criteria. Subsequently, groundwater samples from the immediate area were found to contain perchlorate. Additional wells were installed to determine both the probable direction in which the extant plume was moving and the extent of the plume. The final two wells were installed in June of 2004 along the inferred path of migration. A total of 11 wells remain for monitoring purposes at LF4/DA1: L4MW01A; L4M201B; L4MW02A; L4MW02B; L4MW03A; L4MW03B; L4MW04A; L4MW05A; L4MW07B; L4M217; L4MW18. The A wells are installed and screened in the first water bearing strata encountered, while B wells are completed in the weathered bedrock. Wells L4MW17 and L4MW18 are relatively shallow wells completed just into the bedrock in a location where the alluvium is but a few feet thick (URS 2003).

Due to its relatively small size, location, explosive material hazards and potential impact to groundwater, the Army agreed to excavate and dispose of material in RAU 2C. In June 2004, a source removal action was initiated at LF4/DA1 for which the objective was to remove all fill materials and all soil contaminated above action levels. During the removal action, no construction debris was observed. In addition to materials associated with the surface ordnance disposal activities, three pits were discovered that had apparently been used for burning fireworks. Based on site observations, it appears that excess fireworks were placed in the pits and soaked with diesel oil prior to ignition. Combustion does not appear to have been complete and intact fireworks were recovered during the removal action. The pits were dug well into the heavy clay soil and one pit was completed into the saturated zone. The placement of fireworks in the saturated zone explains the observed contamination of groundwater with perchlorates in an environment that otherwise would not have significant infiltration. Following completion of the IRA excavation in September 2004 (see **Figure 3.17**), confirmatory samples indicated residual impacted soils at >20 feet below ground surface (bgs) for perchlorate, one location at > 8 feet bgs for RDX, and one location for HMX at > 5 feet bgs were present (see **Figure 3.17** and Tetra Tech 2006). Based upon the final confirmatory samples taken in December 2004, Ecology approved the completion of the soil excavation.

The excavation was filled to within three feet of the surface in January 2005 with clean and/or screened soils; however, the excavation was not completely filled in and graded until June 2005. Therefore, there was almost a year-long period (June 2004 to June 2005) when the excavation remained open. The open pit would have induced increased recharge through the ponding of rainfall, which would have infiltrated into the fill and surrounding subsurface soils. This would have resulted in the mounding of groundwater beneath the excavation for one year and in the subsequent mobilization of many dissolved constituents that had not been mobile before.

During the Interim Removal Action in 2004/2005, the likely source of contaminants was found to be a series of pits dug to the water level for the disposal of fireworks (believed to have occurred in the 1991 timeframe). While most of the perchlorate and RDX source material was removed, perchlorate and RDX remain in the subsurface

Changes to the local hydrology occurred during and after the IRA from excavations that were 1) advanced into more permeable zones, 2) were left open and/or filled with granular material for up to a year before final backfilling and placement of topsoil/cover material, and 3) regraded the site which changed the surface runoff/recharge.

Relevant LF4/DA1 Reports include:

- Shannon & Wilson 1999. Final Landfill 4 Investigation Report, Camp Bonneville, Washington. Contract DACA 67-94-D-1014,. August, 1999
- Hart Crower, 2000.. Final Project Completion Report Surface Water Investigation of Lacamas Creek, March 2000
- URS, 2002. Letter Report Slug Tests of Six Monitoring Wells, Landfill 4 Demolition Area 1, Camp Bonneville, Vancouver, Washington,. May 2002.
- URS, 2003.. Final Report Landfill 4 Demolition Area No. 1 Expanded Site Investigation, Camp Bonneville, Vancouver, Washington Volumes 1 and 2, May, 2003.
- PBS, 2004. Monitoring Well Installation Report Landfill 4/ Lacamas Creek, Camp Bonneville, Vancouver, Washington, August, 2004.
- Tetra Tech, 2005.. Groundwater Data Report LF4/DA1,. April 2005.
- Tetra Tech, 2006.. Final Interim Removal Action Report Landfill 4/Demolition Area 1 Camp Bonneville, Vancouver, Washington, February 2006.
- BCRRT, 2008. Draft Perchlorate Evaluation Report Landfill 4/Demolition Area 1 (RAU 2C), Camp Bonneville, Vancouver, Washington,. February 2008.
- BCRRT, 2008. Letter - Scope of Work for the August 2008, Supplemental Data Collection - Landfill 4/Demolition Area 1 Perchlorate Evaluation for the Camp Bonneville Facility located in Vancouver Washington, July 2008.
- BCRRT, 2009. Perchlorate Evaluation Report Landfill 4/Demolition Area 1 (RAU 2C), Revision 1, Camp Bonneville, Vancouver, Washington, February 2009.

BCRRT subsequently conducted three soil borings and collected groundwater samples using a Geoprobe® within the perimeter of LF4/DA1 with the highest residual perchlorate concentrations in soil according to the Final Interim Removal Action Report (Tetra Tech, February 2006) and are discussed below. The locations for the borings were upgradient, east, and southeast of LF4-MW-2B (see **Figure 3.8**).

In addition to the LF4/DA1 sampling, surface water samples were collected from Ecology selected locations in the North Fork of Lacamas Creek where there is a potential to receive groundwater from LF4/DA1. Water samples were collected from the center of the water column and along the eastern bank. Sampling and perchlorate analysis of three surface water locations in the North Fork of Lacamas Creek – (1) upstream/northwest of MW-4A, (2) directly across/west of LF4-MW2A&B pair, and (3) downstream/south where the creek goes through two 90°bends and the mapped residual Troutdale bedrock pinches out (see **Figure 3.8**).

Soil, groundwater, and surface water samples were collected for laboratory analysis for perchlorate and geotechnical/in-situ analysis for hydraulic conductivity (see **Appendix D**):

- Soil samples collected at various depths analyzed for perchlorate contained concentration ranging from non-detect (fill material) to 2,100 ug/kg. Residual perchlorate was detected in the unsaturated soil. The upper zones of the borings indicated sandy silt while the lower zones indicated granular sand with some silt. The concentrations of perchlorate were consistent with the IRA confirmation samples (Tetra Tech 2006).

- Shallow groundwater perchlorate concentrations were 420 ug/L and 760 ug/L while a deeper sample was 350 ug/L.

- Three surface water samples and one field duplicate were collected from Lacamas Creek were all non-detectable for perchlorate.

- Three geotechnical samples revealed the following concerning the following about subsurface soils at LF4/DA1

:

    - 30' to 36' is a Silty Sand (SM) with a specific gravity of 2.757, a soil porosity of 66.0%, and composed of 55.7% sand, 34.1% silt and 10.2% clay,
    - 36' to 39' is a Silty Sand (SM) with a specific gravity of 2.756, a soil porosity of 64.6%, and composed of 60.3% sand, 33.4% silt and 6.3% clay, and
    - 40' to 41' is a Sandy Silt (ML) with a specific gravity of 2.769, a soil porosity of 65.7%, and composed of 49.8% sand, 38.8% Silt and 11.4% clay.

- Hydraulic conductivity results from geotechnical samples, in-situ aquifer tests, and previous aquifer tests performed by others are included as **Appendix D.**

3.7.2 Site Specific Conditions

3.7.2.1 Surface Water Hydrology

The North Fork of Lacamas Creek bounds the LF4/DA1 to the north, west, and southwest and flows to the south where it enters the Central Valley and joins with the East Fork. The water quality of Lacamas Creek is monitored indirectly south of the LF4/DA in two monitoring wells that straddle the North Fork of Lacamas Creek (where it enters the Central Valley) and in the Sentinel Wells located where Lacamas Creek exits Camp Bonneville.

According to the March 2000 Final Project Completion Report, Surface Water Investigation of Lacamas Creek, Camp Bonneville, Vancouver, Washington, (Hart Crowser, 2000), the results of water samples collected from Lacamas Creek and North Fork of Lacamas Creek indicated that LF4/DA1 has not impacted surface water quality..

While the LF4/DA1 area is technically within the Streamflow Source Area for the Troutdale Sole-Source Aquifer System, it is in that portion of the Streamflow Area that contributes via surface water recharge of the Central Valley sediments – no groundwater recharge is believed to occur. The groundwater in the LF4/DA1 area does not directly connect to the Central Valley but may discharge into the North Fork of Lacamas Creek, where it would undergo significant dilution based on the size of the creek's recharge basin vs the LF4/DA1 recharge area.

3.7.2.2 Geology

Figures 2.2 and 3.8 show that the LF4/DA1 site is isolated geologically and is surrounded by wide expanses of the impermeable andesite bedrock (Tbem). Essentially the LF4/DA1 is located within a geologic "island" comprised of the conglomerate (see see **Section 2.4.2**) members of the Troutdale Formation (Ttfc), and there is no connection of the LF4/DA1 to the Troutdale units on the western edge of the CBMR.

In three dimensions, the geology of the LF4/DA1 area may be more accurately described as a Ttfc "cap" on a hillside otherwise consisting of Tbem. However, little remains of the original appearance of either rock formation due to extreme weathering. Well logs show that both units exist as sands, silts, and clays to a depth of about 70 feet. The conglomerate member of the Ttfc has been weathered to clayey silt and the andesite bedrock to sandy clay (see **Section 2.4.2** and well logs in **Appendix B**).

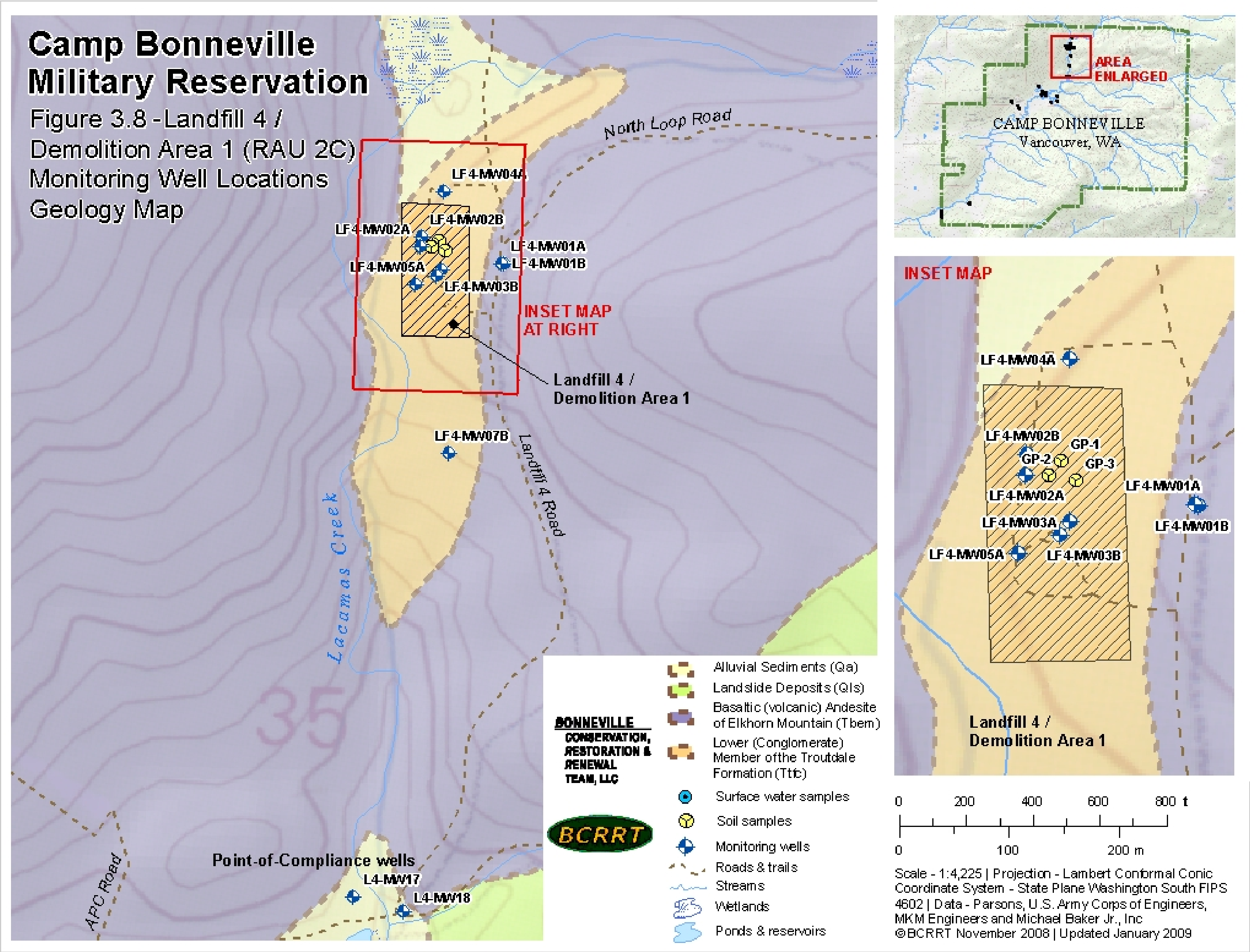
3.7.2.3 Hydrogeology

LF4/DA1 is located in an upland area of Camp Bonneville, north of the Central Valley. **Figure 3.8** presents is a geologic map superimposed upon a topographic map and shows that there is a remnant valley fill of Ttfc (conglomerate member of the Troutdale Formation) beneath the site. However, this formation extends only to a maximum depth of about 15 feet near MW-2B and is not saturated. Groundwater occurs only within the saprolitic soil formed from the heavily weathered andesitic bedrock of the Elk Mountain basalt (Tbem)

A total of ten monitoring wells were installed around and near LF4/DA1 as part of the investigation of RAU 2C –LF4/DA1 (URS, 2003). Five of the wells (LF-MW-1A, 2A, 3A, 4A, 5A,) were screened in shallow soils (30 to 45 feet bgs) and four wells (LF-MW-1B, 2B, 3B, 7B) were screened in deep soils atop competent bedrock (50 to 72 feet bgs). Another shallow well (MW-6A) was installed to bedrock on the steep hillside west of the landfill and east of Lacamas Creek, but was reported as dry and has not been used. In the most recent sampling event (September 2008), the depths to water in the shallow wells ranged from 17 to 31 feet and those in the deep wells from 14 to 41 feet (see **Appendix B**).

At the LF4/DA1 site, all of the saturated overburden material encountered was saprolite and heavily weathered from the parent material (andesitic basalt with zeolite inclusions) into sandy silt or silty sand with white mottling. This overburden material graded into increasingly larger grain sizes with depth until competent rock was reached. There were zones of saturated sandy, silty, or clayey (angular) gravels atop the competent bedrock. Within the competent bedrock, open fractures were noted in the three rock cores (LF-MW-1B, 2B, and 3B) at LF4/DA1, most of which were reported as being oriented horizontally or nearly so (URS, 2003).

Such rock characteristics tend to direct groundwater flow horizontally within the overburden and the relatively shallow weathered zones of bedrock until it can move upwards in response to a hydraulic discharge point of lower pressure head (e.g., a stream). Therefore, groundwater occurrence in the bedrock is generally in the uppermost weathered/fractured zones and especially in the gravelly portions atop the competent rock.


Camp Bonneville Military Reservation
Figure 3.8 - Landfill 4 / Demolition Area 1 (RAU 2C) Monitoring Well Locations Geology Map
North Loop Road
LF4-MW04A
LF4-MW02B
LF4-MW02A
LF4-MW01A
LF4-MW01B
LF4-MW05A
LF4-MW03B
INSET MAP AT RIGHT
Landfill 4 / Demolition Area 1
LF4-MW07B
Landfill 4 Road
Lacamas Creek
35
Point-of-Compliance wells
L4-MW17
L4-MW18
APC Road
AREA ENLARGED
CAMP BONNEVILLE
Vancouver, WA
INSET MAP
LF4-MW04A
LF4-MW02B
GP-1
GP-2
GP-3
LF4-MW01A
LF4-MW02A
LF4-MW03A
LF4-MW01B
LF4-MW05A
LF4-MW03B
Landfill 4 / Demolition Area 1
BONNEVILLE CONSERVATION, RESTORATION & RENEWAL TEAM, LLC
BCRRT
Alluvial Sediments (Qa)
Landslide Deposits (Qls)
Basaltic (volcanic) Andesite of Elkhorn Mountain (Tbem)
Lower (Conglomerate) Member of the Troutdale Formation (Ttc)
Surface water samples
Soil samples
Monitoring wells
Roads & trails
Streams
Wetlands
Ponds & reservoirs
0 200 400 600 800 ft
0 100 200 m
Scale - 1:4,225 | Projection - Lambert Conformal Conic Coordinate System - State Plane Washington South FIPS 4602 | Data - Parsons, U.S. Army Corps of Engineers, MKM Engineers and Michael Baker Jr., Inc
©BCRRT November 2008 | Updated January 2009

3.7.2.4 Groundwater Flow

Groundwater elevation data from a typical sampling event (September 2008, see **Appendix B**) were mapped for groundwater flow direction analysis in the following figures. **Figure 3.9** is typical of the historical groundwater flow pattern in the shallow zone and it indicates that shallow groundwater flows west from LF-MW-1A until a groundwater divide is reached, where the flow separates toward either north (toward LF-MW-4A) or south (toward LF-MW-3A and 5A). **Figure 3.10** is typical of the deeper zone and indicates that the deeper groundwater flows west from MW-1B in a semi-radial fashion toward the North Fork of Lacamas Creek, which is consistent with the surface topography. Therefore, groundwater from the LF4/DA1 site is expected to discharge to the North Fork of Lacamas Creek within 300 feet west and/or 250 feet southwest of the LF4/DA1 site.

Figure 3.9 – Typical shallow groundwater elevation contours.
Black arrows indicate flow lines from area of highest perchlorate concentration in soil.

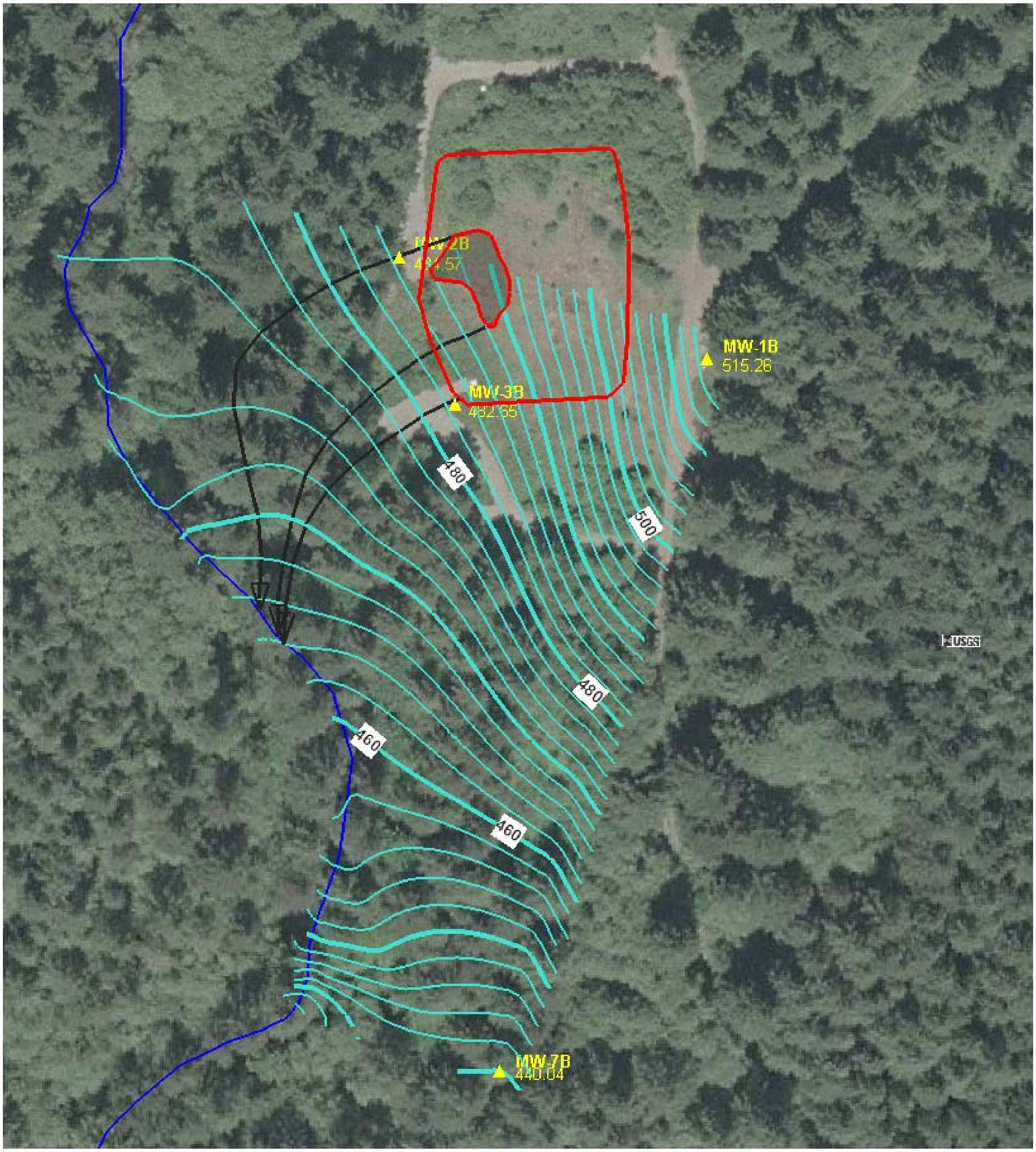


Figure 3.10– Typical deep groundwater elevation contours.
Black arrows indicate flow lines from area of highest perchlorate concentration.

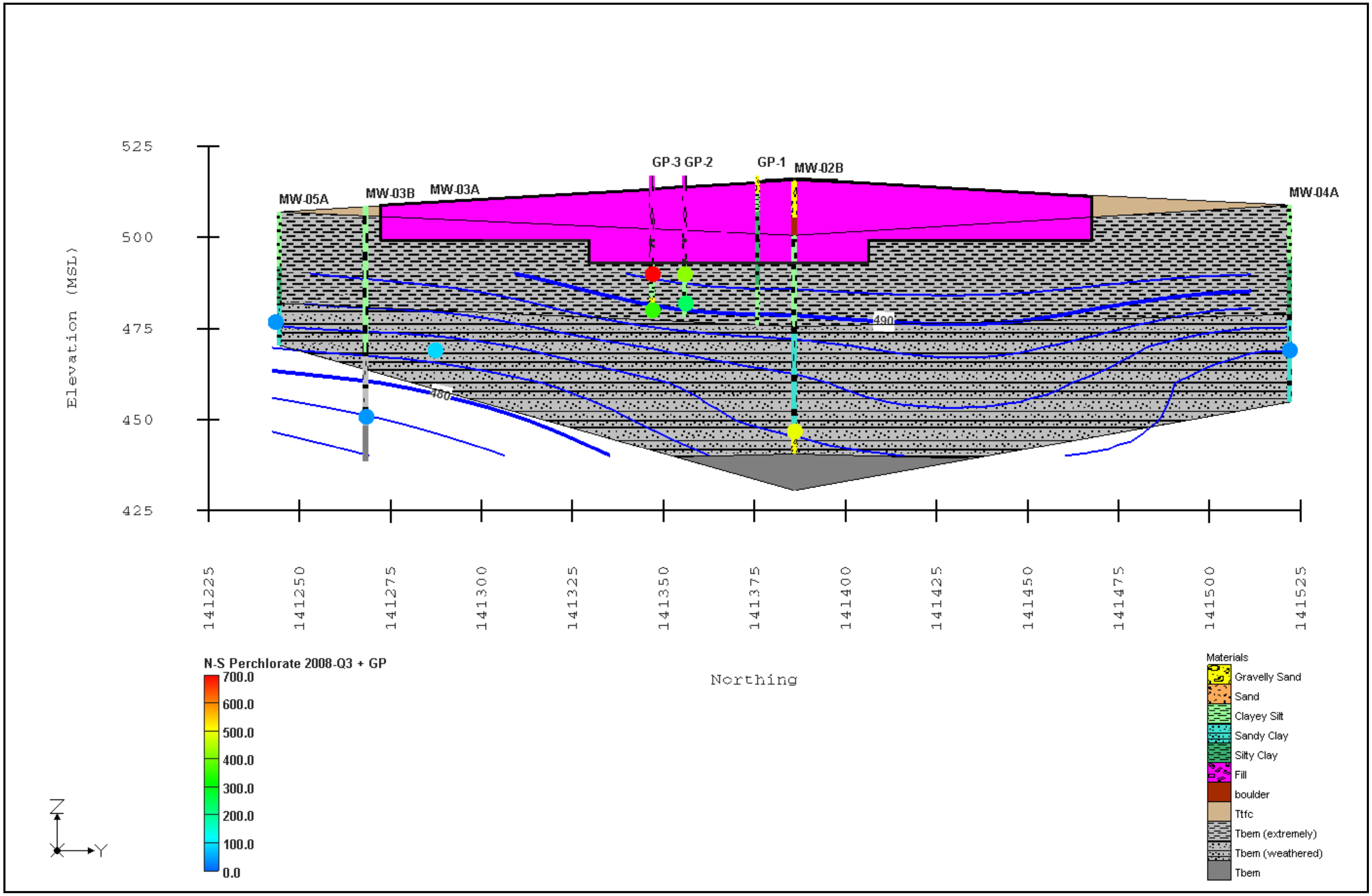
Two hydrogeologic cross-sections were also constructed using the same data set. **Figure 3.11** is a south-to-north cross-section from LF-MW-5A to 4A showing the groundwater divide in more detail, including the vertical dimension. LF-MW-2B lies just south of the groundwater divide. **Figure 3.12** shows a west-to-east cross-section from LF-MW-1A to 2B. This figure shows the change in the vertical flow component across the site: near LF-MW-1B, the flow is mostly horizontal. Toward the west, the flow becomes increasingly vertical. It appears that increased infiltration through the relatively permeable fill in the formerly excavated area is causing this alteration in the vertical flow gradients. **Figure 3.12** also may demonstrate why LF-MW-2B groundwater contains the highest perchlorate/RDX concentrations: the bedrock surface dips toward the west and, as impacted groundwater flows along the top of competent rock, it flows near well LF-MW-2B.

Estimates of the hydraulic conductivity of the saturated zones beneath LF4/DA1 had been made previously by using slug tests in several wells (URS 2003). However, the previous report questioned some of their own results as not corresponding to the observed stratigraphy (i.e., relatively high K values in silts and clays); therefore, the accuracy of their slug test data and/or analyses is doubtful. The raw slug test data and the corresponding digital AqTeSolv® files for those tests are not currently available for re-analysis.

A step-drawdown "yield" test had also been performed (URS 2003) in LF-MW-2B, but the data were not evaluated for hydraulic conductivity; fortunately, those data were available and were re-analyzed. The pumping rate and drawdown/recovery data were input to AqTeSolv® (version 3.5 Professional, Duffield, 2002) and analyzed using the Theis method for variable-rate pumping tests in an unconfined aquifer (a modification of Theis, 1935). The drawdown data in the pumping well were assumed to be greater than that in the formation due to friction in the well. The result was a good graphical match with the late recovery data, which are not affected by friction losses during the pumping phase. The result was a transmissivity value (T) of 9.0 ft^2/d, which, when divided by the aquifer saturated thickness (b) of 44 feet, yields a hydraulic conductivity value (K) of 0.204 ft/d (7.2e-5 cm/sec).

This K value will be used along with other values derived from the Supplemental Data Collection slug tests (see **Appendix D**) conducted recently to obtain a representative K value for fate calculations. GP-3 was slug-tested three times each at two different depths (29 feet and 38 feet bgs). The mean K value for the 29-foot depth interval was 0.37 ft/day and the mean K of the 38-foot depth interval was 0.233 ft/day. The data and the graphical analysis are available in **Appendix D.**

Figure 3.11– South-to-North Cross-Section at LF4/DA1 - Perchlorate Concentrations (ug/L) in Groundwater and Elevation Contours (Interval = 2 ft.)



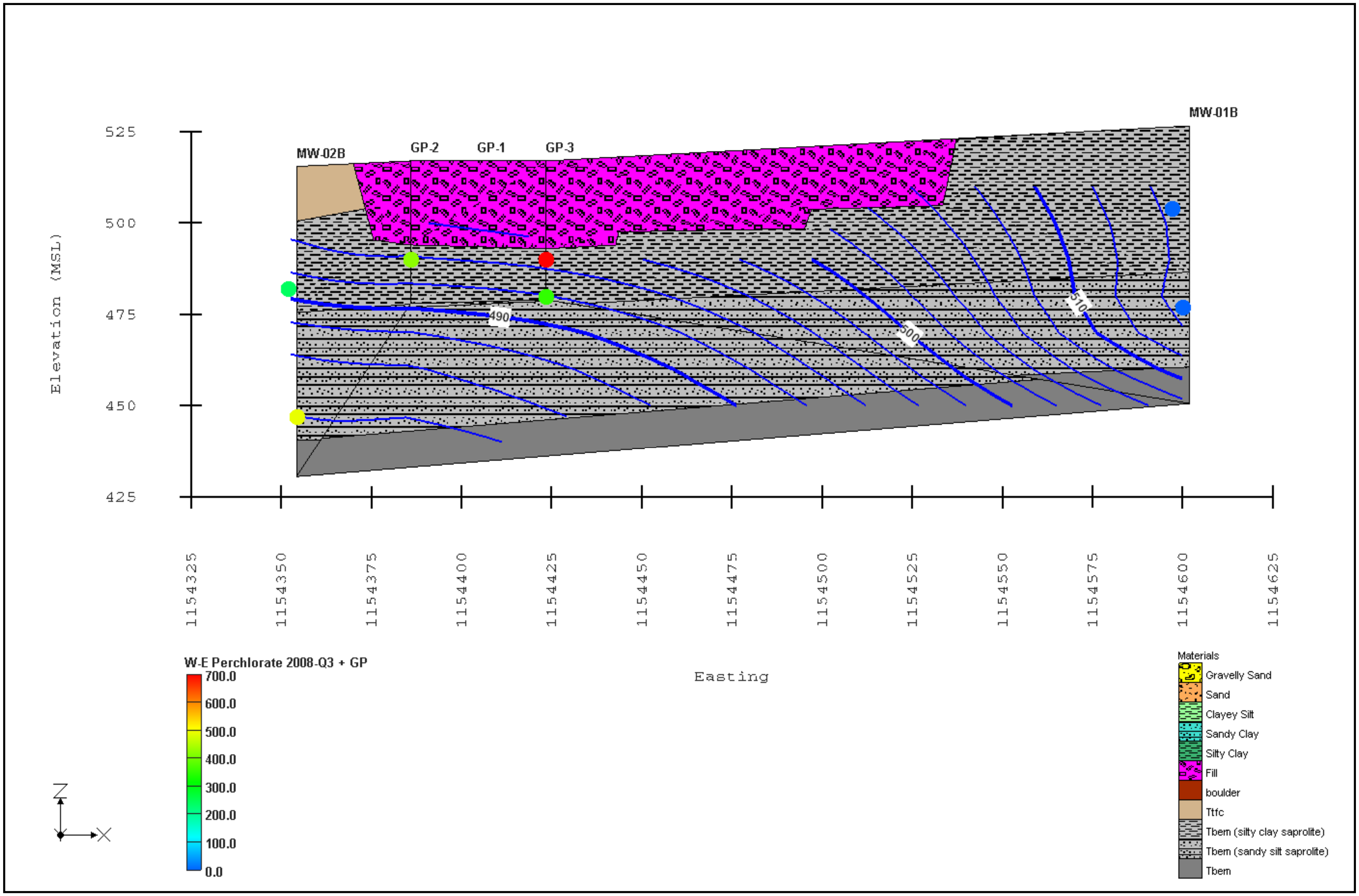


Figure 3.12 – West-to-East Cross-Section at LF4/DA1 - Perchlorate Concentrations (ug/L) in Groundwater and Elevation Contours (Interval = 2 ft.)

3.7.3 Chemical Data Analysis

3.7.3.1 Groundwater Sampling Results

Quarterly groundwater samples have been collected from eleven wells associated with LF4/DA1 (see **Figure 3.8**) since 2001, except between April 2002 and December 2003. Eight of those wells surround the former landfill area (LF4-MW01A&B, LF4-MW02A&B, LF4-MW03A&B, LF4-MW04A, and LF4-MW05A), with one located down/side gradient to the south (LF4-MW07B) and two wells (LF4-MW17 and LF4-MW18) located where the North Fork of Lacamas Creek enters the alluvial deposits in the valley (part of the Troutdale Sole Source Aquifer).

Naturally occurring levels of inorganic elements (metals) were observed in the parts per billion ranges in all of the wells (Ecology 1994). Historically the highest observed concentrations were generally associated with samples that had a high level of suspended solids in them. The comparable filtered sample for many of the metals have displayed lower concentrations, indicating the elevated reading was the result of the acid preservative dissolving materials from the soil particles suspended in the sample. In June 2005 the total mercury concentration in well L4MW03A (5.6 ug/L) exceeded the MTCA Method A criteria (2 ug/L). The associated dissolved mercury analysis (0.09 ug/L) was well below MTCA Method A criteria. All previous and subsequent mercury analyses from this well have been at non-detect levels (that are below the MTCA criteria). A significant fraction of the other site-wide wells also had laboratory reported mercury detections (all below MTCA criteria) in this single sampling event (LFMW1B, 2A, 2B, 4B, 4A, 7B, 17 18; MW3S, 3D, 4S, 4D). This pattern is interpreted to be a laboratory error or laboratory equipment contamination.

No other metals (total or dissolved) from RAU 2C have exceeded the MTCA Method A or Method B criteria. Ecology approved the removal of metals from the routine monitoring parameters at LF4/DA1 in 2006.

Based on our recent review of historic groundwater data, the following observations summarize groundwater conditions at and around the LF4/DA1 site:

- All of the VOCs detected (primarily at LF4-MW-2B) continue to be well below MTCA Method A and B Cleanup Levels (see **Table 3-1**). Concentrations of 1,1-dichloroethene, 1,1- dichloroethane and 1,1,1-trichloroethane have been decreasing slowly and dichlorodifluoromethane, 1,2-dichloroethane, tetrachloroethene and trichloroethene results have been non-detectable for the last year.

- HMX and RDX concentrations in groundwater have been either stable, below MTCA levels, or decreasing slowly with consistent concentration distributions throughout all of the 27 LF4/DA1 groundwater sampling events (2001 to 2009; see **Figure 3.13**).

Table 3-1
Summary of Maximum Groundwater Monitoring Detections vs MCTA Cleanup Levels

	Concentration (ppb/µg/L)		**MTCA Cleanup Level Groundwater (ppb/µg/L)**	
Contaminant	**Maximum Dectection** (1)	**Well ID**	Method A	Method B
HMX	4.6	L4MW02A		400
RDX	**120**	**L4MW02B**		**0.8**
Perchlorate	**530**			**11**
Picric Acid	2.9	L4MW02B	(2)	
Nitroglycerine	8.4		(2)	
1,1-Dichloroethene	36			400
1,1- Dichloroethane	45			1600
1,1,1-Trichloroethane	>200 in '03 >50 in '07		200	
1,2-Dichloroethane	1.58	L4MW02B	5 (2)	
2,4-Dinitrotoluene	0.36		(2)	32
Isopropylbenzene	0.2		(2)	
Methylene Chloride	2.58		5 (2)	
n-Propylbenzene	0.2		(2)	48
Tetrachloroethene	1.1		5	
Trichloroethene	0.26		5 (2)	
Trichlorofluoromethane	0.22		5 (2)	2,400
Dichlorodifluoromethane	190			1,600
1,3,5 Trinitrobenzene	0.13	L4MW01A		43,000
Naphthalene	0.35	L4MW17	160 (2)	

(1) **Bold** values exceeded MTCA Cleanup Levels.
(2) Not retained due to low frequency detection (one or two times our of > 250 samples).

- Well LF4-MW-1A – the shallow upgradient well perchlorate concentrations have decreased to previous levels (ranging from 1.6 to 7 µg/L) from the 36 µg/L detected in 4th Quarter 2008 during and following a heavy precipitation event and correlate with RDX variations.

- Well LF4-MW-1B – the deep upgradient well has low perchlorate concentrations; the adjacent shallow well LF-MW-1A has a history of low perchlorate and RDX concentrations. Since this well is located upgradient of the LF4/DA1, neither the detection nor absence of perchlorate at this well affects the monitoring program.

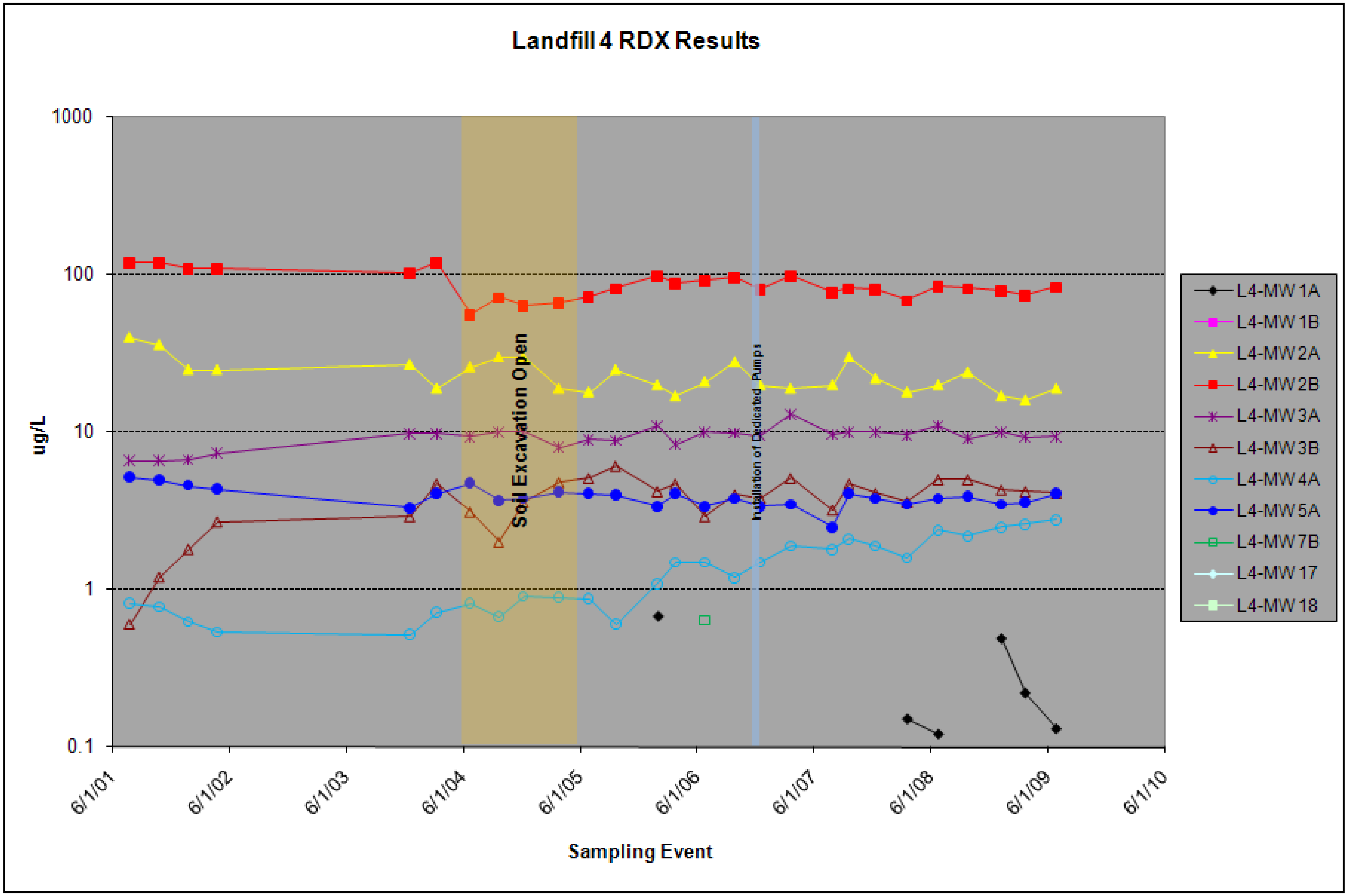


Figure 3.13 LF4/DA1 Groundwater Monitoring RDX Results

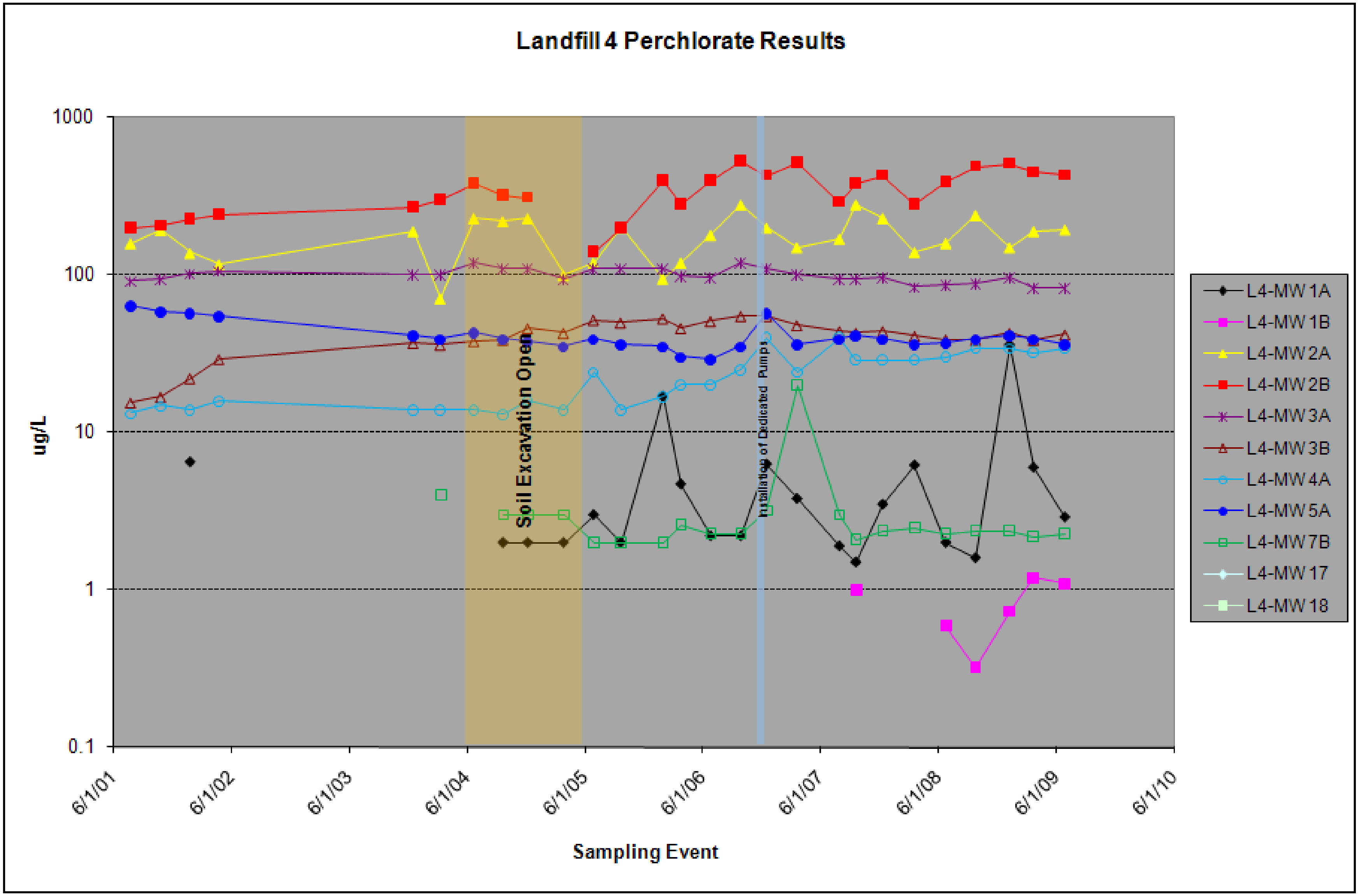


Figure 3.14 LF4/DA1 Groundwater Monitoring Perchlorate Results

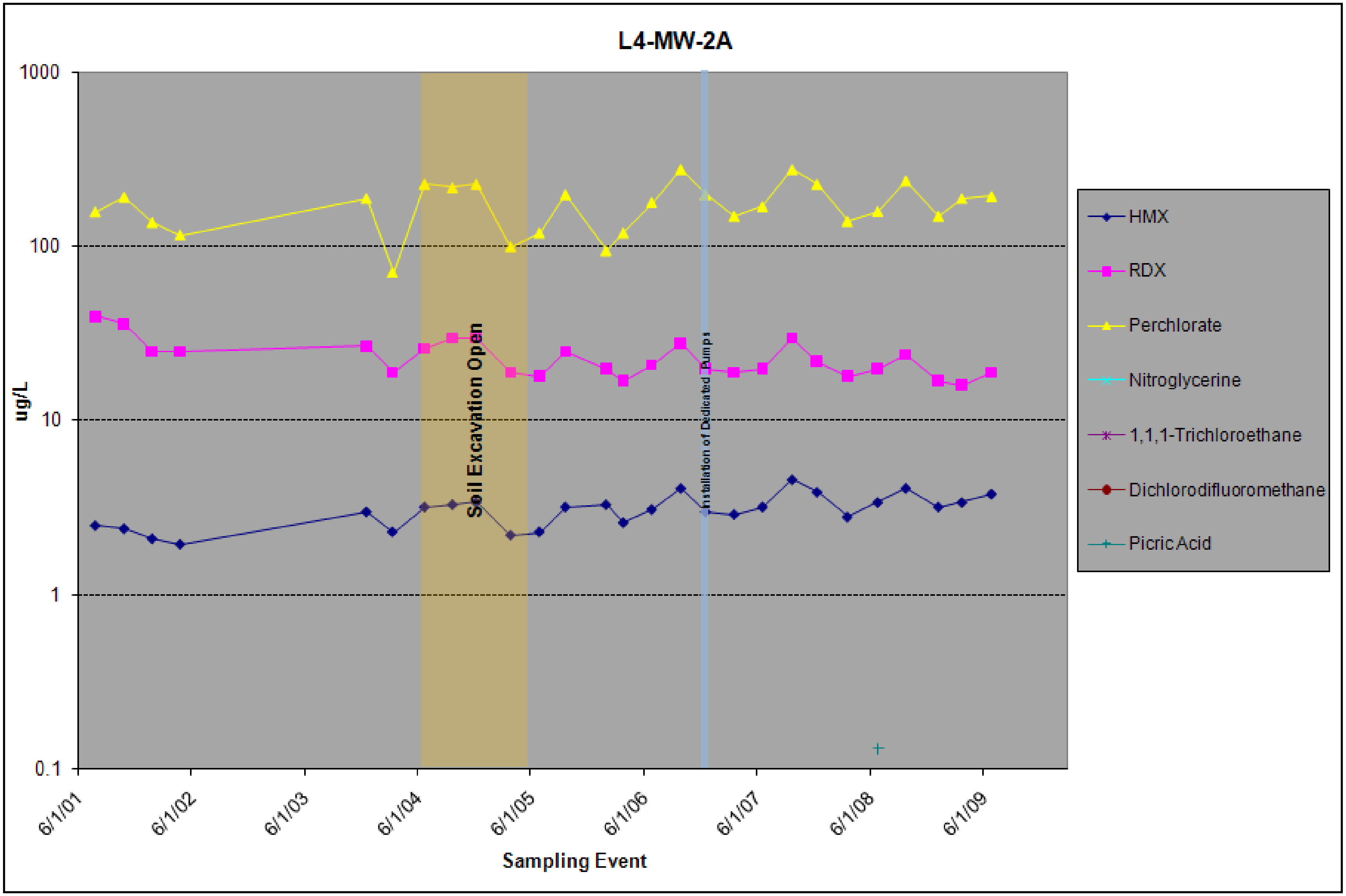


Figure 3.15 LF4/DA1 Perchlorate Results, Groundwater Elevation, and Precipitation - LF4-MW-2A

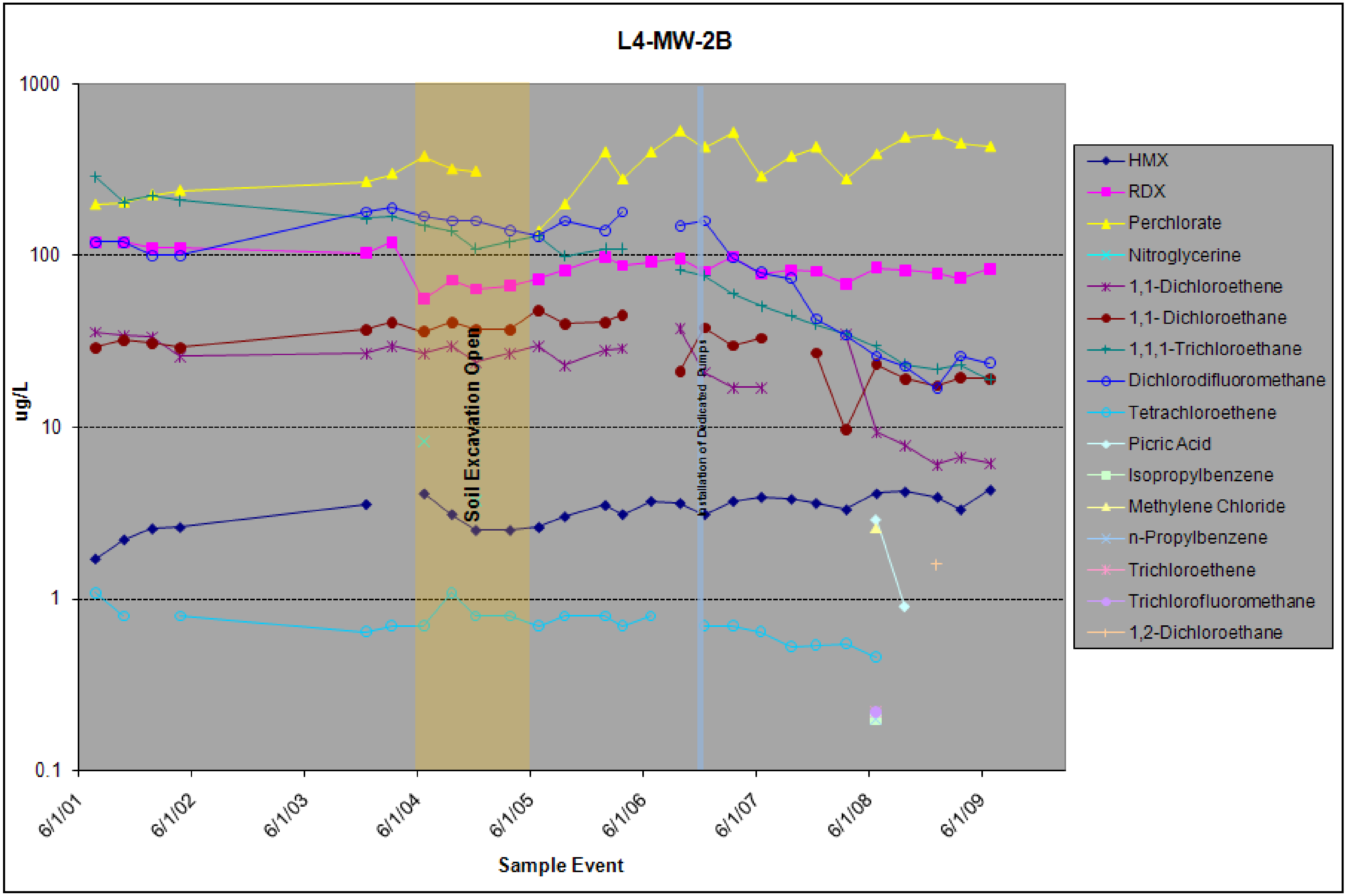


Figure 3.16 LF4/DA1 Perchlorate Results, Groundwater Elevation, and Precipitation - LF4-MW-2B

- Well LF-MW-2A – perchlorate concentrations appear to have reached a degree of equilibrium since 2005 with a consistent concentrations of perchlorate, RDX and HMX, which are all clearly affected by seasonal changes in recharge (see **Figure 3.15**). The seasonal variation appears to be inversely correlated with increased precipitation/groundwater elevations:

  - The lowest reported perchlorate concentrations, the highest measured groundwater levels and the lowest reported precipitation totals have generally occurred in the first quarter (Winter) events each year.

  - The highest reported perchlorate concentrations, the lowest measured groundwater levels, and the highest reported precipitation totals usually occurred in the third quarter (Summer) events of each year.

- L4MW2B perchlorate levels follow a stable, quasi-seasonal pattern. The 1st and 2nd Quarters in 2009 show the beginning of the downward portion of this pattern. The clearly seasonal perchlorate/RDX/HMX concentration patterns observed in L4-MW-2A are not repeated in the LF-MW-2B data (see **3.16**).

- Well L4-MW-3A - perchlorate concentrations have remained relatively stable with a slightly decreasing trend since a peak concentration of 120 µg/L occurred during the 3rd quarter 2006 sampling event. RDX concentrations are stable at about 10 ug/L.

- Well L4-MW-3B - perchlorate concentrations have remained relatively stable with an overall decreasing trend since a peak concentration (55 µg/L) was observed in the 3rd and 4th quarter 2006 sampling events. RDX concentrations are stable at 5 ug/L.

- Well L4-MW-4A - perchlorate concentrations have remained relatively stable (29 to 34 µg/L) since a peak concentration (40 µg/L) was observed in the 4th quarter 2006 and 2nd quarter 2007 sampling events. The common laboratory contaminant, methylene chloride that was detected (0.14 ppb) in the 2nd Quarter 2008 sample, has not been detected in later events.

- Well L4-MW-5A - perchlorate concentrations have been generally decreasing from a peak of 64 ppb in the initial sampling event in the 3rd quarter 2001 to less than 40 ppb during the last 7 quarters. The trace detections of tetrachloroethene have been non-detectable for the last 3 quarters. RDX concentrations have been consistently less than 5 ug/L.

- Well L4-MW-7B - perchlorate concentrations have been generally stable at 2 to 3 ppb for the last 20 quarterly sampling events; with the exception of an apparent field cross contamination issue during the 1st quarter 2006 event.

- Well L4-MW-17 – the 2nd Quarter 2008 estimated (above the MDL but below the MRL) concentrations of 1,2,4-Trimethylbenzene and Naphthalene (0.12 and 0.35 µg/L, respectively) have not been detected in subsequent events.

- Well L4-MW-17 and 18 – the monitoring wells located at the beginning of the Central Valley Floor were non-detectable for perchlorate throughout the 20 sampling events

3.7.3.2 LF4/DA1 Characteristics Derived from Groundwater Results

The seasonal changes at L4-MW- 2A, 2B, and 3A, mounding at 1A, and the continued presence of mobile contaminants all support the observed hydrogeology conditions that the LF4/DA1 is acting in a manner analogous to a "bathtub". The "bathtub" is where water entering the area via infiltration becomes trapped because of the lower permeability "walls" and competent bedrock "floor" with no fast way out. The accumulated water causes mounding which slowly seeps out, taking dissolved contaminants with it.

  - The observed seasonal variations in the shallow wells reflect dilution rather than migration out of the area. The wet/Winter conditions dilute the LF4/DA1 concentrations as fresh water recharges into the area; then as groundwater adsorbs, evaporates, and seeps out, the concentrations increase to peak levels during the dry/Summer conditions.

- The recent 4th Quarter 2008 spike in perchlorate concentration at the upgradient L4-MW-1A is directly attributable to the heavy precipitation event prior to and during the sampling event. The influx of water into the system created a mounding effect that forced impacted groundwater upgradient. The creation of this mounding reflects the inability of groundwater to easily migrate out of the local system.

- The generally stable presence of very mobile constituents such as perchlorate, chlorinated solvents, and RDX in an environment that experiences significant rainfall, lacks an overlying confining layer, and has a long timeline since the placement/release of source material all indicate that the local conditions have to be retarding the migration of contaminants out of the LF4/DA1 area.

Table 3-2
Perchlorate and RDX Maximum and Latest Detections by Well

COCs	**Perchlorate**(1)		**RDX**(1)	
Well	Maximum	June '09	Maximum	June '09
L4MW01A	**36**	2.9	0.49	0.13
L4MW01B	1.2	1.1	**0.92**	ND
L4MW02A	**280**	**195**	**40**	**19**
L4MW02B	**530**	**431**	**120**	**84**
L4MW03A	**120**	**83**	**13**	**9.4**
L4MW03B	**53**	**42**	**6.1**	**4.1**
L4MW04A	**40**	**34**	**2.8**	**2.8**
L4MW05A	**64**	**36**	**5.2**	**4.1**
L4MW07B	3(2)	2.3	ND	ND
L4MW017	ND	ND	ND	ND
L4MW018	ND	ND	ND	ND

(1) **Bold** values exceeded MTCA Cleanup Levels.
(2) Resampled value to correct a field cross-contamination result of 20 ppb that has not been repeated in the subsequent 8 quarterly sampling events.

3.7.3.3 Residual Source Volume Calculations

An estimate was made of the volume of perchlorate/RDX-impacted soils left in place at the end of the interim source removal action using the data provided in the Interim Action Report (TetraTech, 2006). These soils were defined as soils containing greater than 500 ug/kg perchlorate or RDX left in place above the water table (TetraTech, 2006). As such, they are a continuing source of perchlorate/RDX leaching from soil to groundwater.

There were three major areas delineated in the report (see **Figure 3.17** below). Each of these areas was multiplied by the height of soil column below the excavation and above the water table to obtain the volume of each polygonal prism:

- Polygon 1 was the beneath the deepest excavation, but had the shortest (4') soil column above the water table:. The bottom elevation of Polygon 1 was at 493 feet MSL and the average elevation of the water table beneath Polygon 1 was 489 feet MSL. The estimated area of Polygon 1 is 2,630 ft^2 and the average thickness of this soil layer is 4 ft. Based on these estimated values, the calculated estimate of impacted soil voume in this polygon is 10, 520 ft^3

- The estimated area of Polygon 2 is 2,096 ft^2. The bottom elevation of Polygon 2 was 499 feet MSL; the average water table elevation beneath Polygon 2 was 492 feet MSL. The average estimated thickness of impacted soil under this polygon is seven feet. Based on these estimated values, the calculated estimate of impacted soil volume in this polygon is14,672 ft^3

- The average perchlorate concentration in Polygon 3 was less than 500 ug/kg; therefore, its volume was not included in the total volume calculation.

The estimated total volume of perchlorate-impacted soil above the water table was 25,192 ft^3. The area of RDX-impacted soil above the water table was limited to 278 ft^2, based upon estimates made from the ITR report. Assuming a two-foot thick layer of RDX-contaminated soils, the volume is estimated at 556 ft^3.

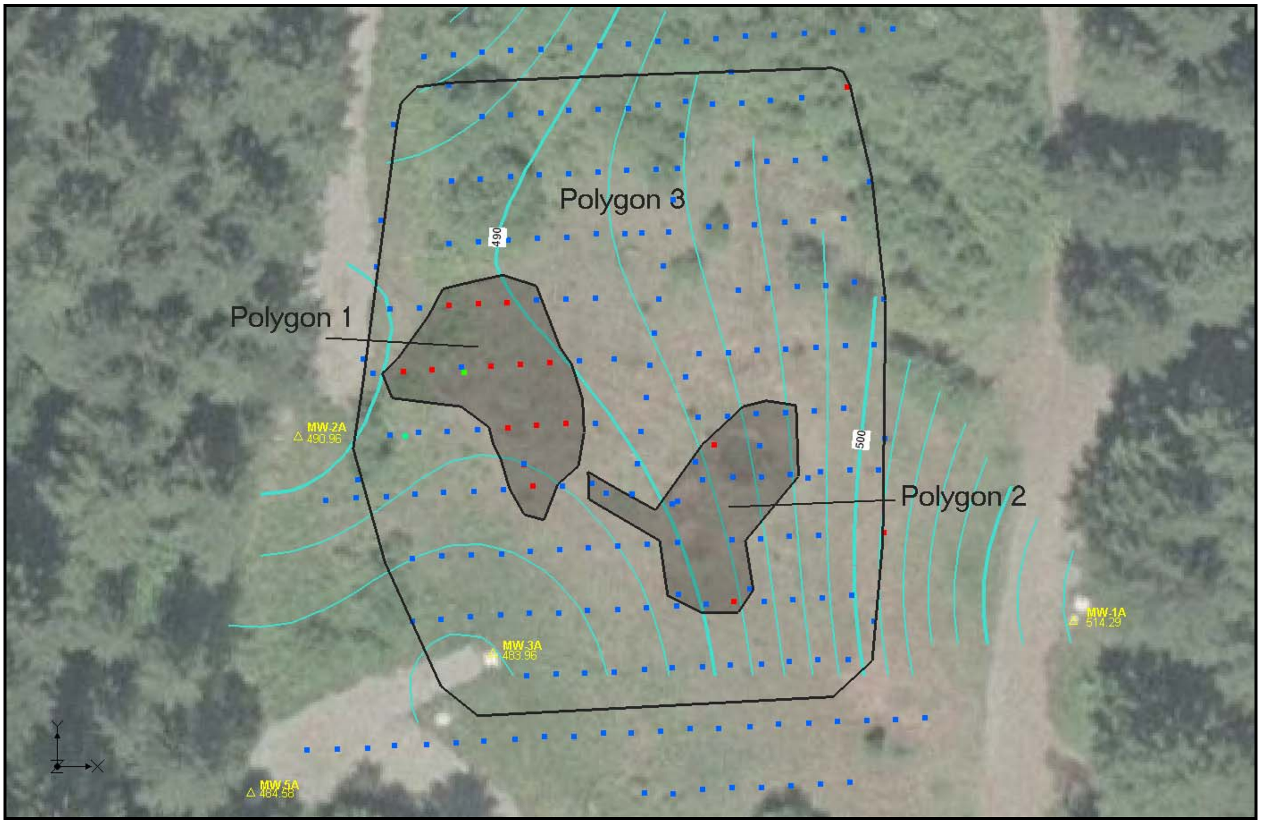


Figure 3.17 – Three polygons used in estimating the volume of residual perchlorate in soil left in place after the IRA. These polygons were also used by VLEACH for simulations of leaching perchlorate into groundwater.

3.7.3.4 Soil Leaching to Groundwater Calculations

Fate calculations for perchlorate in soil were conducted using the VLEACH model (version 2.2, EPA, 1997) to simulate the leaching of perchlorate/RDX from soil into groundwater. **Appendix D** contains the VLEACH soil leaching model input and output. The same polygons used to estimate the volume of residual perchlorate/RDX in soil (above) were used by VLEACH to simulate the leaching process.

VLEACH: Soil to Groundwater Assumptions:

- 6"/year infiltration (~20% of annual precipitation)
- K_v = 0.2 ft/d (from lab permeability of 7e-5 cm/sec)
- Soil characteristics were chosen from the built-in library within VLEACH; the silty clay loam was chosen as representative of LF4/DA1 site soils
- K_h = K_v because volcanic basalt flows are massive and, therefore, are assumed to be homogeneous and isotropic

- Mean concentration of soils not needing excavation (< 500 ppb): 254 ppb
- Mean concentration of "clean" fill material and residual soil (post-excavation): 97 ppb
- Three polygons (described above) adequately characterize the soil and chemical characteristics of the perchlorate-impacted soil above the water table.
- Mean concentration of RDX in soil not needing excavation (< 500 ppb): 250 ppb
- One polygon (278 ft^2) and two feet thick is a reasonable estimate of the RDX-impacted soil above the water table.
- These soil leaching predictions simulate only the perchlorate leaching from the soil into groundwater from the time of the excavation onward.

VLEACH: Soil to Groundwater Results – Post-Excavation Scenario (Current Conditions)

- The peak concentration of perchlorate leaching into the groundwater (530 ppb) was reached within one year after excavation. A subsequent Geoprobe® sample directly beneath the excavation contained 850 ppb of perchlorate; therefore, that value was used in the groundwater transport modeling instead of the value of 530 ppb (see below).
- The time necessary for the leachate to become less than 1 ug/L was >100 years under the post excavation scenario.
- The peak concentration of RDX leaching into the groundwater (6,341 ppb) was reached within 24 years after excavation.

3.7.3.5 Groundwater Mass Transport

Fate calculations for perchlorate/RDX in groundwater were conducted to predict the concentration of perchlorate/RDX traveling toward Lacamas Creek via groundwater. Calculations were performed using the Domenico one-dimensional, analytical solute transport model (1987), which incorporates dispersion, retardation, and degradation (first-order decay) into the mass transport equation. **Appendix E** contains the Domenico groundwater mass transport model input and output.

The vertical hydraulic conductivity results from the lab permeability tests performed on native soil beneath the excavation (K_v = 6.7e-5 cm/s = 0.19 ft/d) agrees with slug test results in the same material at depth of 29 feet (mean $K_{h\text{-}shal}$ = 0.233 ft/d) and with that obtained at 38 feet ($K_{h\text{-}deep}$ = 0.37 ft/d) within a factor of two (see **Appendix E**). This indicates that the material appears isotropic and relatively homogeneous, which would be expected in soils derived from weathered basalt. It also indicates that solute migration from the residual source material left at the bottom of the excavation toward a potential surface water discharge point to be very slow:

- Vertical groundwater velocity, $v_v = K\, i_v / n$
  = (0.2 ft/d • 0.171 ft/ft) / 0.477
  Where: { i_v = 6’/35’ from the MW-2A/2B pair; n from lab test}
  = 0.072 ft/d

- Vertical groundwater travel time to MW-2A $t = x_v / v$
  = 11 ft / 0.072 ft/d
  = 153 days

- Vertical groundwater travel time to MW-2B $t = x_v / v$
  = 46 ft / 0.072 ft/d
  = 639 days

- Horizontal groundwater velocity, $v_h = K_{h\text{-}deep}\, i_h / n$
  = (0.37 ft/d • 0.083 ft/ft) / 0.477
  Where: { i_h = 22’ / 266’ from MW-2B to the creek}
  = 0.064 ft/d

- Horizontal groundwater travel time $t = x_h / v$
  = 266 feet (horizontal) / 0.064 ft/day
  = 4,156 days / 365.242 d/yr = 11.4 years).

These calculations lend credence to the conceptual model that perchlorate and RDX migrate from the site very slowly, even without assuming retardation via adsorption onto soil particles.

Using the calculated mean K value of 0.37 ft/d for the deep zone, a measured hydraulic gradient of 0.077 ft/ft near the North Fork of Lacamas Creek (see **Figure 3.10**) and an effective porosity of 0.477 (representative of a silty clay loam within VLEACH, USEPA, 1997), the calculated groundwater flow velocity is 5.9E-2 ft/d (21.8 ft/yr).

To cross a linear distance of 247 feet measured from the SW corner of the landfill (near MW-3B) to the North Fork of Lacamas Creek, the groundwater time of travel would be 11.3 years. This calculated velocity and time of travel assumes no dispersion from the advective front and no retardation from adsorption to soil. However, dispersion mechanisms occur in nature due to heterogeneities in the subsurface and cause the plume to spread out from the advective front: some dissolved molecules will travel faster than the mean velocity and some slower. As a result, the first detectable presence of perchlorate (i.e., > 1 ppb) contributed by the residual soil after the excavation will arrive at the surface water body sooner than 18 years. If dispersion in three dimensions is taken into account, the travel time for the first detectable concentration (>0.001 mg/L) will be only eight years (see Domenico model input and output, **Appendix E**). The dispersivity used in the calculation was isotropic and based on the empirical formula by Xu and Eckstein (1995).

In order to be conservative, BCRRT constructed several scenarios to show that under various assumptions, the predicted perchlorate/RDX concentrations at critical receptors will be well below the allowable limits (see **Tables 3-3 and 3-4**).

According to this model, perchlorate and RDX concentrations should have reached the creek already since its use began as a disposal location for explosives and fireworks in the late 1960's; however, none has been detected in surface water to date. This indicates that there must be another attenuation mechanism at work, whether it is retardation to slow the movement of the perchlorate, biodegradation in creek sediments or in the root zones of the abundant flora along the creek, or a combination of both of these mechanisms. Even without the inclusion of these probable attenuating factors in the model, the concentrations of perchlorate are predicted to be below the 600 ug/L limit established for surface water.

While the North Fork of Lacamas Creek is by far the most likely primary/only pathway for perchlorate and RDX to migrate from the immediate LF4/DA1 vicinity (i.e. via surface water), BCRRT constructed **Scenario 4** to evaluate the theoretical extent of groundwater migration *with no losses to surface water*, no retardation, and no degradation, and with an unlimited transport timeline.

<u>In summary, the scenarios show the following:</u>

- Perchlorate and RDX do not pose a substantive threat for exceeding the MTCA Method B levels in either the creek or groundwater in the Central Valley, even when the retardation and degradation factors are removed.

- The retardation and degradation factors used correlate well with the site soil, groundwater, and pH data, and available literature (see **Appendix E** for details).

- The model predicts that sustained (statistically significant) concentrations for perchlorate as high as 1,300 ppb and RDX of 95 ppb across the LF4/DA1 wells would be protective of MTCA Method B levels in the creek and groundwater in the Central Valley. Please note that the predicted concentrations are far in excess of actual concentrations measured in groundwater.

TABLE 3-3
PERCHLORATE GROUNDWATER FATE AND TRANSPORT MODEL SCENARIOS

Scenario	Description	Assumptions	Results
1	Contaminant flow to Lacamas Creek, **without** any retardation or degradation factors	1) Lacamas Creek is the only receptor of groundwater 2) The highest on-site perchlorate concentration (850 ug/L in GP-3) represents a release to groundwater (rather than the VLEACH prediction of 530 ug/L) 3) The perchlorate migrated downgradient toward the closest part of Lacamas Creek at a distance of 247 feet from the landfill 4) Dispersion and advection are the only attenuation mechanisms at work; there is no retardation or chemical degradation of perchlorates in the system.	1) Detectable concentrations of perchlorate (1 ug/L) enter the creek after 8 years 2) The MTCA standard for groundwater (11 ug/L) is exceeded after 12 years 3) A maximum concentration of perchlorate (129 ug/L) reaches the creek after 39 years;
2	Contaminant flow to Lacamas Creek, **with** retardation factors	Same as those in Scenario 1, except that retardation was introduced based on the published soil-adsorption properties of perchlorate.	1) Detectable concentrations of perchlorate (1 ug/L) enter the creek after 22 years 2) The MTCA standard for groundwater (11 ug/L) is exceeded after 32 years 3) A maximum concentration of perchlorate (129 ug/L) reaches the creek after 106 years;
3	Contaminant flow to Lacamas Creek, **with** retardation and degradation factors	Same as those in Scenario 2, except that first-order degradation was introduced based on the published environmental half-life of perchlorate.	1) Detectable concentrations of perchlorate (1 ug/L) enter the creek after 8 years 2) The MTCA standard for groundwater (11 ug/L) is exceeded after 12 years 3) A maximum concentration of perchlorate (129 ug/L) reaches the creek after 39 years;
4	Contaminant flow if Lacamas Creek was not the receptor	The theoretical extent of groundwater migration *with no losses to surface water*, no retardation, and no degradation, and with an unlimited transport timeline	A maximum concentration of 7 ppb perchlorate reaches the Point of Compliance wells (LF4-MW-17 and 18 at a distance of 1,900 feet) in 177 years. The perchlorate concentration never reaches the 11 ppb level at the Point of Compliance wells.
5	LF4/DA1 Source Monitoring	The reverse calculation of the highest conservative perchlorate concentration at LF4/DA1 that would still be below the MTCA levels at the Creek and at the Point of Compliance wells (LF4-MW-17 and 18 at a distance of 1,900 feet) *with no losses to surface water*, no retardation, and no degradation, and with an unlimited transport timeline.	If concentrations trends increased above 1,300 ppb perchlorate for a sustained period in the LF4/DA1 wells, there would be an increased potential for a subsequent exceedances of the Method B Cleanup Level in either the Creek and/or in the groundwater entering into the Central Valley.

TABLE 3-4
RDX FATE AND TRANSPORT MODEL SCENARIOS

Scenario	Description	Assumptions	Results
1	Contaminant flow to Lacamas Creek, **without** any retardation or degradation factors	1) Lacamas Creek is the only receptor of groundwater 2) The highest predicted RDX concentration (6,341 ug/L after 24 years of leaching) represents the simulated release to groundwater 3) Dispersion and advection are the only attenuation mechanisms at work; there is no retardation or chemical degradation of RDXs in the system.	1) Detectable concentrations of RDX (1 ug/L) enter the creek after 9 years 2) The MTCA standard for groundwater (0.8 ug/L) is exceeded after 12 years 3) A maximum concentration of RDX (11.1 ug/L) reaches the creek after 39 years;
2	Contaminant flow to Lacamas Creek, **with** retardation factors	Same as those in Scenario 1, except that retardation was introduced based on the published soil-adsorption properties of RDX.	1) Detectable concentrations of RDX (1 ug/L) enter the creek after 17 years 2) The MTCA standard for groundwater (0.8 ug/L) is exceeded after 24 years 3) A maximum concentration of RDX (11.1 ug/L) reaches the creek after 80 years;
3	Contaminant flow to Lacamas Creek, **with** retardation and degradation factors	Same as those in Scenario 2, except that first-order degradation was introduced based on the published environmental half-life of RDX.	1) Detectable concentrations of perchlorate never enter the creek; the farthest that they can travel is 123 feet. 2) The MTCA standard for groundwater (0.8 ug/L) is never exceeded at the creek.
4	Contaminant flow if Lacamas Creek was not the receptor	The theoretical extent of groundwater migration *with no losses to surface water*, no retardation, and no degradation, and with an unlimited transport timeline	A maximum concentration of 0.6 ppb RDX reaches the Point of Compliance wells (LF4-MW-17 and 18 at a distance of 1,900 feet) in 237 years. The RDX concentration never reaches the 0.8 ppb level at the Point of Compliance wells.
5	LF4/DA1 Source Monitoring	The reverse calculation of the highest conservative RDX concentration at LF4/DA1 that would still be below the MTCA levels at the Creek and at the Point of Compliance wells (LF4-MW-17 and 18 at a distance of 1,900 feet) *with no losses to surface water*, no retardation, and no degradation, and with an unlimited transport timeline.	If concentrations trends increased above 95 ppb RDX for a sustained period in the LF4/DA1 wells, there would be an increased potential for a subsequent exceedances of the Method B Cleanup Level in either the Creek and/or in the groundwater entering into the Central Valley.

3.7.3.6 Groundwater to Surface Water Calculations

Even though discharge of surface water into groundwater in the Central Valley would be extremely diluted due to the significant surface water flow within the Lacamas Creek system, BCRRT has assumed that there is no mixing of groundwater when it enters surface water. Groundwater concentrations were compared directly with surface water criteria for the North Fork of Lacamas Creek.

3.7.4 Status Summary

Residual perchlorate and limited RDX remain in subsurface soils in portions of LF4/DA1. Perchlorate and RDX groundwater concentrations exceed MTCA Method B Cleanup Levels and are the only constituents of concern at LF4/DA1.

Based upon the modeling, the reported residual soil and current groundwater concentrations will not result in either perchlorate or RDX exceeding the MTCA Method B surface water values for human health and ecological receptors.

The LF4/DA1 area is addressed in the RI/FS evaluations that start in **Section 4.0**.

3.8 Status Summary by Area

The **Section 3.0** site characterization concluded that the following areas have already addressed associated groundwater issues and corrective actions are either being implemented or have been completed and approved by Ecology:

- Surface Water

  There are no locations on the property where site activities are known to have affected the quality of surface water (Hart Crowser, 2000; BCRRT 2008), and are not part of further RI/FS evaluations.

- RAU 1 - Hazardous waste impact at 20 locations (remediated pre-transfer)

  The RAU 1 investigations and remedial actions have been completed for all of the Bonneville and Killpack Cantonment Areas. The reports concluded that remedial actions were complete and did not identify the potential for impacts to groundwater. Responses to the RAU 1 areas of concern are complete and will not be part of this RAU-2C RI/FS evaluation.

- RAU 2A – 21 Small Arms Ranges where lead or other contaminants may be of concern

  Potential lead impact on groundwater at Camp Bonneville stemming from the Small Arms Ranges was addressed during development of the RAU 2A CAP and will not be addressed further as part of the RAU 2C RI/FS evaluation.

- RAU2B – Open Burn/Open Demolition Areas (OB/OD) 2 and 3

  Responses to the RAU 2B areas of concern are complete. Groundwater data obtained during the 2-years of monitoring at these OB/OD Areas was used as part of the overall groundwater evaluation detailed in this report**.**

- Site-Wide Groundwater Sentinel Wells

  While no constituents of concern have been detected, the Sentinel Wells will continue to be monitored per the Long-Term Monitoring Obligations in the PPCD.

- Explosives Residue at Firing Points and Target Areas

  Numerous soils samples were collected from 30 different firing points, target areas and the "Pop-Up" Pond; AOCs widely spaced across Camp Bonneville. Analysis of these samples revealed few detectable concentrations of residual explosive constituents at locations used for a variety weapons (artillery, mortar, rifle grenade, rockets) and uses (firing and target). When considered as a whole, this data set makes a strong statement that the weapons training activities conducted at these AOCs did not result in appreciable explosive constituent impact to soils. It is our conclusion that explosive residuals from firing points and target areas have not impacted on site-wide groundwater and does not require further evaluation in this RI/FS.

- Newly Discovered OB/OD Areas

  The two areas will be addressed under separate investigations and are being considered as separate from the remainder of RAU 2C per discussions with Ecology and as referenced in the draft final RAU 3 CAP.

Based upon the above evaluations and status summaries, only one area at CBMR site will be carried through the remainder of the RI/FS process:

- Landfill 4 /Demolition Area 1

  - Perchlorate and RDX groundwater concentrations exceed MTCA Method B Cleanup Levels and are the only COCs at the site.

  - Residual perchlorate and limited RDX remain in subsurface soils in small portions of LF4/DA1.

  - The COC concentrations in all the wells except LF-MW- 2A, LF-MW- 2B, and LF-MW-4A are stable and/or decreasing. Variations in concentrations observed in these three wells are likely related to the induced changes to hydrology from the IRA activities. The IRA excavations that were 1) advanced into more permeable zones, 2) were left open and/or filled with granular material for up to a year before final backfilling and placement of topsoil/cover material, and 3) regrading of the site have changed the surface runoff/recharge to local groundwater.

  - The groundwater concentrations at LF4/DA1 appear to have reached their maximum based upon 1) source removal, 2) the site conditions (analogous to a “bathtub” and, 3) the calculated residual soil-to-groundwater values.

- Based upon the modeling, the reported residual soil and current groundwater concentrations will not result in either perchlorate or RDX exceeding the MTCA Method B surface water values for human health and ecological receptors.

4.0 CONCEPTUAL SITE MODEL/RISK ASSESSMENT

As shown in the previous **Section 3.0**, the LF4/DA1 site is the only location on CBMR where data confirms that a release of contaminants has occurred to groundwater. Contaminants of concern (COCs) at LF4/DA1 are limited to perchlorate and RDX. WAC 173-340-708 and 173-340-7492 specifies the human health and ecological receptor evaluation procedures and for sites where a release of a hazardous substance has occurred.

The following conceptual site model (CSM)/risk assessment for LF4/DA1 identifies sources of hazardous substances, pathways for contaminant migration, and potential receptors. The CSM illustrates the potential pathways by which receptors (humans or other ecological endpoint species) may be exposed to chemicals at or released from a source. The purposes of a CSM are to provide a framework for problem definition, to identify exposure pathways that may result in adverse effects to human health or other ecological receptors, to aid in identifying data gaps, and, if necessary, to aid in identifying applicable cleanup measures targeted at significant contaminant sources and exposure pathways. The information used to develop this CSM, and conclusions drawn from this CSM, are presented in the following sections.

4.1 Conceptual Site Model

4.1.1 Hazardous Materials Source

Based on site history and historic groundwater monitoring records, the COC at LF4/DA1 are perchlorate and RDX. At LF4/DA1, perchlorates are reported to be the remnants of the buried fireworks and RDX from the detonation of surplus munitions.

Perchlorates were reportedly deposited as potassium perchlorate ($KClO_4$) and ammonium perchlorate (NH_4ClO_4) from disposal of pyrotechnics and as ammonium perchlorate and magnesium perchlorate [$Mg(ClO_4)_2$] from open detonation of surplus munitions.

RDX is a widely used military explosive. RDX is released to the environment from the burning, detonation and disposal of munitions. When released to the atmosphere, RDX may be removed by reaction with photochemically generated hydroxyl radicals. When released to water, RDX is subject to photolysis RDX undergoes biodegradation in water and soil under anaerobic conditions. Its biodegradation products include hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine (TNX); hydrazine, 1,1-dimethyl-hydrazine, 1,2-dimethly-hydrazine, formaldehyde, and methanol.

The primary source and portions of the secondary source were removed during the LF4/DA1 Interim Removal Action with excavation of December 20, 2004 and filling of the excavation in June 2005 (Tetra Tech 2006).

Residual soil contamination was identified in fifteen confirmatory soil samples with perchlorate and one confirmatory sample for RDX where concentrations exceeded the cleanup criteria of 0.5 ppm, following completion of the Interim Removal Action. The fifteen perchlorate results ranged from 0.52 ppm to 12.9 ppm with an arithmetic mean of 3.67 ppm. These reported exceedances are all from soil samples collected from the west central portion of the excavation limits. This area is an irregular shape occupying approximately 2,700 square feet. The single RDX result was 33 ppm and located on the northeast side of LF4/DA1.

This residual material is believed to comprise the secondary source for the perchlorate/RDX contamination of groundwater at LF4/DA1.

4.1.2 Potential Release and Transport Mechanisms

Perchlorate is very soluble, non volatile, and has very low sorption capacities. Perchlorate has little or no tendency to adhere to the surfaces of soil particles or to be absorbed by those particles. Perchlorate also has little or no affinity for attachment to organic carbon materials in soils. It is therefore reasonable to expect the perchlorates to travel with the groundwater with little or no movement retardation due to adsorption or absorption. RDX has similar properties with the exception of reduced solubility and increased affinity for organic carbon and clay in soils.

The only currently recognized health concern for perchlorates is their potential to interfere with the uptake of iodine by the thyroid gland. Perchlorate is not known as a human carcinogen. RDX has both threshold effects and cancer slope health concerns which reduce the Method B Cleanup Levels to below those for perchlorate.

The primary release mechanism was addressed during the LF4/DA1 Interim Removal Action, with completion of the excavation of impacted soils on December 20, 2004.

The secondary release mechanisms consist of minor soil leaching, groundwater dissolution and migration, discharge to surface water, and surface water transport based upon the following:

- Perchlorate and RDX are non-volatile; therefore no volatilization or dispersion is likely to occur.
- The residual contamination is believed to be approximately 10 to 20 feet below ground surface (bgs) and below the root zone, therefore intake into plants, wind erosion, storm runoff, direct dermal contact, and ingestion mechanisms do not apply.

Contaminated soils are a secondary source from which chemicals may potentially be released to other media such as groundwater. Groundwater may also serve as a secondary source from which chemicals may be released to other media such as surface water.

Most groundwater contaminants around LF4/DA1, including RDX and VOCs, have been decreasing in concentration since the removal action was completed in 2005. However, perchlorate concentrations in groundwater have increased to higher and/or seasonal levels from a combination of long travel time and some leaching from contaminated soils left in place at the conclusion of the 2004 IRA.

To date, perchlorate and RDX contaminated groundwater has not been observed discharging to, or dissolved in, Lacamas Creek. However, perchlorate and RDX in groundwater are expected to discharge from the LF4/DA1 are to the North Fork of Lacamas Creek about 300 feet to the west or southwest of the site (as discussed above) rather than via a groundwater flow.

The LF4/DA1 area groundwater is effectively “perched” in the North Fork of Lacamas

Creek valley surrounded by impermeable clays and andesitic bedrock with only a surface water connection to the lower Central Valley portion of Camp Bonneville.

4.1.3 Potential Human Receptors

All potential exposure pathways were evaluated for reasonable current and future scenarios:

- Particulate inhalation of COCs from surface soils;
- Particulate inhalation of COCs from subsurface surface soils;
- Ingestion and/or dermal contact with COCs in surface soils;
- Inhalation of outdoor vapors originating from volatile COCs in soil and groundwater;
- Inhalation of indoor vapors originating from volatile COCs in soil and groundwater;
- Ingestion and/or dermal contact with COCs in subsurface soil;
- Ingestion and/or dermal contact with COCs in groundwater;
- Migration of COCs from surface and subsurface soil to groundwater;
- Ingestion and/or dermal contact with volatile COCs contained in tap water (via groundwater);
- Inhalation of indoor vapors originating from volatile COCs in tap water (via groundwater);
- Ingestion and/or dermal contact with COCs in surface waters or sediments; and
- Inhalation of outdoor vapors originating from volatile COCs in surface waters.

Based on current and possible future use of the Site, it was determined that the CSM would evaluate the following receptors at the Site:

- On-site construction workers (current and future scenario)
- Recreational users (current and future scenario)
- Trespassers (current and future scenario)
- On-site workers (current and future scenario)

Currently, this site is not used for residential purposes. Agreements made at the time of the property transfer (PPCD, Ecology 2005) preclude its use for residential purposes and limit future uses to park and wildlife management areas. Future use of Camp Bonneville is to be limited to recreational use in the western third of the property and to a Wildlife Management Area for the remaining two thirds, therefore, in the future it will not be used for residential purposes and the on-site resident is not a potential receptor.

Based upon the steep topography in the LF4/DA1 area, its location outside of the planned park limits, and the potential for MEC items in the area, access to the North Fork of Lacamas Creek surface water pathway is considered limited. A remaining but low probability pathway would be potential recreational users in the receiving Lacamas Creek in the Central Valley that would be inside the planned park.

4.1.4 Incomplete Exposure Pathways

The following are considered to be incomplete exposure pathways:

- Surface soil and subsurface soil has been remediated to a depth of 8 to 27 ft bgs with no perchlorate is present in the soil at a depth less than 20 ft and RDX at 8 feet per the Ecology approved completion of the IRA. Therefore, all soil exposure pathways (i.e., incidental ingestion and dermal contact) are incomplete for both the current and future scenarios for the recreational user and onsite worker.

- Perchlorate and RDX are not volatile compounds. As result, exposure via inhalation of ambient volatilized materials from soil and groundwater is not applicable for the site.

- Surface soil and subsurface soil has been remediated to a depth of 8 to 27 ft bgs with no perchlorate is present in the soil at a depth less than 20 ft and RDX at 8 feet per the Ecology approved completion of the IRA. Accordingly, exposure via fugitive dust emission is not a complete exposure pathway.

- Surface soil and subsurface soil has been remediated to a depth of 8 to 27 ft bgs with no perchlorate is present in the soil at a depth less than 20 ft and RDX at 8 feet per the Ecology approved completion of the IRA. Such beng the case, at this site, particulate inhalation is not a complete exposure pathway for subsurface soil.

- Perchlorate and RDX are not volatile compounds. Therefore, exposure via inhalation of ambient emissions from groundwater and surface water is not a complete exposure pathway.

- Perchlorate and RDX are not volatile compounds. Ergo, exposure via inhalation of ambient emissions from sediment is not a complete exposure pathway.

- Perchlorate and RDX do not adsorb well to sediment particles and would rapidly disperse from the groundwater to the surface water, due to the rocky, steep terrain and very thick vegetation, and the potential for MEC items in the area, access to the North Fork of Lacamas Creek surface water pathway is considered limited and the recreational user and onsite work would not access the sediment (there is also little substantive sediment in the North Fork of Lacamas Creek west of LF4/DA1). Based on all of these factors, sediment is not a complete pathway for this area.

- Currently, there are no enclosed structures at the LF4/DA1, and future structures would not have a complete pathway due the greater than 10 ft depth of residual impacted material and since perchlorate and RDXs are non-volatile.

- Site groundwater is not currently used as a potable water supply and a Permanent Institutional Control will be implemented to restrict the use of groundwater from the vicinity of LF4/DA1. All potential exposure pathways related to the current use of groundwater as a potable source are considered to be incomplete for the current and future scenarios.

4.1.5 Complete Exposure Pathways Eliminated from Risk

The following complete exposure pathways have been eliminated from the consideration of risk:

- At the site, it is possible for saturated soil conditions and groundwater to exist above 20 feet bgs. Dermal contact and incidental ingestion of groundwater are not considered to be applicable to the on-site construction worker. Subsurface excavations at or below the water table involve additional constraints (dewatering, confined space entry, etc.) that are not envisioned as part of any anticipated construction activities (minor maintenance activities, subsurface utility work, etc.). The additional constraints required during work at or below the water table will eliminate the potential for significant contact with groundwater by the construction worker. [The potential for MEC at the site requires that any environmental or construction activities conducted at or below the water table will be performed by trained personnel under the terms and conditions of a site-specific health and safety plan (HASP)]. Therefore, the on-site construction worker direct contact exposure to groundwater is eliminated via Site-Wide Institutional Controls.

- Migration of COCs from soil to groundwater at this site is evaluated using actual groundwater data.

4.1.6 Potentially Complete Exposure Pathways

The pathway evaluation has identified only the following potentially complete exposure pathways at the site:

- While there have not been any detections of perchlorate or RDX to date in surface water bodies downstream of the LF4/DA1 area, a slow potential migration rate from LF4/DA1 to a receiving surface water body, and a significant amount of dilution for the Lacamas Creek basin, there remains a potential for incidental ingestion of surface water by recreational users as a potentially complete exposure pathway.

- The future groundwater use of the three existing groundwater supply wells will be contingent on the LF4/DA1 Point of Compliance wells monitoring and potential additional groundwater use restriction Institutional Controls, and/or selected existing well abandonment to be protective of future groundwater ingestion receptors.

4.1.7 Potential Ecological Receptors

Camp Bonneville is a heavily wooded area with Douglas fir, western red cedar, western hemlock, and red alder as the dominant tree species. Depending primarily on moisture gradients, the forest understory is composed of salal, Oregon grape, vine maple, and sword fern (Larson 1980 and GeoRecon International, 1981).

Several species of small mammals and birds reside on the site including cottontail rabbits, ground squirrels, mice, and shrews. Large mammals such as deer, bears, and cougars are also present at Camp Bonneville. There are also several special-status species present at or near Camp Bonneville.

Special status species confirmed at or near Camp Bonneville include:

- Plants
  - Hairy-stemmed checker-mallow (state endangered species)
  - Small-flowered trillium (state sensitive species)
- Amphibians
  - Northern red-legged frog (federal species of concern)
- Birds
  - Vaux's swift (state candidate species)
  - Pileated woodpecker (state candidate species)
- Mammals
  - Brush Prairie (Northern) pocket gopher (state candidate species)
- Fish
  - Coastal Cutthroat Trout: federal species of concern.

WAC 173-340-7490 specifies the terrestrial ecological evaluation procedures for sites where a release of a hazardous substance has occurred. Potential primary ecological receptors on site include terrestrial animals and plants, benthic invertebrates, aquatic plants, and fish. Potential exposure pathways to these receptors are evaluated in the following paragraphs. Potential exposure points include surface soil, subsurface soil, groundwater, surface water, and sediment.

Contaminated groundwater may discharge to a surface water body. Due to the highly soluble nature of perchlorate/RDX, the contaminant will partition to surface water and pore water, rather than to sediment. As such, the sediment exposure pathway is incomplete and is not evaluated further. Aquatic receptors, including plants, benthic invertebrates, amphibians, and fish, may be exposed to perchlorates in surface water through direct contact, ingestion of water, and ingestion of prey items. Terrestrial receptors, including omnivorous mammals, piscivorous mammals, and birds, may be exposed to perchlorate/RDX via ingestion of water and prey items. Because they are not volatile compounds, inhalation of perchlorate/RDX by ecological receptors is not a complete exposure pathway.

4.1.8 Regulatory Classifications

Camp Bonneville is located in air quality maintenance areas for ozone and carbon monoxide. As described above, hazardous substances present at the site are not volatile and generally not being released to the atmosphere, and there are currently no regulatory issues related to air quality.

The creeks and tributaries at Camp Bonneville are classed as Class A water bodies under WAC 173-201A-120 (6). These include Lacamas Creek, Buck Creek, David Creek, and tributary streams. Water quality of this class is designated as "excellent" and shall meet or exceed the requirements for all or substantially all uses. Class A water bodies must support a variety of uses, including fish and shellfish migration, rearing, spawning, and harvesting; recreation; and commerce and navigation.

There are three drinking water wells at CBMR:

- A 385-foot-deep well at the Camp Bonneville Cantonment located 4,750 ft from LF4/DA1 and 3,350 ft from the Point of Compliance wells LF4-MW-17 and 18,

- A 193-foot-deep well at the Camp Killpack cantonment (ESE 1993). This well is apparently different from the 516 –foot-deep well at the Camp Killpack Cantonment described by Mundorff (1964). The 193-foot deep well is located about 1.5 miles from both LF4/DA1 and the Point of Compliance wells LF4-MW-17 and 18..

- A 105-feet-deep well was drilled at the Federal Bureau of Investigation (FBI) range during 1998 (Shannon & Wilson 1999). This well is located about 1.25 miles from LF4/DA1 and 1 mile from the Point of Compliance wells LF4-MW-17 and 18. Please note that this well is not currently in use as the FBI range is closed.

Based on regional information from Mundroff (1964) and the reported depths of the wells at the CBMR, water supply wells in the area around CBMR generally extend into the Troutdale Formation or underlying bedrock. Most of the nearby wells apparently obtain groundwater from depths of 150 to as much as 500-feet bgs.

Groundwater at the site is currently used for non-potable water service (toilets, washing, rinsing of equipment, etc.) at the two cantonment areas. There are separate wells, reservoirs, and independent water conveyance systems each cantonment. Both water systems have been sampled, and the sample analyses did not contain detectable concentrations of perchlorate. While these wells are not currently used for potable water, the water quality from both of these systems is regulated under the Clark County Health Department requirements.

4.2 Risk Assessment/Exposure Analysis

In order for there to be a risk, a complete environmental pathway by which chemicals may be transported to human or ecological receptors must exist. If one or more of these elements is absent, the pathway is incomplete and exposure cannot occur.

4.2.1 Evaluation of Human Exposures

4.2.1.1 Soil

Based on the CSM, there are no exposure pathways for soil to be quantitatively evaluated at LF4/DA1.

4.2.1.2 Sediment

Based on the CSM, there are no exposure pathways for sediment to be quantitatively evaluated at LF4/DA1.

4.2.1.3 Air

Based on the CSM, there are no exposure pathways for ambient or indoor air to be quantitatively evaluated at LF4/DA1.

4.2.1.4 Groundwater

Based on the CSM, while there are no current exposure pathways for groundwater as a potable source to be quantitatively evaluated at LF4/DA1, there is a potential future exposure pathways resulting from groundwater used as a potable source (via use of existing/new well located in other portions of the Site).

BCRRT has calculated Modified Method B per the MTCA WAC 173-340-705 Equation 730-1 to address this potentially complete surface water human health exposure pathway for both perchlorate and RDX:

4.2.1.4.1 Perchlorate

$$\text{Groundwater cleanup level (ug/L)} = \frac{RfD \times ABW \times UCF \times HQ \times AT}{DWIR \times INH \times DWF \times ED}$$

Estimated Groundwater cleanup level (ug/L) = 11.2

RfD = Reference dose (mg/kg-day)	0.0007	(IRIS, 2008)
ABW = Average body weight during the exposure duration (kg)	16	WAC 173-340-720
UCF = Unit conversion factor (ug/mg)	1000	WAC 173-340-720
HQ = Hazard quotient (unitless)	1	WAC 173-340-720
AT = Averaging time (years)	6	WAC 173-340-720
DWIR = Drinking water ingestion rate (L/day)	1	WAC 173-340-720
INH = Inhalation correction factor (unitless)	1	WAC 173-340-720
DWF = Drinking water fraction (1.0) (unitless)	1	WAC 173-340-720
ED = Exposure duration (years)	6	WAC 173-340-720

4.2.1.4.2 RDX - Non-Carcinogenic

$$\text{Groundwater cleanup level (ug/L)} = \frac{RfD \times ABW \times UCF \times HQ \times AT}{DWIR \times INH \times DWF \times ED}$$

Estimated RDX ground water cleanup level (ug/L) = 48

RfD = Reference dose (mg/kg-day)	0.003	(IRIS, 2008)
ABW = Average body weight during the exposure duration (kg)	16	WAC 173-340-720
UCF = Unit conversion factor (ug/mg)	1000	WAC 173-340-720
HQ = Hazard quotient (unitless)	1	WAC 173-340-720
AT = Averaging time (years)	6	WAC 173-340-720
DWIR = Drinking water ingestion rate (L/day)	1	WAC 173-340-720
INH = Inhalation correction factor (unitless)	1	WAC 173-340-720

DWF = Drinking water fraction (1.0)		
(unitless)	1	WAC 173-340-720
ED = Exposure duration (years)	6	WAC 173-340-720

4.2.1.4.3 RDX - Carcinogenic

$$\text{Groundwater cleanup level (ug/L)} = \frac{\text{RISK x ABW x UCF x AT}}{\text{DWIR x INH x DWF x ED x CPF}}$$

Estimated RDX Ground water cleanup level (ug/L) = 0.8

CPF = Cancer Slope Factor		
(mg/kg-day)-1	0.11	(IRIS, 2008)
ABW = Average body weight during		
the exposure duration (kg)	70	WAC 173-340-720
UCF = Unit conversion factor (ug/mg)	1000	WAC 173-340-720
RISK = Acceptable cancer risk level		
(unitless)	1.0E-06	WAC 173-340-720
AT = Averaging time (years)	75	WAC 173-340-720
DWIR = Drinking water ingestion rate		
(L/day)	2	WAC 173-340-720
INH = Inhalation correction factor		
(unitless)	1	WAC 173-340-720
DWF = Drinking water fraction (1.0)		
(unitless)	1	WAC 173-340-720
ED = Exposure duration (years)	30	WAC 173-340-720

Therefore, the MTCA calculated Method B groundwater cleanup concentration for human health are 11 ppb for perchlorate and 08 ppb for RDX. These values were used in the evaluation of the COC fate and transport modeling in **Section 3.7.3.5** and the determination of Cleanup Standards in **Section 5.0**.

4.2.1.5 Surface Water

The CSM identified surface water as the only potentially complete exposure pathway at the site. While there have not been any detections of perchlorate to date in surface water bodies downstream of the LF4/DA1 area, a slow potential migration rate from LF4/DA1 to a receiving surface water body, and a significant amount of dilution for the Lacamas Creek basin, there remains a potential for incidental ingestion of surface water by recreational users as a potentially complete exposure pathway.

BCRRT has calculated Modified Method B per the MTCA WAC 173-340-705 Equation 730-1 and 730-2 to address this potentially complete surface water human health exposure pathway:

4.2.1.5.1 Perchlorate

Surface Water Cleanup Level (ug/L) = $\frac{\text{RfD x ABW x UCF1 x UCF2 x HQ x AT}}{\text{BCF x FCR x FDF x ED}}$

Estimated Perchlorate Surface Water Cleanup Level (ug/L) = 1,814

RfD = Reference dose (mg/kg-day)	0.0007	(IRIS, 2009)
ABW = Average body weight (kg)	70	WAC 173-340-730
UCF1= Unit conversion factor (ug/mg)	1000	WAC 173-340-730
UCF2 = Unit conversion factor (g/L)	1000	WAC 173-340-730
HQ = Hazard quotient (unitless)	1	WAC 173-340-730
AT = Averaging time (years)	30	WAC 173-340-730
BCF = Bioconcentration Factor (L/kg)	1	(1)
FCR = Fish consumption rate (g/day)	54	WAC 173-340-730
FDF = Fish diet fraction (unitless)	0.5	WAC 173-340-730
ED = Exposure duration (years)	30	WAC 173-340-730

(1) The EPA does not have a BCF that is used to calculate surface water criteria. Several references stated that the BCFs are not available for most species of concern but existing evidence supports conclusions that most BCFs will be less than 1. This is based on the octanol/water partition coefficient Kow - 1.4 x 10-6 (low Kow = -5.84) (USEPA 2008 and USACE 2007).

4.2.1.5.2 RDX - Non-Carcinogenic

Surface Water Cleanup Level (ug/L) = $\frac{\text{RfD x ABW x UCF1 x UCF2 x HQ x AT}}{\text{BCF x FCR x FDF x ED}}$

Estimated RDX Surface Water Cleanup Level (ug/L) = 7,777

RfD = Reference dose (mg/kg-day)	0.003	(IRIS, 2009)
ABW = Average body weight (kg)	70	WAC 173-340-730
UCF1= Unit conversion factor (ug/mg)	1000	WAC 173-340-730
UCF2 = Unit conversion factor (g/L)	1000	WAC 173-340-730
HQ = Hazard quotient (unitless)	1	WAC 173-340-730
AT = Averaging time (years)	30	WAC 173-340-730
BCF = Bioconcentration Factor (L/kg)	1	(1)
FCR = Fish consumption rate (g/day)	54	WAC 173-340-730
FDF = Fish diet fraction (unitless)	0.5	WAC 173-340-730
ED = Exposure duration (years)	30	WAC 173-340-730

(1) The EPA does not have a BCF that is used to calculate surface water critieria. The reference listed below indicates that the BCF may range from 1 to 0.7. Conservatively, the maximum value was used; the log Kow for RDX is 0.87 (Rosen 2007).

4.2.1.5.3 RDX - Carcinogenic

$$\text{Surface water cleanup level (ug/L)} = \frac{\text{RISK x ABW x AT x UCF1 x UCF2}}{\text{CPF x BCF x FCR x FDF x ED}}$$

Estimated RDX surface water cleanup level (ug/L) = 59

CPF = Carcinogenic potency factor (kg-day/mg)-1	0.11	(IRIS, 2009)
RISK = Acceptable cancer risk level (unitless)	0.000001	WAC 173-340-730
ABW = Average body weight (kg)	70	WAC 173-340-730
AT = Averaging time (years)	75	WAC 173-340-730
UCF1= Unit conversion factor (ug/mg)	1000	WAC 173-340-730
UCF2 = Unit conversion factor (g/L)	1000	WAC 173-340-730
BCF = Bioconcentration factor (L/kg)	1	(1)
FCR = Fish consumption rate (g/day)	54	WAC 173-340-730
FDF = Fish diet fraction (unitless)	0.5	WAC 173-340-730
ED = Exposure duration (years)	30	WAC 173-340-730

(1) The EPA does not have a BCF that is used to calculate surface water critieria. The reference listed below indicates that the BCF may range from 1 to 0.7. Conservatively, the maximum value was used; the log Kow for RDX is 0.87 (Rosen 2007).

Therefore, the calculated Method B surface water cleanup level for human health is 1,814 ppb for perchlorate and 59 ppb for RDX. These values were used in the evaluation of the COC fate and transport modeling in **Section 3.7.3.5** and the determination of Cleanup Standards in **Section 5.0**.

4.2.2 Evaluation of Ecological Exposures

4.2.2.1 Soil

Based on the CSM, there are no exposure pathways for soil to be quantitatively evaluated at LF4/DA1.

4.2.2.2 Sediment

Based on the CSM, there are no exposure pathways for sediment to be quantitatively evaluated at LF4/DA1.

4.2.2.3 Air

Based on the CSM, there are no exposure pathways for ambient or indoor air to be quantitatively evaluated at LF4/DA1.

4.2.2.4 Groundwater

Based on the CSM, there are no exposure pathways for groundwater to be quantitatively evaluated at LF4/DA1.

4.2.2.5 Surface Water

Contaminated groundwater may discharge to a surface water body. Due to the medium to highly soluble nature of perchlorate and RDX, the contaminants will partition to surface water and pore water, rather than to sediment. As such, the sediment exposure pathway is incomplete and is not evaluated further. Aquatic receptors such as plants, benthic invertebrates, amphibians, and fish) may be exposed to perchlorate and RDX in surface water through direct contact, ingestion of water, and ingestion of prey items. Terrestrial receptors such as omnivorous mammals, piscivorous mammals, and birds may be exposed to perchlorate via ingestion of water and prey items.

4.2.2.5.1 Perchlorate

The USEPA has not established a water quality criterion for aquatic life for perchlorate; however, the agency has conducted toxicological testing on a variety of organisms. USEPA toxicity testing evaluated perchlorate effects on the following species: *Daphnia magna* (water flea), *Ceriodaphnia magna* (water flea), *Lactuca sativa* (lettuce), *Pimephales promelas* (fathead minnow), *Eisenia foetida* (earthworm) and *Microtus pennsylvanicus* (meadow vole). In addition, Frog Embryo Teratogenesis Assay (FETAX) using *Xenopus* (African clawed frog), and a phytoremediation study with willow, Eastern Cottonwood and eucalyptus were conducted. Based on the results of these studies, a "secondary acute value of 5 mg/L (as perchlorate) was derived to be protective of 95% of aquatic organisms during short-term exposures with 80% confidence. The secondary chronic value (SCV) of 0.6 mg/L (as perchlorate) likewise was derived to be protective of 95% of aquatic organisms during long-term exposures with 80% confidence." (USEPA 2002). The USEPA's testing was designed to be the first Tier of testing aimed at deriving ambient water quality criteria for perchlorate. Dean et al. (2004) conducted additional toxicity testing as required for the development of water quality criteria and identified additional studies from the literature that met the USEPA requirements for test methods used in determining water quality criteria. In addition to the aforementioned species, species tested included *Hyalella azteca* (amphipod), *Lepomis macochius* (bluegill), *Oncorhynchus mykiss* (rainbow trout), *Lumbriculus variegates* (Oligochaete), *Rana clamitans* (green frog), *Corbicula fluminea* (Asiatic clam), and *Chironomus tentans* (midge). Dean et al. compiled their test results and existing data and calculated a criterion maximum concentration of 20 mg/L and a criterion continuous concentration (CCC) of 9.3 mg/L. A CCC is the value generally provided by the USEPA as a chronic water quality criterion.

Thus, although the 9.3 mg/L has not officially been identified as the ambient water quality criteria for perchlorate by the USEPA, it was derived via the same methods that the USEPA employs to derive water quality criteria.

It should be noted that the special-status species present at or near Camp Bonneville include terrestrial plants (hairy-stemmed checker-mallow and small-flowered trillium), frogs (Northern red-legged frog), birds (Vaux's swift and Pileated woodpecker), small mammals (Brush Prairie pocket gopher), and fish (Coastal Cutthroat Trout). With the exception of birds, toxicological data used to establish the above benchmarks included data from species similar to each of these receptors (specifically: lettuce, green frog, meadow vole, and rainbow trout).

<u>Of the benchmarks discussed above, the most conservative (i.e. lowest value) is the SCV established by the USEPA of 600 ppb for perchlorate.</u>

4.2.2.5.2 RDX

The USEPA has not established a water quality criterion for aquatic life for RDX; however, the following ecological screening values are available for RDX in surface water:

- USEPA Region 6 recommends use of surface water benchmarks developed for the Texas Natural Resource Conservation Commission. These benchmarks are conservative screening level values intended to be protective of aquatic biota. Values were compiled from a prioritized list of published values. The primary benchmarks are chronic criteria obtained from Texas surface water quality standards or the most current federal National Ambient Water Quality Criteria. Additional benchmarks were derived using the LC50 approach. TNRCC Water Quality Division chronic values, ORNL secondary chronic values (Suter and Tsao 1996), or EPA Region 4 chronic screening values, in that order, were consulted to expand the number of chemicals with acceptable benchmarks. Values for hardness-dependent metals assume a hardness of 50 mg/L. Values for arsenic, cadmium, chromium, copper, lead, nickel, silver, uranium, and zinc apply to dissolved concentrations. USEPA Region 6 Ecological Screening Benchmarks: Freshwater = 360 ppb (Texas, 2001)

- Tier II values were developed so that aquatic benchmarks could be established with fewer data than are required for National Ambient Water Quality Criteria. The Tier II Secondary Acute Value (SAV) is derived by taking the lowest genus mean acute value from data meeting specified criteria and dividing it by a Final Acute Value Factor whose value depends on the number of acute data requirements that are met. Values provided here are from Suter and

Tsao (1996). National Ambient Water Quality Criteria. The Tier II Secondary Acute Value (SAV) = 1,400 ppb (Suter and Tsao 1996).

- Tier II values were developed so that aquatic benchmarks could be established with fewer data than are required for National Ambient Water Quality Criteria. The Tier II Secondary Chronic Value (SCV) is derived by dividing the Secondary Acute Value (see above) by the Secondary Acute-Chronic Ratio.
  Values provided here are from Suter and Tsao (1996). National Ambient Water Quality Criteria. The Tier II Secondary Chronic Value (SCV) = 190 ppb (Suter and Tsao 1996).

Of the benchmarks discussed above, the most conservative (i.e. lowest value) is the SCV established by the USEPA of 190 ppb RDX.

Therefore, the surface water cleanup levels for ecological receptors are 600 ppb for perchlorate and 190 ppb for RDX. These values were used in the evaluation of the COC fate and transport modeling in **Section 3.7.3.5** and the determination of Cleanup Standards in **Section 5.0**.

4.3 Summary

In order for there to be a risk, a complete environmental pathway by which chemicals may be transported to human or ecological receptors must exist. The only potentially complete pathways for constituents in groundwater moving away fromLF4/DA1 are:

1) Future groundwater receptor, in the event that existing or new on-site wells (deep/bedrock wells) are used as a potable water source in the Central Valley.

2) Surface water for human health receptors (recreational users/fishers) via Lacamas Creek.

3) Surface water for ecological receptors in Lacamas Creek.

5.0 CLEANUP STANDARDS

This section presents Cleanup Standards for RAU 2C to prevent the potential exposure of contaminants in groundwater to human and ecological receptors and support the proposed re-use and/or redevelopment of the site. The Cleanup Standards of comprised on two components:

- Cleanup Levels – the concentration where exposure to by human and ecological receptors will not cause risk above MTCA requirements.
- Points of Compliance – the locations where the achievement of the Cleanup Levels will be protective of human and ecological receptors.

5.1 Cleanup Levels

5.1.1 Site-Wide Groundwater

The Cleanup Levels for the Site-Wide Groundwater are the lower of default MTCA Method A and B levels for Site COCs to be protective of off-site human and ecologic receptors.

5.1.2 LF4/DA1

5.1.2.1 MTCA Method B

MTCA Method B Cleanup Levels have been determined for LF4/DA1 for groundwater and surface water outside of the immediate LF4/DA1 area, based on the potential future land use and risk assessment:

Table 5-1. MTCA Method B Cleanup Levels

Contaminant of Concern	Human Health		Ecological Receptors	
	Groundwater	**Surface Water**	**Groundwater**	**Surface Water**
Perchlorate	11 ppb [1]	1,814 ppb	NA [2]	600 ppb
RDX	0.8 ppb [1]	59 ppb	NA[2]	190 ppb

Notes:

[1] Groundwater is not accessible for human health receptors due to Institutional Controls (see **Section 6.0**).

[2] Groundwater is not accessible for ecological receptors due to depth (see **Section 4**).

5.1.2.2 MTCA Method C

The unique hydrogeologic conditions at the LF4/DA1 site contain the dissolved constituents in groundwater near LF4/DA1 resulting in no current risk to human health and the environment, and that risk is very unlikely to change in the future. BCRRT calculated conservative fate and transport models for potential migration from the LF4/DA1to determine at the concentration of COCs could constitute an increased risk to water quality outside of LF4/DA1.

If statistically significant trends exceed 1,300 ppb for perchlorate and 95 ppb for RDX in the LF4/DA1 wells, there would be an increased potential for exceeding the Method B Cleanup Level in either the Creek and/or in the groundwater entering into the Central Valley.

The highest LF4/DA1 concentration of perchlorate in groundwater was 850 ppb in a direct push sample taken immediatly beneath the residual soil contamination and the highest monitoring well sample was 530 ppb at LF4MW02B. RDX has exceeded the 95 ppb level at LF4MW02B, prior to and soon after the IRA in 2004/2005, but has been steadily decreasing and is now been consistently less than 95 ppb for the last 9 quarters (over 2 years).

Therefore, BCRRT proposes that the Method C Cleanup Levels of 1,300 ppb for perchlorate and 95 ppb for RDX for those wells located within the hydrologic containment area of LF4/DA1.

5.2 Points of Compliance

BCRRT has determined Point of Compliance (POCs) for monitoring at CBMR, based on the **Section 3.4** site conditions and groundwater modeling, the CSM, and Risk/Exposure Pathways:

5.2.1 Site-Wide Groundwater

The POCs for Site-Wide Groundwater are the four pairs of shallow/deep monitoring wells located on the southwestern boundary of CBMR, where Lacamas Creek exists the Site. These POCs are to confirm that groundwater migrating from the Site meet the MTCA Method A or B Cleanup Level and are protective of off-site human and ecologic receptors.

5.2.2 LF4/DA1

The POCs for LF4/DA1 consist of the following:

- Source Monitoring - via the nine wells around the LF4/DA1 location. Results from these wells will be compared to Method C Cleanup Levels calculated to be protective of surface water receptors associated with Lacamas Creek, potential future groundwater receptors in the Central Valley, and ultimately, of off-site human and ecologic receptors.

- Groundwater Monitoring - via the wells located on either side of the North Fork of Lacamas Creek, where it enters the Central Valley (LFMW17 & 18). This data will be compared to Method B Cleanup Levels to be protective of potential future groundwater receptors in the Central Valley, and ultimately, of off-site human and ecologic receptors.

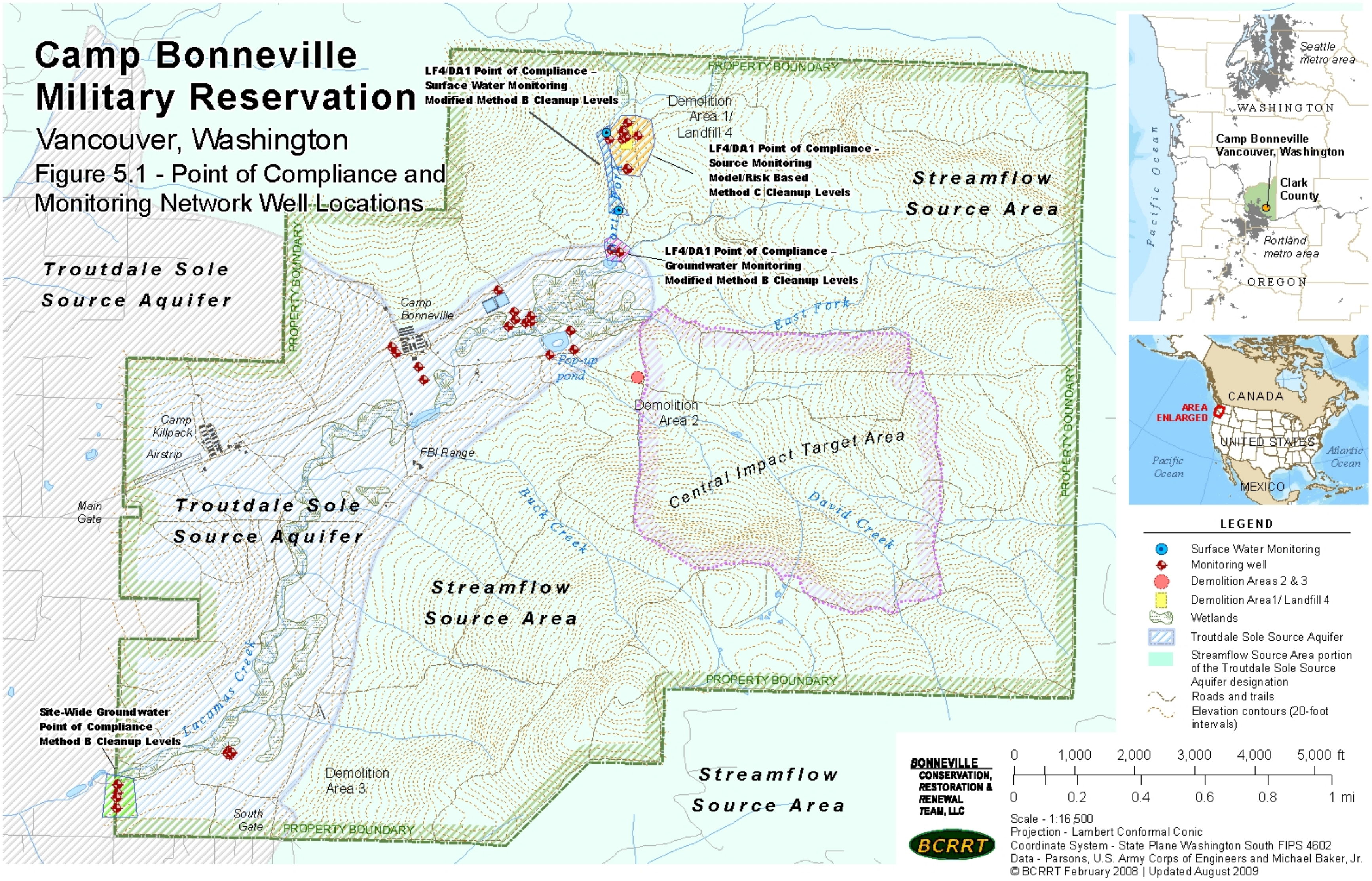
- Surface Water Monitoring - via two monitoring points located on the eastern stream bank of the North Fork of Lacamas Creek. This data will be compared to Method B Cleanup Levels to be protective of human and ecological receptors that may come in contact with Lacamas Creek both on and off-site.

Table 5-2. Summary of Points of Compliance and Applicable Cleanup Levels.

	Landfill 4/Demolition Area 1			**Site-Wide Groundwater**
Point of Compliance:	LF4MW 1A&B, LF4MW 2A&B, LF4MW 3A&B, LF4MW 4A, LF4MW 5A, and LF4MW 7B	Surface Water Monitoring Points	LF4MW 17 and LF4MW 18	LCMW 1A&B, LCMW 2A&B, LCMW 3A&B, and LCMW 4A&B
MTCA Cleanup Level:	Model/Risk Based Method C [1]	Modified Method B [2]	Method B	Method B
Perchlorate	1,300 ppb	600 ppb	11 ppb	11 ppb
RDX	95 ppb	59 ppb	0.8 ppb	0.8 ppb

Notes:
[1] Based upon the **Section 3.7.3.5** groundwater modeling and **Section 4** risk assessment criteria.
[2] Based upon the lowest cleanup level for Method B human health or ecologic receptors.

The following sections of this report consist of an abbreviated Feasibility Study that presents an evaluation of remedial technologies including a qualitative assessment of benefits and order of magnitude costs. The final section presents a detailed plan for monitoring the continued attainment of the above proposed cleanup levels and specifies the Site–Specific Institutional Controls to be implemented.


Camp Bonneville Military Reservation
Vancouver, Washington
Figure 5.1 - Point of Compliance and Monitoring Network Well Locations
LF4/DA1 Point of Compliance - Surface Water Monitoring Modified Method B Cleanup Levels
Demolition Area 1/ Landfill 4
LF4/DA1 Point of Compliance - Source Monitoring Model/Risk Based Method C Cleanup Levels
LF4/DA1 Point of Compliance - Groundwater Monitoring Modified Method B Cleanup Levels
Streamflow Source Area
Troutdale Sole Source Aquifer
PROPERTY BOUNDARY
Camp Bonneville
Pop-up pond
East Fork
Demolition Area 2
Central Impact Target Area
Camp Killpack
Airstrip
FBI Range
Buck Creek
David Creek
Main Gate
Lacamas Creek
Site-Wide Groundwater Point of Compliance Method B Cleanup Levels
Demolition Area 3
South Gate
Seattle metro area
WASHINGTON
Camp Bonneville Vancouver, Washington
Clark County
Portland metro area
OREGON
Pacific Ocean
CANADA
AREA ENLARGED
UNITED STATES
Atlantic Ocean
MEXICO
LEGEND
Surface Water Monitoring
Monitoring well
Demolition Areas 2 & 3
Demolition Area1/ Landfill 4
Wetlands
Troutdale Sole Source Aquifer
Streamflow Source Area portion of the Troutdale Sole Source Aquifer designation
Roads and trails
Elevation contours (20-foot intervals)
BONNEVILLE CONSERVATION, RESTORATION & RENEWAL TEAM, LLC
BCRRT
0 1,000 2,000 3,000 4,000 5,000 ft
0 0.2 0.4 0.6 0.8 1 mi
Scale - 1:16,500
Projection - Lambert Conformal Conic
Coordinate System - State Plane Washington South FIPS 4602
Data - Parsons, U.S. Army Corps of Engineers and Michael Baker, Jr.
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6.0 SCREENING OF CLEANUP TECHNOLOGIES

This section presents the screening of potentially applicable technologies to insure continued compliance with the cleanup standards specified in **Section 5.0**. The following technology categories have been developed:

- **Institutional Controls**: Institutional controls refer to a broad category of measures that can be used to limit or prevent contact with affected soils. These controls might include deed restrictions, permitting requirements, training programs, and use restrictions. Controls that may be applicable include signs, access restrictions (fences), land use restrictions, and runoff control.

- **Long-Term Monitoring**: Long-term monitoring of a site typically is performed to verify that contaminants pose no risk to human health or the environment and that natural processes are reducing contaminant levels and risk as predicted.

- **Containment (Capping)**: Containment for soil refers to a vertical physical barrier (soil cap) intended to reduce infiltration of rainwater through contaminated soil and to restrict direct contact with the soil. Capping would involve placing clean soil cover over the contaminated soil and leaving the contaminated soil in place. An impermeable cap of asphalt, concrete, or geomembrane, also satisfies the basic requirements of physical barriers described above and would further reduce the potential for infiltration of rainwater.

- **Passive Treatment**: An in-situ engineering intervention that prevents, diminishes, and/or treats contaminated groundwater using existing slope/hydraulic gradient with a biologic and/or chemical agent that requires only infrequent maintenance.

- **Active Groundwater Treatment**: Either an in-situ or ex-situ treatment that requires input of energy into the groundwater system (circulation, injection, and/or extraction) and frequent maintenance/monitoring to ensure effectiveness.

After performing an initial screening of alternatives as part of the Perchlorate Evaluations (see **Appendix D**); those technologies that merited further consideration are summarized on the following **Table 6.1**. This table also presents a screening of technologies for qualitative factors of permanence, human health and environmental benefits, order of magnitude cost, as well as general applicability factors.

6.1 Screening Rationale

The previous **Section 3.7.3, Section 4.2,** and **Section 5.0** have shown that since completion of the IRA/source removal, the current conditions at the site are meeting the applicable Method B and Method C Cleanup levels at the proposed Points of Compliance. **Table 6-1** illustrates that there is potentially significant cost, uncertain effectiveness, and little reduction in risk for the capping, passive treatment and active groundwater treatment technologies. Therefore, the only technologies moving forward to alternative evaluation are Institutional Controls and Long-Term Monitoring. These technologies were found to be the most appropriate and cost effective given the current site status which demonstrates compliance with the cleanup standards. Because there is no current or foreseeable future human health or environmental risk posed by the COC, the incremental costs for the active remediation technologies greatly exceed the incremental degree of benefits. Consequently, long-term monitoring combined with ICs provides the most practicable permanent cleanup option for the site. In addition, to the incremental costs for the other technologies there are some significant technical challenges involved with implementation at this site.

Any technology which relies on the injection of substrate or chemicals is extremely dependent on the hydrogeologic and geochemical properties of the aquifer and subsurface environment. Low permeability aquifers (10^{-5} cm/sec or less) or low groundwater velocities (less than 50 ft/yr) can complicate substrate delivery, resulting in insufficient amounts of reagent being dispersed into the treatment zone. In addition, the reagent can accumulate near the injection point, resulting in the formation of organic acids and low pH conditions that are detrimental to the naturally occurring microbes. Low permeability conditions can also lead to uneven application of the reagent, lack of sufficient or timely data during a pilot test, and the requirement for an unpractical number of injection points for a pilot- or full-scale application. As a point of comparison, the hydraulic conductivity value at LF-MW-2B was measured to be 1.6×10^{-5} cm/sec, determined from a step/drawdown test performed in this well. Based on this, the infiltration fluid's ability to sustain the reducing conditions within the perched aquifer is expected to be a major concern, since no guarantee can be made that the aquifer will accept the injection fluids at the quantity required.

Another point of concern is the geochemical state of the aquifer prior to any injection of reducing compounds (typically electron donors). Because the aquifer at LF4/DA1 is generally toxic (as reported in the ongoing quarterly groundwater reports) the injection quantities of the substrate will need to be increased in order to promote reduction in the aquifer to the point where microbial actions attack the compound in question. Because both situations exist, a low permeability aquifer matrix combined with a toxic geochemical state, there is a reduced likelihood of success using any injection technology designed to promote reducing conditions necessary for achieving remediation in the subsurface at LF4/DA.

Table 6-1 – Selected Technology Screening for LF4/DA1

Technology Category	Technology	Representative Unit or Annual	Degree of permanence	Implementability	Advantages	Disadvantages	Representative Implementation or Annual Cost	Representative total an/or Long-Term Cost	Human Health and Environmental Benefits	Forward to alternatives
	Technologies Meriting Further Consideration or Maybe Appropriate as Supplemental Technologies									
No Further Action	No Further Action	Stop current groundwater monitoring program and take no other actions for monitoring or cleanup	1[1]	Demonstrated technology	Low cost	Probably not acceptable to WADOE, Clark County, or public without persuasive risk assessment	None	None	Does not provide data for ongoing review of site conditions for assessing continued compliance with cleanup standards.	No
Institutional Controls	Site-Specific Institutional Controls	Implement and enforce institutional controls as land and groundwater use restrictions covering LF 4/DA 1 and impacted groundwater	1[1]	Demonstrated technology	Low cost	Not acceptable to WADOE, Clark County, or public as sole approach.	$20,000 per yr [2]	$400,000	Does not provide data for ongoing review of site conditions for assessing continued compliance with cleanup standards	Yes
Long-term Monitoring	Long-Term Groundwater Monitoring	Continue the current groundwater monitoring program	2[1]	Demonstrated technology	Low cost	Dependent on subsequent actions by Clark County following transfer.	$25,000 per yr [2]	$500,000	Will provide data for ongoing review of site conditions for assessing continued compliance with cleanup standards	Yes
		Expand the groundwater monitoring program, possibly with the reopening of some existing wells and/or the development of some additional wells							Will provide data for ongoing review of site conditions for assessing continued compliance with cleanup standards	Yes
Containment	Regrading and Run-Off/Drainage Improvements Over and Around Fill Area	Focused earthwork effort to recontour the fill area to promote precipitation run-off and to divert uphill run-on away from the fill area	3[1]	Demonstrated technology	Low cost Can be implemented with locally available personnel, equipment and supplies.	Appropriate only as a supplement to other actions.	$225,000	$1,125,000	Will not provide data for ongoing review of site conditions for assessing continued compliance with cleanup standards. Will not provide any additional benefit as the site currently meets cleanup standards.	No
	Capping	Placement of geomembrane materials as a cover over the area of LF 4/DA 1 to minimize infiltration and groundwater recharge through any remaining contaminated soils	3[1]	Demonstrated technology	Effective engineering control. Can be implemented with locally available personnel, equipment and supplies.	Partially effectiveness as it only controls surface infiltration.	$492,000	$1,392,000	Will not relieve long-term monitoring responsibilities. Will not provide data for ongoing review of site conditions for assessing continued compliance with cleanup standards. Will not provide any additional benefit as the site currently meets cleanup standards.	No

Table 6.1 – Selected Technology Screening for LF4/DA1 (continued)

Passive Treatment	Reactive Biological Barrier (Holistic Groundwater In-Situ Biological)	Installation of a anaerobic biologically active barrier (trench) utilizing chemicals and nutrients to produce in-situ dissolution of COCs	4[1]	Demonstrated applicability, dependent on site-specific conditions	Destructive technology with benign wastes.	Site topography and proximity of Lacamas Creek may preclude use of this approach. Bench or pilot scale testing may be required	$615,000	$1,265,000	Will not relieve long-term monitoring responsibilities. However, groundwater monitoring duration may be lessened. Assume 10 years of monitoring. Will not provide any additional benefit as the site currently meets cleanup standards.	No
	Reactive Chemical Barrier (Holistic Groundwater In-Situ Chemical)	Installation of chemical reaction barrier (trench) utilizing zero-valent iron(ZVI) to produce in-situ dissolution of COCs	4[1]	Demonstrated applicability dependent on site-specific conditions	Destructive technology with no ex-situ waste management. May be effective in granular soils used for backfill at site.	Site topography and proximity of Lacamas Creek may preclude use of this approach. Bench or pilot scale testing may be required	$645,000	$1,295,000	Will not relieve long-term monitoring responsibilities. However, groundwater monitoring duration may be lessened. Assume 10 years of monitoring. Will not provide any additional benefit as the site currently meets cleanup standards.	No

Table 6.1 – Selected Technology Screening Summary for LF4/DA1 (continued)

Active Groundwater Treatment	Anaerobic Bioremediation by Nutrient Injection (Source Area In-Situ Biological)	Injection of nutrients to the remaining source area, possibly with an oxygen-displacement gas (nitrogen), to create an anaerobic environment with enhanced biological activity to produce in-situ dissolution	4[1]	Applicable to the COC however, dependent on site-specific conditions.	Destructive technology. No external wastes. Allows "shock treatment" approach for rapid response. May be effective in backfill previously placed at this site.	Effectiveness is site-specific and determined by contaminant levels and distribution and by chemical and physical characteristics of site soils and groundwater	$520,000	$1,170,000	Will not relieve long-term monitoring responsibilities. However, groundwater monitoring duration may be lessened. Assume 10 years of monitoring. Will not provide any additional benefit as the site currently meets cleanup standards.	No
	Reducing Reagent Injection (Source Area In-Situ Chemical)	Injection of one or more reducing agents to produce in-situ dissolution of perchlorates to dissolved metal(s), chlorine, and oxygen	4[1]	Applicable to the COC however, dependent on site-specific conditions.	Destructive technology No external wastes Allows "shock treatment" approach for rapid response. May be effective in backfill previously placed at this site	Regulatory resistance to chemical injection Unproven technology for ClO4. Effectiveness is site-soil dependent.	$925,000	$1,375,000		No
	Sodium Lactate Injection (Source Area In-Situ Biological)	Injection of sodium lactate to the remaining source area, possibly with an oxygen-displacement gas (nitrogen), to create an anaerobic environment with enhanced biological activity to produce in-situ dissolution	4[1]	Applicable to the COC however, dependent on site-specific conditions.	Destructive technology No external wastes Allows "shock treatment" for rapid response. May be effective in backfill previously placed at this site	Effectiveness is site-specific and determined by contaminant levels and distribution and by chemical and physical characteristics of site soils and groundwater	$5,000,000	$5,000,000		No

NOTE: 1. NUMBER INDICATES LOWEST (1) TO HIGHEST (4) DEGREE OF PERMANENCE.
2. INCLUDED AS AN ALLOWANCE FOR THIS ACTIVIETY AS A NET PRESENT VALUE IN THE ESCA.

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7.0 CLEANUP ACTION ALTERNATIVE EVALUATION

This section presents the cleanup action alternative determined to be appropriate based on the selected technologies screening in **Section 6.0** and presents an evaluation of this alternative with respect to the selection criteria shown below:

- Threshold requirements (WAC 173-340-360 (2) (a)
  - Protect human health and the environment
  - Comply with applicable cleanup standards
  - Comply with applicable state and federal laws
  - Provide for compliance monitoring

- Other requirements (WAC 173-340-360 (2) (b)
  - Use permanent solutions to the maximum extent practical
  - Provide for a reasonable restoration time frame
  - Consider public concerns

7.1 Description of Alternative

This alternative consists of an expanded groundwater and surface water monitoring program that would include the current network of monitoring wells and one additional new well; sampling locations are shown in **Figure 5.1**. Groundwater and surface water sampling would be conducted initially on a quarterly basis and chemically analyzed for RDX and perchlorate. ICs would restrict groundwater usage in the vicinity of LF4/DA1 and designate acceptable land uses and restrictions on use. Reports would be prepared and submitted to Ecology within 30 days of receipt of the analytical data.

7.2 Threshold Requirements:

7.2.1 Protection of Human Health and the Environment: The institutional controls are a key component of this alternative. The ICs will insure that no potable water wells are installed in areas affected by the COC and land use remains as the Wildlife Refuge. The groundwater monitoring program would provide the data necessary to insure continued compliance with the cleanup standards and coincidentally continued low potential risk to human health or the environment posed by the COCs.

7.2.2 Compliance with Cleanup Standards: This alternative will demonstrate compliance with the cleanup standards by collecting numerical values of COCs in groundwater and surface water at the conditional compliance points.

7.2.3 Compliance with Applicable Laws: Deed restrictions and zoning changes would have to be implemented in accordance with local, county, and state laws and regulations.

7.2.4 Provision of Compliance Monitoring: Monitoring of the condition of institutional controls would be required to confirm the condition and effectiveness of the control measures. The long-term monitoring would constitute compliance monitoring.

7.3 Other Requirements:

7.3.1 Permanent Solution to the Maximum Extent Practicable: This alternative will result in the reduction of the toxicity but not the mobility or volume of site COCs. The toxicity will be reduced by natural attenuation to concentrations that pose no threat to human health or the environment.

7.3.2 Provide for Cleanup in a Reasonable Restoration Time Frame: This requirement lists the following factors for completing this evaluation.

- Potential risks to human health and the environment
- Practicality of achieving a shorter restoration time frame
- Current uses of the site and surrounding areas
- Potential future uses of the site
- Availability of alternative water supplies
- Likely effectiveness and availability of institutional controls
- Control of migration of hazardous substances from the site
- Toxicity of the hazardous substances
- Potential for natural attenuation of the hazardous substances

Many of these factors have been previously discussed in this report and in these cases they will only be addressed in an abbreviated manner herein.

- Potential risks to human health and the environment is currently and expected to continue to be low. This remedial alternative has been specifically designed to provide the data necessary to insure continued compliance with the cleanup standards.

- The practicality of achieving a shorter restoration time frame is addressed in section 6.0, in which it is concluded that based on the current low risk potential the incremental costs of implementing another alternative is not practicable.

- The site is currently part of the closed military facility and is not used for any residential or commercial purposes. The future use would be as part of the Wildlife Management Area.

- The availability of alternative water supplies is not an issue as the three water supply wells located at the site are not impacted and unlikely to become affected by the COC at LF4/DA1 due to their locations and depths.

- Institutional controls are already in place on a site-wide basis and would restrict land use and provide educational material to park visitors regarding the former uses of the facility and potential hazards. The ICs associated with this remedial action would restrict potable well installation, provide signage, and stipulate land use restrictions.

- During the soil excavation conducted at LF4/DA1 the bulk of the source soils were removed and no longer provide a continuing source of contaminants to the groundwater. This action has contributed significantly to controlling the migration of COC from the LF4/DA1 site. Based on the groundwater modeling presented in this report the COC are not predicted to reach the property boundary and thus would not migrate from the site.

- The toxicity of the COC is discussed in detail in the risk assessment portion of this report.

- The COC at the LF4/DA1 site have the ability to biologically and chemically degrade under the proper conditions, it is also reasonable to assume that dilution and dispersion as a means of attenuating the COC is also occurring.

7.3.3 Consideration of Public Concerns

This criterion would be addressed after the report has been issued and made available for public review and comment. Factors to be considered in evaluating this criterion included the following:

- Public comments received during public participation activities mandated under MTCA. Concerns expressed verbally or in writing by local officials (e.g. Clark County) or members of local non-governmental organizations representing the interests and concerns of the local community.

- Comments and guidance from federal and state officials regarding compliance with applicable laws and regulations, risk issues, and implementation of cleanup action alternatives.

7.4 Site-Wide Groundwater Compliance Monitoring

As required as part of the long term obligations of the site groundwater monitoring will be performed based upon the following:

7.4.1 Site-Wide and LF4/DA1 Groundwater Sampling

Based on the rationale proved in **Section 6.1**, BCRRT is proposing the following parameters be collected as part of the Long-Term groundwater monitoring:

Table 7-1 Recommended Points of Compliance Sampling

	Landfill 4/Demolition Area 1 [1]			**Site-Wide Groundwater** [2]
Point of Compliance:	LF4MW 1A&B, LF4MW 2A&B, LF4MW 3A&B, LF4MW 4A, LF4MW 5A, and LF4MW 7B	Surface Water Monitoring Points	LF4MW 17 and LF4MW 18	LCMW 1A&B, LCMW 2A&B, LCMW 3A&B, and LCMW 4A&B,
Sample Frequency	Model/Risk Based Method C Cleanup Levels	Modified Method B	Method B Cleanup Levels	Method B Cleanup Levels
Quarterly	Perchlorate	Perchlorate	Perchlorate	
	RDX	RDX	RDX	
Annually				Explosives with perchlorate and RDX
				Water elevation, temperature, specific conductivity, dissolved oxygen, pH, and oxidation reduction potential
				Total Priority Pollutant (PP) Metals
				Semi-Volatile Organic Compounds (SVOCs)
				Poly-Aromatic Hydrocarbons (PAHs/ Low Level)
				pH

Notes:

[1] The LF4/DA1 wells and surface water monitoring points will be sampled quarterly until a decreasing trend of perchlorate and RDX for 4 quarters. Once this is reached, the sampling would be reduced to semi-annual for 3 years. If the decreasing trend continues, then sampling would be reduced to annual sampling until MTCA cleanup levels are achieved.

[2] The Site-Wide Groundwater Sentinel wells will be sampled annually for 10 years. If a decreasing trend of all COCs continues at the LF4 wells and no COC is detected at the Sentinel Wells, then the sampling could be reduced to once every 5 years until MCTA compliance is achieved.

7.4.2 Development of Long-Term Monitoring and Contingency Plan

BCRRT will prepare a Long-Term Monitoring and Contingency Plan (LTM&CP, per the PPCD) that will serve both as a Cleanup Action Plan (CAP, per WAC 173-340-380) and as a Compliance Monitoring Plan (CMP, per WAC 173-340-410) for Site-Wide Groundwater.

The LTM&CP will detail the data gathering, analysis, statistical method for data evaluation, and reporting requirements as well as contingency plans in the event that the Point of Compliance monitoring results increase or fail to meet MTCA requirements.

This Plan will be developed to provide Ecology and the public with additional confidence in the protectiveness and permanence of the selected remedy. For example, the Plan could specify that if any detection of COCs is found in wells LF-MW-18 or LF-MW-17 the on-site potable supply wells will be sampled for confirmed detections of COCs.

7.4.3 Establishment of Site-Specific Institutional Controls

BCRRT proposes to provide Ecology and the public with additional confidence in the protectiveness and permanence of both human and ecological receptors to the only potentially complete exposure pathway by placing deed restrictions for the following Site-Specific Institutional Controls:

- Groundwater production wells and groundwater consumption will not be allowed the LF4/DA1 area.
- Subsurface excavation will not be allowed to prevent potential exposure of residual impacted soils or creation of preferential pathways and/or flushing of same.
- Land use will be restricted with a ban on structures, publicly accessible trails, and only conservation based activities as part of the Wildlife Management Area.

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There are appendices available for this document but not included here due to size restrictions. Please contact Ecology for copies of these appendices.

Appendix A: NFA's (these are already in our Document Repository) DSARS
Appendix B: Groundwater Reports
Appendix C: Soil and Sediment Report
Appendix D: Perchlorate Evaluation
Appendix E: Groundwater Evaluation