Office of Solid Waste and
Emergency Response
(5102G)

EPA-540-R-11-020
October 2010
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Remediation System Evaluation
Colbert Landfill Superfund Site

Spokane County, Washington

REMEDIATION SYSTEM EVALUATION

COLBERT LANDFILL SUPERFUND SITE
SPOKANE COUNTY, WASHINGTON

Report of the Remediation System Evaluation
Site Visit Conducted at the Colbert Landfill Superfund Site
April 13, 2010

Final Report
October 14, 2010

NOTICE

Work described herein was performed by GeoTrans, Inc. (GeoTrans) for the U.S. Environmental Protection Agency (U.S. E.P.A). Work conducted by GeoTrans, including preparation of this report, was performed under Work Assignment #48 of EPA contract EP-W-07-078 with Tetra Tech EM, Inc., Chicago, Illinois. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

This report was prepared as part of a project conducted by the United States Environmental Protection Agency Office of Superfund Remediation and Technology Innovation (U.S. EPA OSRTI). The objective of this project is to conduct independent, expert reviews of soil and groundwater remedies with public funding with the purpose of optimizing the remedy for protectiveness, cost-effectiveness, and sustainability. The project contacts are as follows:

Organization	Key Contact	Contact Information
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1.0INTRODUCTION

1.1 PURPOSE

During fiscal years 2000 and 2001 independent reviews called Remediation System Evaluations (RSEs) were conducted at 20 operating Fund-lead pump and treat (P&T) sites (i.e., those sites with pump and treat systems funded and managed by Superfund and the States). Due to the opportunities for system optimization that arose from those RSEs, EPA OSRTI has incorporated RSEs into a larger post-construction complete strategy for Fund-lead remedies as documented in *OSWER Directive No. 9283.1-25, Action Plan for Ground Water Remedy Optimization*, and has also started conducting RSEs at some PRP-lead sites. A strong interest in sustainability has also developed in the private and public sector. Consistent with this interest, OSRTI has developed a Green Remediation Primer (http://cluin.org/greenremediation/) and as a pilot effort now considers green remediation during independent evaluations.

The RSE process involves a team of expert hydrogeologists and engineers that are independent of the site, conducting a third-party evaluation of the operating remedy. It is a broad evaluation that considers the goals of the remedy, site conceptual model, available site data, performance considerations, protectiveness, cost-effectiveness, closure strategy, and sustainability. The evaluation includes reviewing site documents, potentially visiting the site for one day, and compiling a report that includes recommendations in the following categories:

- Protectiveness
- Cost-effectiveness
- Technical improvement
- Site closure
- Sustainability

The recommendations are intended to help the site team identify opportunities for improvements. In many cases, further analysis of a recommendation, beyond that provided in this report, may be needed prior to implementation of the recommendation. Note that the recommendations are based on an independent evaluation, and represent the opinions of the evaluation team. These recommendations do not constitute requirements for future action, but rather are provided for consideration by the Region and other site stakeholders.

The Colbert Landfill Superfund Site was selected by EPA OSRTI based on a nomination from EPA Region 10. The site is located approximately 2.5 miles north of Colbert, Washington, and approximately 15 miles north of Spokane, Washington. Contaminants of concern in groundwater are specific volatile organic compounds (VOCs):

- 1,1,1-Trichloroethane (TCA)
- 1,1-Dichloroethene (DCE)
- 1,1-Dichloroethane (DCA)
- Trichloroethene (TCE)

- Tetrachloroethene (PCE)
- Methylene Chloride (MC)

There have also been low levels of 1,4-Dioxane observed in groundwater. The groundwater remedy includes a pump-and-treat (P&T) system as well as components of landfill post-closure (e.g., landfill cap, landfill gas system) that serve to reduce contaminant source loading to groundwater over time. The remedy has also included the provision of an alternate water supply to impacted residents plus institutional controls. The RSE provides an opportunity for an independent third-party review of these remediation efforts.

1.2 TEAM COMPOSITION

The RSE team consisted of the following individuals:

Name	Affiliation	Phone	Email
Peter Rich	GeoTrans, Inc.	410-990-4607	prich@geotransinc.com
Rob Greenwald	GeoTrans, Inc.	732-409-0344	rgreenwald@geotransinc.com

In addition, the following individuals from EPA Headquarters participated in the RSE site visit.

- Jennifer Hovis
- Jennifer Edwards

1.3 DOCUMENTS REVIEWED

The following documents were reviewed. The reader is directed to these documents for additional site information that is not provided in this report.

- Fourth Five Year Review Report (USEPA Region 10) – September 2009
- Quarterly Progress Reports (Spokane County)
    - Second Quarter 2009
    - Fourth Quarter 2008
    - Third Quarter 2008
    - Second Quarter 2008
    - First Quarter 2008
- Map showing layout of landfill gas system (CH2MHill) and spreadsheet with landfill gas concentrations over time
- Operation and Maintenance Manual (Landau Associates, Inc.), December 15, 1999
- Operations and Maintenance Manual for Colbert Landfill Closure (CH2MHILL) – May 1997
- Final Extraction Well Plan – Phase II Remedial Design/Remedial Action (Landau Associates, Inc.) – August 7, 1992

- Final Phase 1 Engineering Report: Volume 1 of 3 (Landau Associates, Inc.) - December 30, 1991

- Scope of Work for Remedial Action to Address Groundwater Contamination Emanating from Colbert Landfill (also referred to as the "Consent Decree") - September 27, 1988

- Record of Decision (downloaded without figures) – September 29, 1987

In addition, Deb Geiger from Spokane County forwarded information via email after the RSE site visit regarding electrical usage and costs, estimated labor costs for system operation and project management (for County personnel), specific capacity values at extraction wells, recent water level maps, gas probe locations, results of field gas concentrations at the blower over time, and annual VOC analyses for extracted landfill gas (before and after the vapor GAC units).

1.4 PERSONS CONTACTED

The following individuals associated with the site were present for the visit:

Name	Affiliation	Phone	Email
Piper Peterson Lee (RPM)	U.S. EPA Region 10	206-553-4951	peterson-lee.piper@epa.gov
Bernie Zavala	U.S. EPA Region 10		
Michael Kuntz	Washington Dept. of Ecology		
Deb Geiger	Spokane County		
Bill Wedlake	Spokane County		
Larry Beard	Landau Associates		

Spokane County operates the remedy, and Landau Associates is a consultant to Spokane County.

1.5 BASIC SITE INFORMATION AND SCOPE OF REVIEW

1.5.1 LOCATION

Colbert Landfill is located approximately 2.5 miles north of Colbert, Washington, and approximately 15 miles north of Spokane, Washington (see Figure 1 from the Fourth Five Year Review Report, included in Attachment A of this report). The closed landfill is bounded by Elk-Chattaroy Road on the east and Big Meadows Road on the south. Groundwater impacts associated with the site extend west to the Little Spokane River, which is approximately 3,000 feet to the west of the closed landfill. Groundwater impacts associated with the site also extend more than 1 mile to the south of the closed landfill. There are also groundwater impacts that extend up to several thousand feet north and east of the closed landfill, though the exact cause of the impacts north and east of the landfill are not fully understood.

The closed landfill is surrounded primarily by residential developments and open lands. The area south of the site contains forested lands, open fields, and a few residential homes. The Spokane County Recycling Center and Transfer Station is located immediately west of the treatment facility. There are residences located within the footprint of the groundwater plume (i.e., beyond the landfill) in all directions around the landfill.

1.5.2 SITE HISTORY, POTENTIAL SOURCES, AND RSE SCOPE

The 1987 ROD and the Fourth Five-Year Review (September 2009) provides the following information:

- The landfill operated from 1968 to 1986. During a five year period between 1975 and 1980 the Landfill accepted solvent and other chemical waste from Key Tronic Corporation (a local electronic manufacturing company) and Fairchild Air Force Base (FAFB). Typically these wastes were delivered to the landfill in 55-gallon drums and were subsequently poured into open trenches to mix with the soil or ordinary municipal refuse already in the trench. According to Table 1 of the ROD, the solvents from Key Tronic were methylene chloride and 1,1,1-TCA, and the solvents from Fairchild Air Force Base were methyl ethyl ketone, poly thinner, enamel thinner, toluene, paint remover, and primer wastes.

- In 1980, nearby residents complained to the Eastern Regional Office of the Washington Department of Ecology (Ecology) about the chemical disposal practices. EPA and Ecology along with Spokane County Utilities Department conducted an investigation into these complaints by initiating a groundwater sampling study of nearby domestic water wells. Twenty domestic water wells had samples with contaminants at concentrations above drinking water standards which could in part be traced to the spent solvents disposed of at the landfill.

- Following the initial domestic groundwater sampling investigation, Phase I and II studies resulted in the installation of monitoring wells, injection testing, and development of a groundwater monitoring program. In 1983, EPA placed the Colbert Landfill on the National Priorities List (NPL) and identified Spokane County, Key Tronic Corporation and FAFB as potentially responsible parties (PRP). In 1984, Ecology entered into a cooperative agreement with EPA for conducting a Remedial Investigation/Feasibility Study (RI/FS). During that same year, bottled water was supplied to some of the households with high contamination levels in their water wells. In 1985, the County extended the Whitworth Water District public water supply main to affected households where concentrations of contaminants were greater than Maximum Contaminant Levels (MCLs), and the hookup was subsidized by the PRPs if the resident was less than 500 feet from a water supply main, and the resident signed a hold-harmless agreement. Other residents who did not meet these conditions elected to receive this water supply at their own expense.

- The final RI report was completed in May 1987, and the final FS report was submitted for public comment in May 1987. On September 29, 1987, EPA issued the Record of Decision (ROD) which selected an interim final remedy for the site based on the Remedial Investigation/Feasibility Study (RI/FS). The selected remedy included a pump and treat (P&T) system for water, connection to public water for residences negatively impacted by site contaminants and/or the groundwater remedy, institutional controls, and landfill closure and post-closure maintenance (e.g., capping, landfill gas management, monitoring, etc.).

- During the RSE site visit it was stated that there is some disagreement among the site stakeholders if the 1987 ROD was "interim". The RSE team notes that the term "interim final remedial action" is used in ROD Section VI (Selected Remedy), and the term "interim final ROD" is used in the State concurrence letter (Appendix C of the 1987 ROD). Additionally, section VI of the ROD refers to a future "final ROD" with respect to evaluating the closure of the landfill. These examples suggest this was intended as an interim ROD.

- On January 23, 1989, a Consent Decree between EPA, Ecology, Spokane County and Key Tronics Corporation was lodged in federal court. Fairchild Airforce Base contributed waste to the landfill; however, they were not a party to this Consent Decree. On February 28, 1989, the Decree was entered by the Court. The Decree addressed implementation of remedial actions specified in the 1987 ROD.

This RSE includes a holistic third-party review of overall site remedy.

1.5.3 HYDROGEOLOGIC SETTING

The hyrdrogeology of this site is extremely complex. The interpretation of the hydrogeologic system presented in the ROD (1987) was subsequently updated in the Final Phase 1 Engineering Report by Landau Associates, Inc. (1991), and the reader is referred to that document for the most detailed description of the hydrogeologic system. A series of cross-sections provided in the Phase 1 Engineering Report (1991) are included in Attachment A of this RSE report. Key components of the hydrogeologic system in the vicinity of the Colbert Landfill are described below.

The geology consists of vertically stratified and laterally discontinuous geologic units derived from glacial material, modified by erosional (and possibly landslide) process, overlaid on granitic bedrock. There are two primary aquifers (according to the fourth five-year review, the primary aquifers would be classified as drinking water sources according to the EPA groundwater classification system):

- The *upper aquifer* is unconfined and consists of a sand and gravel unit that extends from the eastern hills west to the bluffs of the Little Spokane River. Groundwater flow in the upper aquifer is predominantly toward the southwest and south (see January 2010 water level map for upper aquifer prepared by Spokane County in Attachment A), towards a discharge point well south of the landfill. The fluvial unit associated with the Little Spokane River (west of the landfill) receives some recharge from the upper aquifer, and there are some springs reportedly present on the bluff adjacent to the Little Spokane River. The Phase 1 Engineering Report (1991) stated that pump testing performed at extraction well CP-S1 indicated transmissivity of 10,000 to 12,000 ft^2/d, and hydraulic conductivity of 530 to 640 ft/day (using approximate saturated thickness of 19 ft). This represents very conductive aquifer material.

- The l*ower aquifer* is confined to the west of the landfill and unconfined to the east of the landfill. To the west of the landfill, the upper and lower aquifers are separated by the lacustrine unit which causes the confined conditions in that area. The lower aquifer consists of sands and gravels. Groundwater flow in the lower aquifer is predominantly toward the west (see January 2010 water level map for lower aquifer prepared by Spokane County in Attachment A), with discharge to the Little Spokane River. The Phase 1 Engineering Report (1991) stated that pump testing performed at extraction well CP-W1 indicated transmissivity of 30,000 to 40,000 ft^2/d, and hydraulic conductivity of 170 to 230 ft/day (using approximate saturated thickness of 175 ft). The Phase 1 Engineering Report (1991) stated that pump testing performed at extraction well CP-E1 indicated transmissivity of 10,000 to 14,000 ft^2/d, and hydraulic conductivity of 100 to 140 ft/day (using approximate saturated thickness of 100 ft). These values for hydraulic conductivity also represent very conductive aquifer material.

The lacustrine unit, which consists of silt and clay with sand interbeds, pinches out under the eastern portion of the landfill, and where it is not present the upper and lower aquifers are connected. West of the landfill, where the lacustrine unit is present, the water levels in the upper aquifer are nearly 100 ft higher than in the lower aquifer.

Other stratigraphic units that are illustrated on the cross-sections in Attachment A (for instance, section B-B' and C-C') include the following:

- *Latah Formation and Weathered Latah.* The Latah Formation consists of fine-grained lacustrine sediments that overlie the granitic bedrock. The Basalt Unit (described below) is interbedded within the Latah Formation. The Weathered Latah, where present, overlies the Latah formation and consists of weathered material from the Latah Formation and also weathered material from the basalt that is contained within the Latah Formation. In some places the Latah/Weathered Latah are below the lower aquifer, and in other places the lower aquifer is absent and the Latah/Weathered Latah are below the upper aquifer.

- *Basalt Unit.* Interbedded within the Latah Formation, these basalts form secondary aquifers that appear to be of limited extent. One of the remedy extraction wells (CP-E2) is completed in the basalt. The Phase 1 Engineering Report (1991) stated that pump testing performed at extraction well CP-E2 indicated transmissivity of 25 ft^2/d, and hydraulic conductivity of 0.7 ft/day (using approximate saturated thickness of 35 ft). These parameter values are much lower than for the upper aquifer and lower aquifer, and limit the rate at which groundwater can be extracted.

- *Granite*. This represents the bedrock unit. As illustrated on the cross sections in Attachment A, the granite bedrock is several hundred feet below ground surface in the vicinity of the landfill.

The discontinuous nature of the lacustrine unit, the lower aquifer, and the other units (Latah/Weathered Latah/bedrock) makes the hydrogeology extremely complex, and has impacted the contaminant distribution and remedy design.

1.5.4 POTENTIAL RECEPTORS

Based on discussions during the RSE site visit, the primary potential receptors are groundwater users. Residents whose wells have been impacted by the site have reportedly been provided alternate water and the Spokane County Health Department has procedures in place to detect any wells installed as part of a new development (discussed in Section 4.2.3 and Section 5.1).

The fourth five-year review summarized the potential for impacts due to vapor intrusion. It stated that the current landfill gas management system would prevent this pathway for indoor air in residences or businesses adjacent to the landfill. With respect to areas away from the landfill, the fourth five-year review included a screening level analysis using the Johnson and Ettinger (J&E) Vapor Intrusion Model, and concluded that the concentrations of COCs in groundwater in the upper aquifer do not appear to pose a risk to indoor air. The RSE team reviewed these calculations and agrees with the conclusion that the vapor intrusion pathway does not appear to be a concern. The J&E model incorporates a groundwater concentration value at the top of the groundwater surface that attenuates via several mechanisms in the distance between the water table and the structure, and the larger that distance, the lower the impact due to vapor intrusion will be in the structure (for a specific concentration in groundwater). The J&E calculations in the five-year review very conservatively used a groundwater depth of only three feet (which is the case immediately adjacent to the Little Spokane River). The RSE team notes that depth to groundwater in the upper aquifer is generally on the order of 80 to 90 ft. Even using the conservatively small depth to water, the J&E results in the five-year review suggested for most COCs that concentrations in the upper aquifer would need to be orders of magnitude higher than are actually observed in the upper aquifer (e.g., the threshold concentration for 1,1,1-TCA was greater than 5,000 ug/l). The two constituents with relatively low threshold concentrations were PCE (~1 ug/l) and TCE (~ 5 ug/l). However, based on the groundwater data presented in Attachments 3 to 5 of the five-year review (Compliance Monitoring Wells, Compliance Extraction Wells, and MFS Wells) the concentrations of PCE and TCE are below these threshold levels in the upper aquifer. Coupled with the conservatively shallow depth to groundwater utilized for the J&E analysis, the RSE team does not feel that vapor intrusion is a concern.

1.5.5 DESCRIPTION OF GROUNDWATER PLUME

The primary site contaminants are VOCs. The observed VOC concentrations have not been high enough to suggest the presence of any significant free product (i.e., concentrations in groundwater are well below one percent of the aqueous solubility of each COC). As stated earlier, the complex hydrogeology at the site has led to a complex distribution of contaminants. The pre-remedy plume extended to the southwest and south of the landfill in the upper aquifer, and primarily to the west of the landfill in the lower aquifer.

Concentrations of VOCs in the upper aquifer are very low (i.e., close to cleanup standards), and the groundwater extraction wells in the upper aquifer associated with the remedy (located more than one mile south of the landfill) have been shut off for several years. Concentrations of VOCs in the lower aquifer are higher than in the upper aquifer. Figures 27 to 29 from the fourth five-year review are included in Attachment A, and represent results from the 2007 “supplemental monitoring” at lower aquifer wells for PCE, DCE, and TCE. These figures provide a general summary of the concentration distribution in the lower aquifer. It is particularly noteworthy that some of the highest concentrations in the lower aquifer are found east and south of the landfill, which seem to be upgradient from the landfill in that aquifer. Based on discussion during the RSE site visit, it is not certain why this occurs.

Low concentrations of 1,4-Dioxane, which was frequently used as a stabilizer for TCA, have also been detected in groundwater within the footprint of the VOC plume. That chemical is often found in association with TCA, and it is likely associated with the solvents disposed of in the landfill. There is currently no attempt made at the site to actively capture and treat groundwater with 1,4-Dioxane levels above standards (i.e., in locations beyond the capture zone of the P&T system); rather, if 1,4-Dioxane is found at supply wells the approach is for Spokane to provide bottled water and then pay for a hook-up to public water. This approach for 1,4-Dioxane is essentially the same approach that is used in the domestic well program for the other site COCs.

2.0 SYSTEM DESCRIPTION

The primary active components of the groundwater remedy include the following:

- A P&T system that began operation in May 1994, and has consisted of three separate extraction systems (only two of which are now operating). Extracted water is conveyed to a treatment plant with an air stripper that is located at the closed landfill, and treated water is discharged to surface water (Little Spokane River).

- Landfill post-closure components (e.g., landfill cap, landfill gas system) that serve to reduce contaminant source loading to groundwater over time.

These active remedy components are discussed in more detail below. As discussed earlier, the remedy has also included alternate water supply to impacted residents plus institutional controls.

2.1 GROUNDWATER EXTRACTION SYSTEMS

The remedy has included three groundwater extraction systems (locations indicated on Figure 3-2 from the O&M Manual which is included in Attachment A):

- West System – Consists of three extraction wells (CP-W1 to CP-W3) screened in the lower aquifer, intended to provide hydraulic containment at the western edge of the closed landfill. Extraction well CP-W1, which is located southwest of the closed landfill, was shut down in January 2005 because it achieved low concentrations of target COCs. The remaining two west system extraction wells currently pump on the order of 400 to 450 gpm combined.

- East System – Consists of three extraction wells (CP-E1 to CP-E3) screened in lower aquifer and/or weathered basalt/Latah, intended to remove groundwater with highest concentrations located near the eastern edge of the closed landfill. CP-E1 and CP-E3 currently pump on the order of 225 to 250 gpm combined. CP-E2 is screened in the basalt and has a much lower pumping rate (approximately 0.5 to 2 gpm).

- South System (shut down since June 2004 due to low concentrations) – Consists of four extraction wells (CP-S1 and CP-S4 to CP-S6) located more than one mile south of the closed landfill, screened in the upper aquifer, and intended to control contaminant migration to the south of those wells. During the 2006 fourth quarter groundwater monitoring event, water from one of the south system extraction wells had a TCE concentration of 3.3 ug/L, which is just over the “adjustment criteria” that is used to determine when wells can be shut off (discussed later). This well was reactivated and ran until January 2007 when concentrations of TCE decreased to below the adjustment criteria. All of the south extraction wells have been on standby since that date (and are sampled quarterly).

The extracted groundwater from each system is conveyed through a PVC piping system (illustrated on Figure 3-2 from the O&M Manual which is included in Attachment A) to a treatment facility located in the southwest corner of the Landfill property.

2.2 GROUNDWATER TREATMENT SYSTEM

This is a relatively simple treatment system that consists of an air stripper that removes VOCs from the groundwater. The O&M manual indicates the air stripper is capable of treating up to 1600 gpm, though recent flow rates for this system have been lower (currently on the order of 650 gpm). The air stripper has a 50 Hp blower with a motor controlled by a variable frequency drive (VFD) such that less electricity is used when the motor is throttled down, and during the RSE site visit the system operator indicated that the stripper operates at approximately 15 Hz (or approximately 10 HP). A scale control chemical (NALCO 8357, shipped from Carson, CA) is added to the water at a rate of 20 ml diluted solution per 1000 gallons of water (the diluted solution is 1 part scale inhibitor to 7 parts water). There is also a small tank near the air stripper that was intended for use with disinfection chemicals, but those have only been used once.

There is no vapor treatment for the stripped VOCs. It was stated during the RSE site visit that there were no permit issues for discharged vapors based on the original flow rates and concentrations, and the current system has lower flow rates and lower concentrations. Treated groundwater is discharged via gravity to the Little Spokane River through an underground 12-inch diameter PVC pipeline.

2.3 COMPONENTS ASSOCIATED WITH LANDFILL POST-CLOSURE

2.3.1 LANDFILL COVER

The landfill cover (approximately 32 acres), installed in 1996, consists of one 60 mil (0.06” or 1.52mm) thick High Density Polyethylene (HDPE) membrane installed over a 6 in. subgrade of prepared native material. The HDPE membrane is covered with a free-draining 18 inch sand layer, then a 6 inch layer of topsoil. A strip drain collection system is installed directly on top of the cover system to carry surface water that has infiltrated through the topsoil and granular cover material to a toe discharge system or directly into the perimeter drainage ditch. The landfill does not have a bottom liner or leachate collection system.

2.3.2 LANDFILL GAS (LFG) SYSTEM

A landfill gas (LFG) system was installed to prevent off-site gas migration and to prevent build-up of gas pressure. It consists of wells inside the landfill and at the perimeter of the landfill, as well as trenches.

The system utilizes a 15 Hp blower (no VFD). The extracted gas is treated with granular activated carbon (GAC), followed by discharge to the atmosphere. Two condensate traps remove condensate droplets and other particles from the gas stream, and condensate is manually drained into a transport vehicle for treatment off-site.

2.4 MONITORING PROGRAM

The following components of monitoring are discussed below:

- Water Levels – Section 2.4.1
- P&T process monitoring (including extraction wells) – Section 2.4.2
- Sampling at groundwater monitoring wells – Section 2.4.3
- Sampling at domestic wells – Section 2.4.4
- LFG system monitoring – Section 2.4.5

Currently there are quarterly reports prepared by Spokane County that summarize monitoring results.

2.4.1 WATER LEVELS

Water levels are measured quarterly at a variety of monitoring wells and residential wells. In some cases the site operator estimates values where water levels could not be collected based on historical/recent data that are available. Water level maps for the upper and lower aquifers are prepared using Surfer and presented in the quarterly reports. Discussion regarding these water level maps is presented in Section 4.2.1 of this RSE report.

2.4.2 P&T PROCESS MONITORING (INCLUDING EXTRACTION WELLS)

Process monitoring for P&T system includes the following:

- The extraction wells are sampled quarterly for VOCs plus field parameters (pH, temperature, conductivity, turbidity)
- Influent to the treatment system is analyzed monthly for VOCs and field parameters
- Effluent from the treatment system is analyzed as follows:
  - Monthly for VOCs and field parameters
  - Quarterly for chloride
  - Four times per year (January, May, June, July) for total phosphorous and NO3+NO2
  - Semi-annual for “toxicity”

Sampling is performed by County personnel.

2.4.3 SAMPLING AT GROUNDWATER MONITORING WELLS

Groundwater monitoring is comprised of several components:

- Compliance monitoring (24 wells)
- Supplemental monitoring (approximately 40 wells)
- Minimal Function Standards (MFS) monitoring (currently at 4 upper aquifer wells)

Each of these is described below.

Compliance Monitoring

Compliance monitoring is based on the Consent Decree and detailed in the O&M Manual. The compliance monitoring program is intended to focus on the down-gradient boundaries to determine if the interception systems are containing the groundwater plume. The 24 compliance wells are sampled annually for VOCs. The compliance monitoring cluster locations are illustrated on Figure 8 from the fourth five-year review (which is included in Attachment A) and are summarized below:

- *West Extraction System*. These are designated as follows.
    - Set A monitoring well clusters (CD-41C1/2/3, CD-42C1/2/3, and CD-48C1/2/3) are located down-gradient of the system and monitor those portions of the lower aquifer believed to be within the capture zone of existing supply wells. These well clusters are located directly up-gradient of the existing supply wells.
    - Set B monitoring well clusters (CD-43C1/2/3 and CD-44C1/2/3) monitor portions of the lower aquifer not directly impacting the water quality of the existing supply wells.
    - Two monitoring well clusters were also placed at the outboard limit of the interception system (CD-45C1/2/3and CD-48C1/2/3). One of these clusters (CD-48/C1/2/3) is also considered to be part of Set A.
- *East Extraction System*. The east extraction system was intended for source control and does not have required performance monitoring.
- *South Interception System*. Six upper aquifer monitoring wells are used to monitor performance: four wells are located directly down-gradient of the south extraction system (CD-31A1, CD-36A1, CD-37A1, and CD-38A1) and two wells are located near the western and eastern outboard limits of the system (CP-S3 and CD-34A1).

Supplemental Monitoring

The compliance monitoring locations listed above do not provide a comprehensive monitoring network for tracking groundwater concentrations within much of the plume. To address this issue, the County voluntarily collects supplemental groundwater samples about every 5 years throughout the extent of the plume. The last supplemental sampling was completed in May 2007 and the data were presented in the second quarter 2007 monitoring report. The supplemental sampling occurs at approximately 40 wells with analysis for VOCs. It was stated during the RSE site visit that many of the monitoring wells associated with the supplemental sampling do not have dedicated pumps, and this makes the supplemental sampling a major effort.

MFS Monitoring

The MFS groundwater monitoring is required as a component of the landfill post-closure. Samples are analyzed for COCs plus chloride, nitrite/nitrate/ammonia, sulfate, total organic carbon, chemical oxygen demand, iron, manganese, and zinc. Initially, quarterly sampling was performed at a total of six wells (four in the upper aquifer and two in the lower aquifer). Quarterly monitoring and monitoring of the two lower aquifer wells was discontinued in January 1999, and currently the four upper aquifer wells are sampled annually. The four current MFS monitoring locations are illustrated on Figure 8 from the fourth five-year review (which is included in Attachment A).

2.4.4 SAMPLING AT DOMESTIC WELLS

Approximately 40 domestic wells are monitored for VOCs according to a schedule (see Attachment 6 of the fourth five-year review). Domestic well sampling locations are illustrated on Figure 28 from the fourth five-year review (which is included in Attachment A). According to Section VII of the Consent Decree, all wells in the domestic well monitoring program are required to be sampled annually. Specific wells can be sampled more frequently if necessary. Sampling of a well may be discontinued or reduced if (1) an alternative water supply has been provided, (2) it is determined the well is not threatened by contamination from the Colbert Landfill Site or (3) the remedial action is complete. According to the fourth five-year review, the County uses the following methodology to determine the appropriate sampling frequency:

- Quarterly – Wells near the leading edge of the plume or in areas where contaminants are not migrating in the direction of groundwater flow and contaminants have been detected at levels below Evaluation Criteria; wells in areas where contaminants exceeding Evaluation Criteria were detected in nearby wells; multiple user wells where contaminants were previously detected at levels below Evaluation Criteria.

- Semi-Annual – Wells in close proximity of the leading edge of the plume that are not separated from the plume by another well currently in the sampling program.

- Annual – Previously contaminated wells that currently show non-detectable levels of contaminants; wells without detectable concentrations of contaminants and that do not fall into the Bi-annual sampling category.

- Bi-Annual – wells previously in the sampling program that do not fall into any of the above categories (could be used as a transition from annual to no sampling).

- No Sampling - Wells hooked up to an Alternate Water Supply; wells not used for domestic purposes; wells that the owner requests not to be tested; no access to the property or sampling site.

The fourth five-year review (September 2009) indicated there is little documentation on the domestic wells that have been connected to municipal water since the original water supply extension, and recommended that a review of all residences within the groundwater plume area also be completed. It also recommended that changes to the domestic sampling program or new wells installed within the groundwater plume area should be documented in the quarterly reports including the sampling frequency (quarterly, semi-annual, etc), well numbers and addresses, and a location map.

It was stated during the RSE site visit that all potable wells were sampled once for 1,4-Dioxane during 2008 and 2009, and there were no detections except for one well (with a detection close to the performance criterion). It was stated that follow-up sampling would only occur at wells with detections.

2.4.5 LANDFILL GAS (LFG) SYSTEM MONITORING

The LFG system is part of landfill post-closure and is not a focus of this RSE. However, the RSE team notes that there is a variety of sampling for vacuum and landfill gas (methane and carbon dioxide) at a variety of sampling points throughout the collection/treatment system as well as at gas probes. The frequency of this monitoring ranges from monthly to quarterly to annually depending on the type of location. The RSE team also notes that, in addition to field measurements for vacuum and landfill gases, VOC analyses are performed annually, before and after the vapor GAC, by method TO-14A (note that this is an older method than method TO-15 which is now more widely used). Additionally, Gastech (tube) readings are taken monthly after the carbon adsorbers to monitor for possible breakthrough.

3.0 SYSTEM OBJECTIVES, PERFORMANCE, AND CLOSURE CRITERIA

3.1 CURRENT SYSTEM OBJECTIVES AND CLOSURE CRITERIA

The 1987 ROD identifies the following objectives:

- Prevent further spread of contaminated groundwater (in the south and west) in two aquifers by installing and operating interception wells and treating the extracted groundwater
- Remove contaminated materials (in the east) which have entered the aquifers and are contributing to the contaminant plume, by installing and operating extraction wells in the area where the plumes originate and treating the effluent
- Provide an alternate water supply system to any residents who are deprived of their domestic supply by demonstrated contamination from the landfill or due to the action of the extraction systems

The 1987 ROD stated that extraction wells and pumping rates should be implemented to prevent contamination from migrating beyond the down-gradient extent of the plume (at the time of the remedy implementation). The 1987 ROD indicated the following performance criteria to be met in groundwater to indicate completion of the remedy.

Groundwater Performance Standards in the 1987 ROD

Compound	Maximum Concentration (ppb)	Basis
1,1,1-Trichloroethane	200	MCL
1,1-Dichloroethene	7	MCL
1,1-Dichloroethane	4050	MAC
Trichloroethene	5	MCL
Tetrachloroethene	0.7	1e^{-6} cancer risk
Methylene Chloride	2.5	1e^{-6} cancer risk

MAC = maximum acceptable concentrations values which should not be exceeded in water used for drinking (ingestion) or bathing (dermal) calculated in Risk Assessment and summarized in Table 5of the 1987 ROD

The consent decree states the following objectives for the remedial action:

- Prevent ingestion of contaminated groundwater
- Provide alternative drinking water supplies to those residents whose domestic water supply well(s), in use prior to the date of entry of this Consent Decree, are now contaminated or become contaminated at levels exceeding those described in Section

VIII of [the Consent Decree], or where the productivity of their existing supply well(s) is adversely impacted by remedial measures

- Prevent the further spread of contaminated groundwater and remove contamination related to the site from the groundwater
- Protect surface waters from groundwater discharges potentially harmful to aquatic organisms
- Establish institutional controls as authorized by law to promote and support remedial actions
- Prevent transfer of Constituents of Concern from water to air at levels above health protection criteria

The Consent Decree indicates additional criteria to the performance criteria identified in the 1987 ROD, summarized below.

Additional Criteria Described in the Consent Decree and O&M Manual

Compound	Performance Criteria (ppb)	Evaluation Criteria (ppb)	Adjustment Criteria (a) (ppb)
1,1,1-Trichloroethane	200	200	103 (South), 101 (West)
1,1-Dichloroethene	7	7	4.5
1,1-Dichloroethane	4050	4050	2026
Trichloroethene	5	5	3.3
Tetrachloroethene	0.7	7	na
Methylene Chloride	2.5	25	na

(a) Calculated in O&M Manual based on method presented in the Consent Decree
na – not applicable

The Fourth Five Year Review defines these criteria as follows:

- *Performance Criteria*. Identified in the 1987 ROD (Section V, Alternatives Evaluation, Table 6). Numeric standards used for discharge levels of treated groundwater and groundwater performance standards for termination of the remedial action.
- *Evaluation Criteria*. Identified in the Consent Decree (Section IV.2.b, Table IV1). At the time the Consent Decree was written, quantifying PCE and MC concentrations in the groundwater was not possible using the available analytical methods; therefore, alternative evaluation criteria were developed to substitute for the performance criteria for these two COCs. The evaluation criteria for the remaining COCs (1,1,1-TCA; 1,1-DCE; 1,1DCA; and TCE) are equal to the performance criteria. The evaluation criteria for PCE and MC are ten times higher than the performance criteria. The Consent Decree provided for potential improvements to the analytical methods and stated: "If the levels to which these compounds can be accurately quantified (using Method 8010) change during the source of this project, the evaluation criteria will be adjusted accordingly." The project is now using EPA Method 524.2 to analyze for VOCs, which is capable of

quantifying PCE and MC to the performance criteria. For this reason, the evaluation criteria for PCE and MC are no longer applicable and only the performance criteria should be used to determine compliance.

- *Adjustment Criteria*. Identified in the Consent Decree (Section V.A.2.a, Table V-1 and Section V.C.2.a). Adjustment criteria were developed to conservatively evaluate the need for extraction system operational changes and are also used to determine when an extraction well can be put into standby mode. The Consent Decree identified a method to develop adjustment criteria for indicator compounds (1,1,1-TCA; 1,1-DCA; 1,1-DCE; and TCE), which was equal to the lesser value of (1) the baseline concentration (average of the time-averaged concentrations in the performance monitoring wells following startup) plus 50% of the evaluation criteria or (2) 65% of the evaluation criteria. Adjustment criteria are only used to manage operation of the extraction systems. The termination of the entire remedial action will be complete when the performance criteria for groundwater have been met throughout the plume extent.

1,4-Dioxane was not identified as a COC but has been sampled for as an emerging contaminant. It was stated during the RSE site visit that a performance criteria for 1,4-Dioxane at this site is 4 ug/l, which is the Washington Department of Ecology Model Toxics Control Act (MTCA) Method B (carcinogenic) cleanup level for 1,4-dioxane.

3.2 TREATMENT PLANT OPERATION STANDARDS

The 1987 ROD specified that the performance of the treatment plant would be to “[treat] the wastewater effluent to or below the MCLs (40 CFR 141.65) or a similar health-based level (the 10^{-6} risk level for carcinogens) for contaminants for which MCLs have not been determined.” Table 6 of the 1987 ROD presented the treatment plant criteria, which were identical to the remedy performance criteria described above.

Groundwater Treatment Performance Criteria in the 1987 ROD

Compound	Treatment Performance Criteria (ppb)
1,1,1-Trichloroethane	200
1,1-Dichloroethene	7
1,1-Dichloroethane	4050
Trichloroethene	5
Tetrachloroethene	0.7
Methylene Chloride	2.5

4.0FINDINGS

4.1 GENERAL FINDINGS

The RSE team observed that the active remedy components are operated by an extremely capable and organized operator. The observations provided below are not intended to imply a deficiency in the work of the system designers, system operators, or site managers but are offered as constructive suggestions in the best interest of the EPA and the public. These observations have the benefit of being formulated based upon operational data unavailable to the original designers. Furthermore, it is likely that site conditions and general knowledge of groundwater remediation have changed over time.

4.2 SUBSURFACE PERFORMANCE AND RESPONSE

4.2.1 PLUME CAPTURE

The design of the extraction system was intended to provide hydraulic capture in the upper aquifer with the south system extraction wells (located more than one mile south of the site), and to provide hydraulic capture in the lower aquifer with the west system extraction wells (located on the western side of the closed landfill). The east system extraction wells are intended as source area wells and are not intended to provide plume capture.

The south system wells have generally been shut off since 2004 due to concentrations below the pertinent criteria. Thus, the current evaluation of capture focuses on the west system extraction wells. Extraction well CP-W1 (located southwest of the closed landfill) has been shut off since 2005 due to low concentrations. Extraction well CP-W2 (located at the northwest corner of the closed landfill) generally pumps between 170 and 200 gpm. Extraction well CP-W3 (located west of the closed landfill) generally pumps between 200 and 250 gpm.

Capture for the west system (i.e., lower aquifer) is evaluated by Spokane County using two primary lines of evidence: potentiometric surface maps generated quarterly using the Surfer software, and concentration trends at the compliance monitoring wells located downgradient of the west system extraction wells. The RSE team makes the following observations:

- An example of the potentiometric surface maps for the lower aquifer is provided in Attachment A (for lower aquifer, January 2010). The water level values used to develop the contours are not posted, which makes it difficult for the reader to establish the validity of the contours.

- The values used to generate this map were provided to the RSE team. Based on these data, it appears that the water levels at the extraction wells are utilized to generate the contours, which is not recommended because water levels at extraction wells are subject to well losses and/or inefficiencies that often make the water levels measured in extraction wells lower than water levels in the surrounding aquifer materials. Based on *A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems* (EPA/600/R-08/003, January 2008), EPA recommends that piezometers be placed near extraction wells for determining water levels in the aquifer adjacent to the pumping wells. There are no water levels available near CP-W2 (other than the pumping well itself) and only one well near CP-W3 (location CD-46) with no other locations nearby.

- The overall density of water level measurement points does not allow for extent of capture to be clearly discerned. The RSE team notes that this is true for most sites, and other lines of evidence (such as concentration trends downgradient of the interpreted capture) should also be considered as is being done at this site. At this site, the lower aquifer compliance monitoring wells to the west of the western extraction wells along Hwy 2 (clusters at locations CD-41, CD-42, and CD-43) have remained generally non-detect for site COCs, with only a few minor detections of COCs well below criteria, and this is consistent with water level contour maps generated by the County which suggest that hydraulic containment is provided by the extraction wells.

- There is no clearly defined “Target Capture Zone” for the lower aquifer described in text or figures of the quarterly reports. This makes evaluation of the adequacy of hydraulic capture difficult to interpret within those reports. The intended capture zone for the lower aquifer was illustrated on Figure 2-7 in the Final Extraction Well Plan (Landau Associates, 1992) which is included in Attachment A.

- Some of the VOC impacts in the lower aquifer are in areas that might not be captured by these extraction wells. For instance, based on the supplemental sampling results (see figures in Attachment A) some of the highest VOC concentrations (e.g., DCE of 32.4 ug/l in 2007 versus performance criteria of 7, and TCE concentration of 79 ug/l in 2007 versus performance criteria of 5 ug/l) are located at CD-26, located appoximately1500 ft south of the closed landfill. Based on the potentiometric surfaces, which are based on relatively sparse water level measurements, impacted water in this area might be captured by the extraction wells, but it is also possible that impacted water in this area may not be captured by the extraction wells.

- Prior to the remedy, groundwater flow in the vicinity of CP-W3 was generally to the west (see, for instance, Figure ER-4.19 of the Final Phase 1 Engineering Report), and there does not appear to be a compliance monitoring well due west of extraction well CP-W3 (see “Figure 8 – Groundwater Monitoring Locations” in Attachment A).

- Given the heterogeneity of the subsurface at this site, simple calculations of capture zone width using simplifying assumptions are likely not meaningful.

In summary, there are some uncertainties regarding the exact extent of capture, but the Surfer maps produced by the County and the concentration histories at the compliance wells are consistent with hydraulic capture of most, if not all, of the impacted portion of the lower aquifer.

4.2.2 GROUNDWATER CONTAMINANT CONCENTRATIONS

Groundwater concentrations have declined significantly over time at the extraction wells and throughout the plume. Attachment A includes Figures 9 to 15 from the fourth five-year review which illustrate concentration trends for key VOCs at the extraction wells (i.e., not included for VOCs that are typically below performance criteria). Observations from these figures (and the VOC database for the site) include the following:

- For the south system, COC concentrations are at or near the performance criteria (in some events the PCE concentrations at CP-S4 are just above the criteria of 0.7 ug/l). The south system extraction wells have generally been shut down since 2004 due to low concentrations.

- For the east system, the highest concentrations are at CP-E2 (e.g., TCE and DCE concentrations are currently on the order of 100 ug/l at CP-E2), which is screened in basalt and pumps at a very low rate. The concentrations at CP-E2 declined by approximately 50% between 1994 and 1998, and have remained stable since 1998. At the other two east system extraction wells, concentrations are lower than at CP-E2. At those wells concentrations declined significantly early in the remedy (e.g., DCE declined at CP-E1 from more than 250 ug/l in the mid-1990s to less than 50 ug/l by 1998), but at CP-E1 and CP-E3 concentrations have also been relatively stable since 1998.

- For the west system, CP-W1 was shut down in early 2005 due to low concentrations. At CP-W2 and CP-W3 concentrations of COCs are low (e.g., DCE concentrations of approximately 10 to 20 ug/l versus performance criteria of 7 ug/l, and TCE concentrations of approximately 5 to 10 ug/l versus performance criteria of 5 ug/l). The concentrations have generally declined slowly over the course of the remedy. For instance, at CP-W3 the DCE concentration has declined from more than 200 ug/l in the mid-1990s to approximately 10 ug/l recently. Again, much of that decline occurred by 1998.

Based on Attachment 3 of the fourth five-year review, the compliance wells typically exhibit low concentrations of COCs (generally below the performance criteria). For instance, compliance wells CD-43C1, CD-43C2 and CD-43C3, which are located downgradient of extraction well CP-W2, have generally been non-detect for site COCs through the entire period monitored (since 1994 when the P&T system began). It is unclear if VOC concentrations would exceed criteria at this compliance location in the absence of remedy pumping. With respect to the supplemental sampling (which provides a more comprehensive picture of the plume extent approximately every five years), the fourth five-year review observed that concentrations of COCs above performance criteria remain in the lower aquifer to the north, east, and south of the landfill. The fourth five-year review also observed that overall size and shape of the contaminated groundwater plume has not changed significantly since the active extraction remedy began operation in 1994, but contaminant concentrations in the upper and lower aquifers have declined. The fourth five-year review attributed this to the active extraction associated with the remedy. The RSE team attributes it to a combination of groundwater extraction and treatment, the construction of the low permeability cap over the landfill (which essentially eliminates the infiltration of precipitation through affected soil and further release to the aquifer), natural dilution, and to a lesser extent other natural processes (e.g. biodegradation if present based on field conditions) and landfill gas extraction. As discussed later, the groundwater extraction has removed significantly more mass of VOCs than the landfill gas extraction. However, it is not possible to determine how much of the concentration reductions over time are attributable to the extraction versus other factors listed above. Initial notable concentration reductions (1994-1998), during the time when the groundwater extraction wells were removing >1000lbs/yr of VOCs, was likely due to the groundwater extraction. Since about 1998 concentrations at the extraction wells have remained relatively stable, and our conceptual model is that relatively higher VOC concentrations that are remaining in the lower permeability Latah sediments and basalt (e.g., at CP-E2 and other similar locations) are continuing to diffuse out into the higher permeability sediments. This diffusion causes lower (but stable) concentrations in the lower aquifer than were observed when the remedy first started to operate (i.e., before significant mass was flushed/removed from the lower aquifer). It is possible that pulsed pumping could have led to even greater mass removal over time, but perhaps at the expense of some plume capture effectiveness.

As mentioned earlier, there have been low level detections of 1,4-Dioxane within the footprint of the plume. Initial 1,4-Dioxane sampling was performed from 2005 through 2007 at every extraction, compliance, MFS, domestic and supplemental well in both the upper and lower aquifers of the Colbert Landfill site program at least one time. Subsequent sampling was performed quarterly at wells selected near known concentrations of 1,4-dioxane as outlined in a Work Plan approved by EPA and Ecology (not reviewed by the RSE team). This quarterly sampling concluded in April 2009 and is currently ongoing on an annual basis. Based on the Second Quarter 2009 Progress Report (Chapter 6) concentrations of 1,4-Dioxane were detected at five of the six locations. The locations and results are illustrated on Figures 6-1 and 6-2 and Table 6-2 from the Second Quarter 2009 Progress Report, which are included in Attachment A. The highest concentrations were at CD-40C1 (southwest of the landfill near Little Spokane River with 1,4-Dioxane concentrations up to 13 ug/l) and at south system extraction well CP-S1 (with 1,4-Dioxane concentrations up to 20 ug/l). These exceed the MTCA Method B cleanup standard of 4 ug/l, and do not appear to be within the capture zone of the P&T system. There is currently no attempt made at the site to actively capture and treat groundwater with 1,4-Dioxane levels above standards (i.e., in locations beyond the capture zone of the P&T system); rather, if 1,4-Dioxane is found at supply wells the approach is for Spokane to provide bottled water and then pay for a hook-up to public water. This approach for 1,4-Dioxane is essentially the same approach that is used in the domestic well program for the other site COCs. The fourth five-year review recommends that sampling of wells with concentrations of 1,4-dioxane above cleanup criteria be included in the long-term monitoring program.

4.2.3 INSTITUTIONAL CONTROLS TO PREVENT USE OF IMPACTED GROUNDWATER

The following description is provided in the fourth five-year review regarding the procedures for preventing consumption of impacted water:

> *The Spokane County Health Department maintains procedures for groundwater protection and prevention of the use of contaminated water within the Colbert Landfill plume boundaries. The following procedures were described by Jim Sackville-West of the Spokane County Health Department. The historical extent of the 1,1,1-TCA plume is used to define the groundwater protection area. For reference, the 1994/1995 1,1,1-TCE plumes for the upper and lower aquifers are presented on Figures 4 and 6 [of the fourth five-year review]. According to Spokane County Health Department officials, new wells are identified through applications for new development. If a proposed development is within the plume boundaries, they are encouraged to connect to municipal water. If a proposed residence is within 0.5 miles of the plume boundary and a well is installed, the Health Department will sample the groundwater for VOCs to verify that groundwater is not contaminated. This procedure does not detect any new wells that would be installed at existing residences; however, the Health Department reviews start cards (i.e. notice of intent to construct a water well) from Ecology for new wells and should be able to detect wells installed within the groundwater protection area. No official documentation of these procedures exists;*

> *maintenance of such procedures is based on Health Department officials working in conjunction with Ecology to ensure institutional controls for the Colbert Landfill area are met. An Institutional Control Plan is needed to ensure that the process for permitting wells is protective of human health and a lead agency is designated for oversight.*

The RSE team concurs with the five-year review findings that the current institutional controls are somewhat lacking with respect to documentation of procedures.

4.3 COMPONENT PERFORMANCE

4.3.1 GROUNDWATER EXTRACTION SYSTEM

Information about the extraction pumps is provided below.

Extraction Pump Information

Extraction Well	Original Pump Size[1] (Hp)	Designed Pump Capacity[1] (gpm)	Converted to Newer VFD?[3]	Typical Current Pumping Rate[2] (gpm)
CP-W1	30	250	Yes	0
CP-W2	30	250	Yes	170 – 200
CP-W3	30	250	Yes	200 – 250
CP-E1	20	200	Yes	125 – 135
CP-E2	0.75	6	Yes	0 – 2
CP-E3	20	200	No	100 -120
CP-S1	10	90	No	0
CP-S4	10	90	No	0
CP-S5	7.5	90	No	0
CP-S6	7.5	90	No	0

(1) from O&M Manual

(2) based on specific capacity calculation spreadsheet provided by system operator, except CP- W1 based on fourth five-year review report

(3) All extraction wells were originally installed with VFDs. Spokane County is currently replacing old VFDs with newer more efficient models that don't require the inclusion of an air conditioning unit, thus saving on power and associated equipment and repair costs.

Wells may be operated by either a flow mode or a level mode setting. Unless there is a need to acquire a specific flow or the level instrumentation is in repair, wells are operated using level controls that are set by the plant operator. For the western extraction wells, the operator seeks a balance between maximizing extracted concentrations and achieving adequate capture based on her experience interpreting capture for the system. The east and west system well pumps (except CP-E3) have had the original variable frequency drive (VFD) motors updated to newer models, and during the RSE site visit the system operator said that the VFDs for the operating extraction wells are running at anywhere from 65% to 98% of possible output based on a scale of 30 to 60Hz. There are plans to update the VFD at CP-E3. The south system has had updates to the VFDs since the wells are no longer in use. Each well has its own totalizing flow meter and electricity meter.

4.3.2 TREATMENT SYSTEM FOR EXTRACTED WATER

Quarterly progress reports prepared by the County include calculations of mass of the COCs removed by the groundwater extraction system. In the report for Q2 2009, the total mass removed to date was reported to be approximately 10,500 lbs, and the current removal rate was estimated at approximately 200 lbs/yr. Figure 2-18 of that same report suggests that the mass removal rate was much higher (more than 1,000 lbs/month) when the system was first operated in 1997, but stabilized at values similar to current levels by approximately 2002.

4.3.3 VOCS REMOVED BY LFG SYSTEM

The County provided the RSE team with TO-14a results for a variety of dates. The RSE team calculated mass removed by the LFG system for three dates (August 1996, August 1997, and July 2004) for the following four major COCs: DCA, DCE, TCA, and TCE (PCE concentrations were minimal and VC concentrations were low and inconsistent):

- August 1996:
  - DCA= 460 ppbv
  - DCE = 600 ppbv
  - TCA = 240 ppbv
  - TCE = 28 ppbv
  - Approximate flow rate of 200 cfm
  - Calculate mass removed = 38 lbs/yr

- August 1997
  - DCA= 290 ppbv
  - DCE = 190 ppbv
  - TCA = 190 ppbv
  - TCE = 24 ppbv
  - Approximate flow rate of 200 cfm
  - Calculated mass removed = 21 lbs/yr

- July 2004
  - DCA= 33 ppbv
  - DCE = 62 ppbv
  - TCA = 17 ppbv
  - TCE = 9.9 ppbv
  - Approximate flow rate of 50 cfm
  - Calculated mass removed = 1 lb/yr

To calculate mass, the concentrations in ppbv must first be converted to units of ug/m^3:

$$C_{air}(ug/m^3) = \frac{Conc(ppbv)}{10^6} \times \frac{1\ \text{mole air}}{24.1\ \text{L}} \times \frac{1000\ \text{L}}{\text{m}^3} \times \frac{1000\ \text{mg}}{\text{g}} \times \text{MW}_\text{X}$$

where MW_x is the molecular weight of each compound in grams per mole (DCA = 99, DCE = 97, TCA = 133, and TCE = 131). Then the mass (M_{air} in lbs/day) is calculated as follows:

$$M_{air} = Q_{air} \times C_{air} \times \frac{0.0283 \text{ m}^3}{\text{ft}^3} \times \frac{1440 \text{ min.}}{\text{day}} \times \frac{2.2 \text{ lbs.}}{10^9 \text{ ug}}$$

Where Q_{air} is the flow rate (cfm).

It is evident from the data and calculations provided above that the extracted landfill gas concentrations declined over time, and the mass removed by the LFG system (less than 50 lbs per year in the mid-1990s and 1 lb per year recently) is far lower than the mass removed by the groundwater extraction wells (which was initially more than 1,000 lbs per year and is currently on the order of 200 lbs per year).

4.4 COMPONENTS OR PROCESSES THAT ACCOUNT FOR MAJORITY OF ANNUAL COSTS

Rough annual cost estimates for operating this remedy are summarized below, based on information provided by the site team and/or estimated by the RSE team based on discussions with the site team.

Item Description	**Approximate Annual Cost***
Project Management (County)	$ 26,000
O&M Labor including sampling (County)	$ 215,000
Electricity	$ 54,000
Materials Vapor Carbon for LFG System Scale Inhibitor for Air Stripper Other	 $ 10,000 $ 6,600 $ 3,400
Misc Equipment/Supplies etc.	$15,000
Lab Analysis	$22,000
Total Estimated Annual Cost	**$352,000**

*does not include supplemental groundwater sampling approximately every 5 years

Additional details regarding these items are provided below.

4.4.1 UTILITIES

The site operator provided electric usage and costs by month for each of the 10 extraction wells, plus the "plant" which includes the LFG system blower. The total usage for 2009 was approximately 703,000 kWh and the total cost for 2009 was approximately $54,000. This translates to an approximate unit cost of $0.08 per kWh. The site operator indicates the rate for the extraction wells is slightly higher than this amount per kWh, and the rate for the plant is slightly lower than this amount per kWh, resulting in the blended rate of $0.08 per kWh.

4.4.2 NON-UTILITY CONSUMABLES AND DISPOSAL COSTS

Based on discussions during the RSE site visit, the vapor carbon for the LFG system requires approximately 4,400 lbs exchanged each year by Siemens (located in the Yakima area). The scale inhibitor cost is approximately $6,600 per year.

4.4.3 LABOR

Estimated costs were provided by the County for routine project management ($26,000 per year) and O&M ($215,000 per year). The O&M labor includes operating the treatment plant and the LFG system, all related sampling for process monitoring and groundwater monitoring, and reporting.

4.4.4 CHEMICAL ANALYSIS

There are likely on the order of 200 samples per year for VOCs consisting of extraction wells samples (40 per year), influent/effluent samples (24 per year), compliance well samples (24 per year), MFS samples (4 per year), domestic well samples (approximately 80 per year), and various duplicates and blanks. Assuming VOC analysis cost of approximately $100/sample, this would translate to approximately $20,000 per year. Additional lab analyses, such as the annual TO-14a for the LFG system, influent/effluent, toxicity testing for treatment plant process water, and the additional parameters for the MFS samples, should be minimal (less than ~$2,000 per year). Thus, the RSE team estimates that laboratory analysis cost is on the order of $22,000 per year. Note that this does not include supplemental groundwater sampling that is conducted approximately every five years. It also does not include extra analysis for 1,4 dioxane, which likely requires approximately $150 additional per sample.

4.5 APPROXIMATE ENVIRONMENTAL FOOTPRINTS ASSOCIATED WITH REMEDY

Direct energy usage for the site includes electricity and diesel associated with materials transportation. Energy is also associated with manufacturing of materials that are used at the site (e.g., vapor GAC and scaling inhibitor). We have not included off-site services associated with laboratory analysis. Air emissions of greenhouse gases, nitrogen oxides (NOx) and sulfur oxides (SOx) result from the direct energy usage and from manufacturing site-related materials. Greenhouse gas emissions are of global concern, and other pollutants are of more local concern as they adversely affect local/regional air quality. Briefly, nitrogen oxides (NOx) are respiratory irritants and precursors to ground level ozone. Sulfur dioxide is also a respiratory irritant and is a precursor to acid rain. Emissions of other pollutants may also be of concern, but these common pollutants were selected because emissions information is more readily available for them and they may be adequate indicators for other potential air emissions.

Spreadsheets were used to calculate the energy and emissions footprints for the remedy on an annual basis(see Attachment B). The landfill gas system is included in these calculations (e.g., electricity and methane), though CO_2 for the landfill gas system is not included in GHG emission because similar CO_2 would ultimately be emitted under any approach. Footprint results are summarized in Table 4.1.

Table 4.1 Summary of Footprint Results

Green and Sustainable Remediation Parameter	Annual Value (per year)
Greenhouse gas emissions	990,775lbs CO2e
Nitrogen oxide emissions	617 lbs
Sulfur oxide emissions	971 lbs
Total energy use	8,471,922 MMbtu
Water use (groundwater extraction)	343,210,000 gallons

CO2e = carbon dioxide equivalents of global warming potential
MMbtu = million British thermal units

For the greenhouse gas emissions (CO2e) approximately 83% is from methane emissions from landfill gas, approximately 11% is from electricity use, and the remaining 6% is from various other activities. By contrast, almost all of the energy use is associated with electricity use. The disparity between greenhouse gas emissions and energy use is because over 80% of the electricity provided by the local electricity provider is from hydropower.

With respect to water usage, essentially all of the water use is from the groundwater extraction system. The water that is extracted and treated from this system is discharged to Little Spokane River, and therefore is unavailable as a resource for groundwater usage.

Waste disposal associated with this remedy is minimal. With respect to more qualitative issues, the remedy does not cause any aesthetic issues (noise, visual, odor) and there are no major traffic issues associated with the remedy that would impact the surrounding land or ecosystems.

4.6 RECURRING PROBLEMS OR ISSUES

No significant issues reported.

4.7 REGULATORY COMPLIANCE

During the RSE process, the site team did not report any exceedances of discharge standards or other compliance related standards.

4.8 SAFETY RECORD

During the RSE process, the site team did not report any health and safety concerns or incidents related to the remedial activities.

5.0EFFECTIVENESS OF THE SYSTEM TO PROTECT HUMAN HEALTH AND THE ENVIRONMENT

5.1 GROUNDWATER

The following protectiveness statement was included in the fourth five-year review:

> *The remedy at the Colbert Landfill Site currently protects human health and the environment because residences with affected wells have been connected to County water supplies; the groundwater extraction systems are preventing further migration of the groundwater plume; domestic wells are sampled on a schedule to confirm that the drinking water exposure pathway is blocked; and the Spokane County Health Department has procedures in place to detect any wells installed as part of a new development.*
>
> *However, in order for the remedy to be protective of human health and the environment in the long term the following actions need to be taken:*
>
> - *Put restrictive covenants in place for the landfill and complete an Institutional Controls Plan that documents procedures to control installation of domestic wells.*
> - *Improve the current groundwater monitoring program to track the remaining contaminant concentrations within the plume area. Currently, the County voluntarily collects samples throughout the plumes (upper and lower aquifer) approximately every five years to account for this short coming.*
> - *Conduct a RSE to determine if the current extraction system is adequate to maintain containment and/or achieve long term cleanup goals within a reasonable timeframe.*

The RSE team is not certain that the current groundwater extraction from the east and west systems adds to the overall protectiveness of the remedy, for the following reasons:

- Initial concentration reductions at the extraction wells (1994 to 1998) were likely due to flushing and mass removal associated with the P&T system plus the implementation of landfill post-closure systems (capping, landfill gas collection, etc.). However, there have only been minor concentration reductions at the extraction wells since 1998, and it is not clear if continued extraction leads to meaningfully reduced concentrations of COCs observed in the lower aquifer.

- The overall extent of the VOC plume in the lower aquifer has not changed significantly, although concentrations have gone down over the course of the remedy. If extraction did not continue, it is not clear that the plume extent would subsequently grow and/or that concentrations of COCs away from the landfill would increase, given the remaining strength of the contaminant source which has been reduced over time by groundwater remedy extraction and engineered controls such as landfill capping.

The RSE team believes this is a challenging site because there are diffuse COC concentrations in the lower aquifer over a large area, with some apparent source areas to the north, east, and/or south of the actual landfill. It is likely that some low levels of VOCs (and 1,4-dioxane) will persist above performance standards for some period of time over a large area, some of which are beyond the capture zone of the P&T system. These relatively low level concentrations of the COCs (and 1-4-Dioxane) that persist are being addressed with a combination of domestic well sampling, institutional controls, and hook-ups to public water. The RSE team agrees that this general approach is appropriate, given the complex nature of the site and the large extent of a diffuse plume. The RSE team also feels that a shut-down test of the remaining extraction wells may be appropriate, in conjunction with some increased monitoring, to determine if terminating extraction has a negative impact on water quality. The RSE team also agrees with the fourth five-year review that the process for documenting and implementing the institutional controls should be improved, and that the process for sampling VOCs and 1,4-Dioxane throughout the plume footprint should be more clearly defined.

5.2 SURFACE WATER

The RSE did not focus on surface water, but the RSE team believes it is very unlikely that the low levels of VOCs observed in the groundwater plume would have negative impacts on surface water quality, including the Little Spokane River.

5.3 AIR

The fourth five-year review summarized the potential for impacts due to vapor intrusion. It stated that the current landfill gas management system would prevent this pathway for indoor air in residences or businesses adjacent to the landfill. With respect to areas away from the landfill, the fourth five-year review included a screening level analysis using the Johnson and Ettinger (J&E) Vapor Intrusion Model, and concluded that the concentrations of COCs in groundwater do not appear to pose a risk to indoor air. As discussed in Section 1.5.4, the RSE team agrees that vapor intrusion does not appear to be a concern.

5.4 SOIL

Not addressed as part of the RSE, but not expected to be a concern.

5.5 WETLANDS AND SEDIMENTS

Not addressed as part of the RSE, but not expected to be a concern.

6.0 RECOMMENDATIONS

Cost estimates provided herein have levels of certainty comparable to those done for CERCLA Feasibility Studies (-30%/+50%), and these cost estimates have been prepared in a manner consistent with EPA 540-R-00-002, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, July, 2000. The costs and sustainability impacts of these recommendations are summarized in Tables 6-1 and 6-2.

6.1 RECOMMENDATIONS TO IMPROVE EFFECTIVENESS

6.1.1 ADD MONITORING WELL WEST OF CP-W3

As noted in Section 4.2.1, there does not appear to be a compliance monitoring due west of extraction well CP-W3, and based on the figures included in Attachment A, there also do not appear to be supplemental or domestic monitoring wells in that region. If a shut-down test of the P&T system is to be considered, it will be important to have at least one monitoring well due west of CP-W3. It is recommended that at least one monitoring well be drilled to the west of CP-W3 (i.e., between the CD-42 and CD-43 compliance locations), perhaps at a depth consistent with CD-42C2 and CD-43C2 (i.e., middle of lower aquifer). Based on cross-section E-E’ in Attachment A, this would correspond to a depth of approximately 300 ft, and using a generic approximate cost of $100/ft for well installation (including oversight and associated equipment and logistics), this would require a capital cost of approximately $30,000 (assuming no major access limitations). Note this is not a site-specific cost estimate, it is only intended as a rough estimate. Annual sampling of this well for VOCs (similar schedule as compliance wells) would have a minor cost impact (perhaps $500/yr). This well will provide valuable information under continued pumping conditions, and is especially important for monitoring a shut-down test of the extraction system if that occurs (see Section 6.4.1).

6.1.2 INCLUDE 1,4-DIOXANE IN FUTURE RESIDENTIAL SAMPLING (AT SOME FREQUENCY)

As discussed in Section 4.2.2, there have been low level detections of 1,4-Dioxane within the footprint of the plume. It was stated during the RSE site visit that follow-up sampling for 1,4-dioxane at residential wells would only occur for wells with detections. The RSE team recommends that future residential well samples be analyzed for 1,4-Dioxane (at some frequency) in addition to the other COCs. The lack of a detection for 1,4-Dioxane in one sampling event does not guarantee that future detections will not occur at that location, especially if the flow system changes (for instance, due to changes in remedy pumping). Perhaps the 1,4-Dioxane analysis at residences could be done at reduced frequency relative to other COC’s. Assuming 80 residential samples are taken per year for other site COCs, and analysis for 1,4-Dioxane is performed for every other sample over time at each residential well (i.e., 40 analyses per year for 1,4-Dioxane), and a cost of approximately $150 per analysis for 1,4-Dioxane, this should add approximately $8,000 per year of cost for analysis and reporting. The actual frequency for 1,4-Dioxane analysis should be worked out by site stakeholders, and could possibly be different for wells in different locations. The RSE team recommendation, however, is that residential wells not be excluded from all future analysis for 1,4-Dioxane base on one result of “non-detect”.

6.1.3 TIGHTEN INSTITUTIONAL CONTROLS REGARDING GROUNDWATER USE AND DOCUMENT APPROACH REGARDING 1,4-DIOXANE DETECTIONS

As discussed in Section 5.1, the RSE team agrees with the fourth five-year review that the process for documenting and implementing the institutional controls should be improved. Based on the RSE site visit and the documents reviewed, it appears that the current implementation of the institutional controls is likely effective but not fully documented or formalized. Furthermore, it was stated during the RSE site visit that if 1,4-Dioxane is detected at "high enough levels" (assumed to be 4 ug/l, which is the MTCA Method B cleanup level), Spokane County then provides bottled water and subsequently pays for a hook-up to public water. However, the RSE team is not aware if this approach has been formally documented as part of the remedy, and recommends that this be documented more clearly. The RSE does not have a basis for quantifying the cost of implementing this recommendation to tighten and document the institutional controls, buts suspects it could cost on the order of $40,000 to address this recommendation for the entire site.

6.2 RECOMMENDATIONS TO REDUCE COSTS

None are provided above and beyond the potential cost savings associated with recommendations in other categories.

6.3 RECOMMENDATIONS FOR TECHNICAL IMPROVEMENT

6.3.1 MODIFICATIONS TO WATER LEVEL MAPS

It is recommended that future water level maps include posted data values. If necessary, the plots can be zoomed in to the area of interest (using the limits and scale properties in Surfer) so the labels can be viewed. Also, it is best to avoid use of water levels from pumping wells, but if they are to be used it should be clearly noted on the water levels maps. Also, in some cases the site operator estimates values where water levels could not be collected based on historical/recent data that are available. It is recommended that any estimated water levels be clearly documented on figures and/or tables associated with the water levels. Implementing this recommendation is not expected to have any cost impact.

6.3.2 OTHER SUGGESTED MODIFICATIONS TO QUARTERLY REPORTS

The quarterly reports present an impressive amount of information. It is recommended that an executive summary be included to indicate any important (i.e., non-routine) changes or observations from the reporting period. Also, there are some instances where concentrations for domestic wells are reported as "ND" and it is recommended that the detection limits be included (i.e., "1 U" or "< 1"). Implementing this recommendation is not expected to have any cost impact.

6.4 CONSIDERATIONS FOR GAINING SITE CLOSE OUT

6.4.1 CONSIDER SHUT DOWN TEST OF REMAINING ACTIVE EXTRACTION WELLS

As discussed in Section 5.1, the RSE team is not certain that the current groundwater extraction from the east and west systems adds to the overall protectiveness of the remedy. The RSE team believes it is technically reasonable to consider a shut-down test of the remaining extraction wells, with monitoring to determine if concentrations increase significantly downgradient of the landfill (including at the new monitoring well west of extraction well CP-W3 recommended in Section 6.1.1).

A shut-down test seems technically appropriate given that source area strength has been reduced due to previous groundwater extraction associated with the remedy, plus engineering controls for the closed landfill such as the cap. The concentrations at the remedy extraction wells are quite low (except CP-E2, which removes water from the basalt at a very low rate). There are many areas at distance from the landfill with relatively low COC concentrations that are nevertheless above cleanup standards (i.e., a diffuse plume over a large area), and the overall extent of the COC plume has not been changed dramatically since the remedy began operation. It is not clear that the current P&T system will achieve the goal of remediating groundwater to cleanup levels throughout the entire impacted area. The impacted areas away from the landfill are being addressed with a combination of domestic sampling, institutional controls, and water hookups, and this seems appropriate. This shut down test and associated monitoring can help determine if a final remedy at the site should or should not include P&T, and can also indicate if a TI waver should be considered as part of the final remedy. Given the low concentrations of COCs over a large area, there are no in-situ technologies that could reasonably be suggested to achieve cleanup levels throughout the plume. If the shutdown test indicates that the P&T system provides no significant benefit with respect to achieving cleanup levels, and there are no identified alternatives that are likely to achieve cleanup goals throughout the plume, then evaluating a TI waiver as part of the final remedy may be appropriate.

Although a shut-down test may be technically reasonable, it is beyond the scope of the RSE to determine how to implement such a test given the existing ROD, Consent Decree, and EPA policy. It is anticipated that this would require substantial work among the stakeholders to develop an acceptable approach and work plan. The approach and work plan would need to establish a monitoring program and related triggers for turning back on the P&T system based on observed concentrations and concentration trends. The existing compliance monitoring wells west of the landfill, plus the suggested new monitoring well west of CP-W3, would provide a good network for monitoring potential plume migration to the west after a shut down test is initiated. Groundwater flow in the lower aquifer near CP-W1 was reported to be on the order of 0.6 feet/day (approximately 200 feet/year) per year in the 1991 Final Phase 1 Engineering Report, and the pertinent compliance wells are on the order of 1,000 feet west of the western extraction wells, so the shut down test will have to be monitored initially for years to determine if there are unacceptable results. The RSE team has no basis for calculating the required level of effort for establishing a shut down test approach and work plan. The RSE team notes that a shut-down test should not be implemented until effectiveness recommendations 6.1.1 to 6.1.3 provided above are all implemented, to ensure protectiveness of the remedy during the shutdown test and to better monitor the shutdown test.

A shutdown test would likely lead to significant annual cost savings. It would eliminate approximately $45,000 per year of electrical usage, and approximately $15,000 of materials and supplies (such as the anti-scaling chemical and other miscellaneous supplies). It is assumed that quarterly sampling at the extraction wells would continue, but it would eliminate process monitoring analysis costs for influent and effluent (approximately 24 samples per year for VOCs plus toxicity testing), which likely would save approximately $4,000 per year. We assume that some significant savings would be realized on labor (perhaps a savings of $70,000 from the estimated $215,000 per year for the current system, since there would still be labor associated with monitoring, reporting, landfill gas control, etc). These add up to approximately $134,000 per year of savings. We anticipate that the work plan developed to implement a shut-down test may include some additional sampling frequency at selected wells west of the landfill, perhaps reducing the net savings to approximately $125,000 per year. It is noted, however, that this recommendation for a shut-down test is made primarily with regard to potential for achieving site closeout, and the potential cost savings associated with a shut down test should not be the primary basis for determining if this approach is acceptable to all stakeholders.

Implementing this recommendation will preclude the need to add additional water level monitoring points to better resolve capture zones for the extraction wells. If the extraction system is expected to operate for a long time into the future, then additional water level measurement locations would be recommended for drawing improved potentiometric surface maps, particularly at locations near the extraction wells (to preclude the use of water levels at extraction wells) to be consistent with EPA guidance regarding capture zone evaluation. Therefore, it is likely that the addition of multiple new water level measurement points would be appropriate if a shut-down test is not anticipated, but we have not quantified the costs since we believe the shut-down test is merited.

Although this recommendation for a shut-down test is not being made based on sustainability considerations, a shut-down test would also have positive results with respect to sustainability. The current system uses approximately 700,000 kWh per year of electricity, and the vast majority of that would be eliminated (electricity would still be required for the LFG system, which we estimate is approximately 17% of the electricity usage). The use and transport of the anti-scaling chemical would also be eliminated. In sum, we estimate that implementing this recommendation would cut the calculated greenhouse gas emissions per year (CO2e per year) from approximately 794,708 lbs to approximately 136,903 lbs (approximately an 83% reduction). Reductions in NO_x and SO_x would scale accordingly.

6.5 RECOMMENDATIONS FOR IMPROVED SUSTAINABILITY

The site team has initially implemented VFDs for motors, and has upgraded these VFDs for most of the motors used in the remedy, which is commendable. No specific recommendations for sustainability are recommended. As discussed earlier, a shut-down test at the remaining extraction wells would eliminate significant electrical usage and some supplies, but the recommendation is made on the basis of costs savings and not sustainability.

Table 6-1. Cost Summary Table

Recommendation	Reason	Additional Capital Costs ($)	Estimated Change in Annual Costs ($/yr)	Estimated Change in Life-Cycle Costs $*	Estimated Change in Life-Cycle Costs (net present value) $**
6.1.1 Add Monitoring Well West Of CP-W3	Effectiveness	$30,000	$500	$37,500	$40,000
6.1.2 Include 1,4-Dioxane In Future Residential Sampling (At Some Frequency)	Effectiveness	$0	$8,000***	$120,000	$160,000
6.1.3 Tighten Institution Controls Regarding Groundwater Use And Document Approach Regarding 1,4-Dioxane Detections	Effectiveness	$40,000	$0	$40,000	$40,000
6.3.1 Modifications To Water Level Maps	Technical Improvement	$0	$0	$0	$0
6.3.2 Other Suggested Modifications To Quarterly Reports	Technical Improvement	$0	$0	$0	$0
6.4.1 Consider Shut-Down Test Of Remaining Active Extraction Wells	Site Closeout	Not quantified, potentially substantial	(125,000)	($1,850,000)	($2,500,000)

Costs in parentheses imply cost reductions
* assumes 20 years of operation with a discount rate of 0% (i.e., no discounting)
** assumes 20 years of operation with a discount rate of 3% and no discounting in the first year
***assumes 80 residential samples per year for site COCs, but only every other sample per well over time sampled for 1,4-Dioxane (i.e., 40 per year for 1,4-Dioxane)

Table 6-2. Sustainability Summary Table for Recommendations

Recommendation	Reason	Effects on Sustainability
6.1.1 Add Monitoring Well West Of CP-W3	Effectiveness	Minor
6.1.2 Include 1,4-Dioxane In Future Residential Sampling (At Some Frequency)	Effectiveness	Minor
6.1.3 Tighten Institution Controls Regarding Groundwater Use And Document Approach Regarding 1,4-Dioxane Detections	Effectiveness	None
6.3.1 Modifications To Water Level Maps	Technical Improvement	None
6.3.2 Other Suggested Modifications To Quarterly Reports	Technical Improvement	None
6.4.1 Consider Shut-Down Test Of Remaining Active Extraction Wells	Cost-Effectiveness	Major

ATTACHMENT A

SELECTED FRIGURES FROM SITE DOCUMENTS

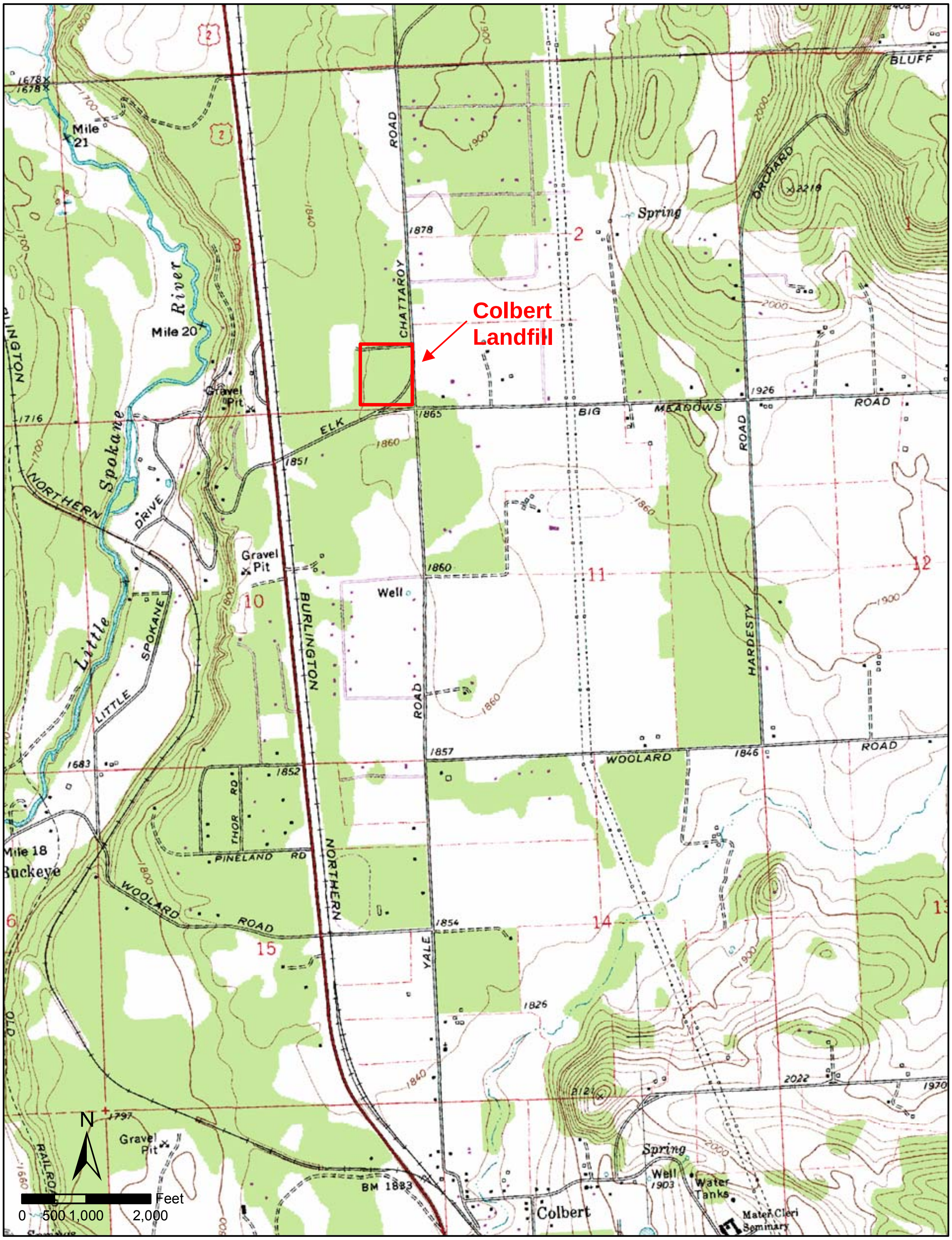
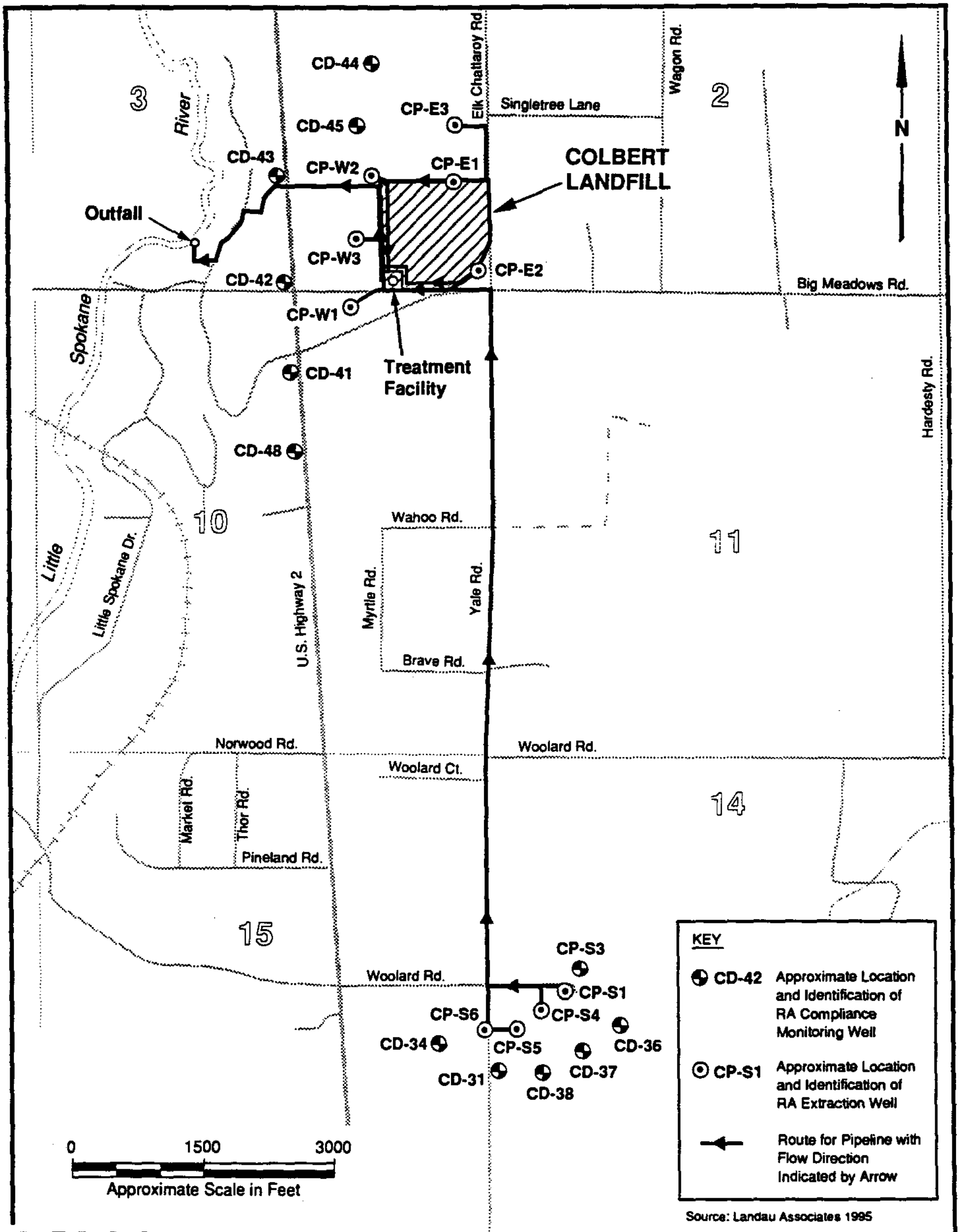


Figure 1. Location of Colbert Landfill

From Fourth Five-Year Review (September 2009)



Source: Landau Associates 1995

124004.110 Spokane Co/Colbert Landfill/Operations & Maintenance Plan (M) 1/97

Remediation Action System Components

Figure 3-2

From O&M Manual (Landau Associates, December 1999)

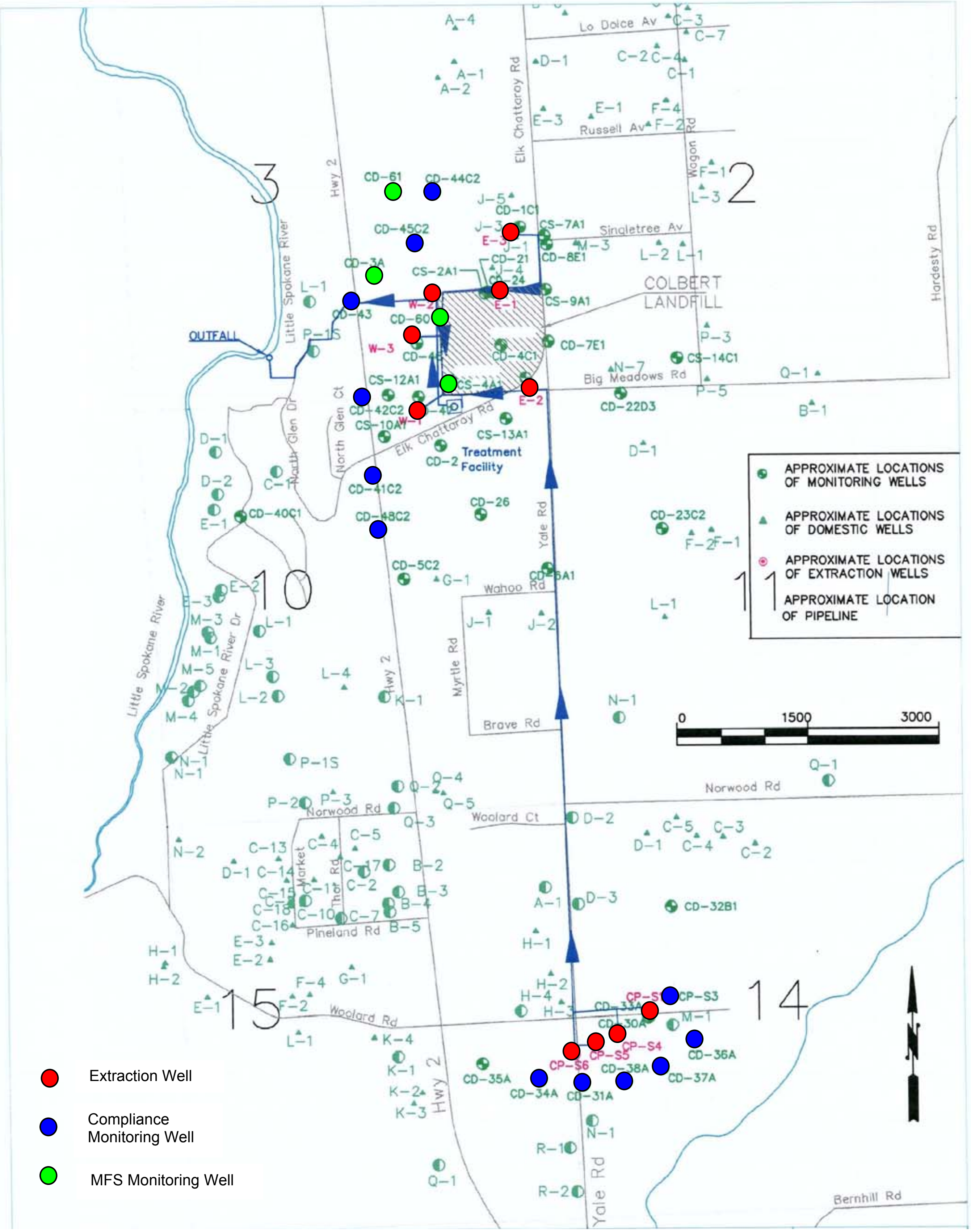
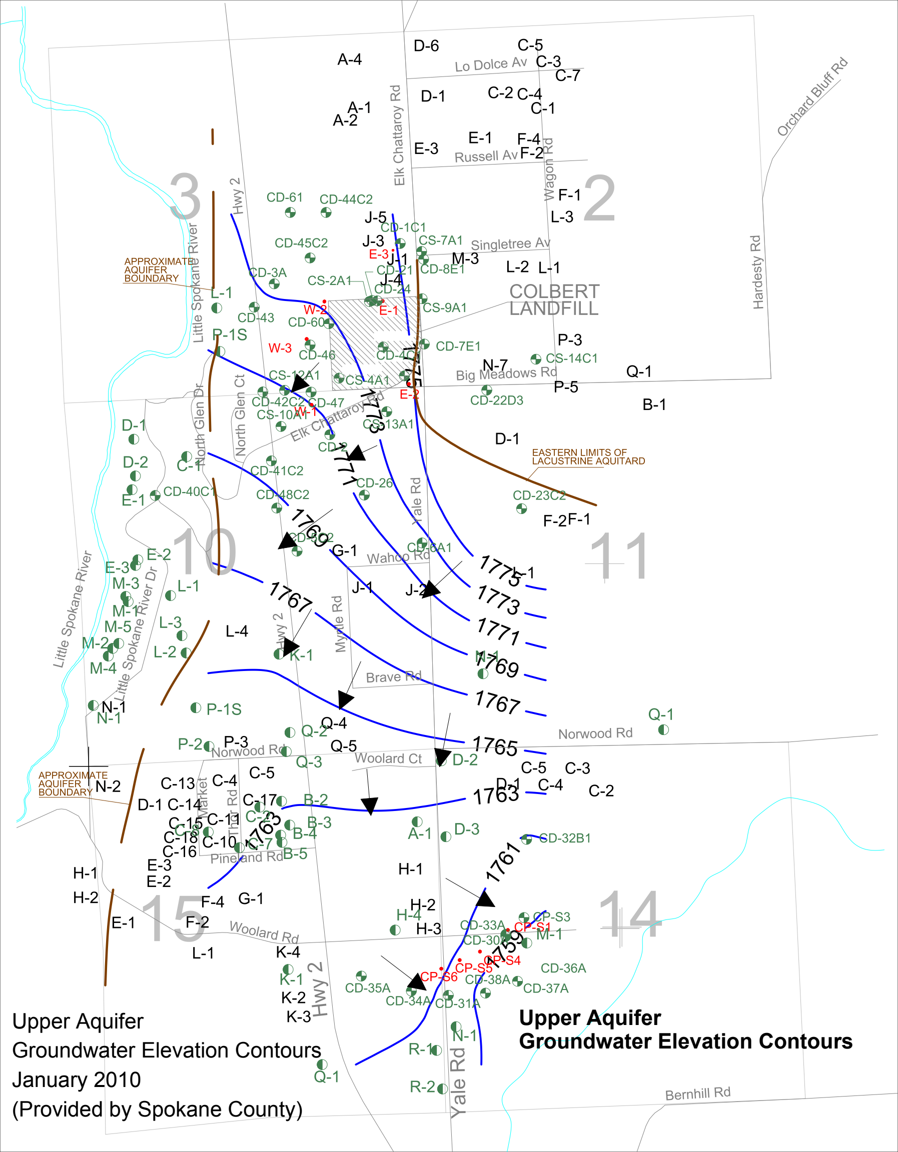


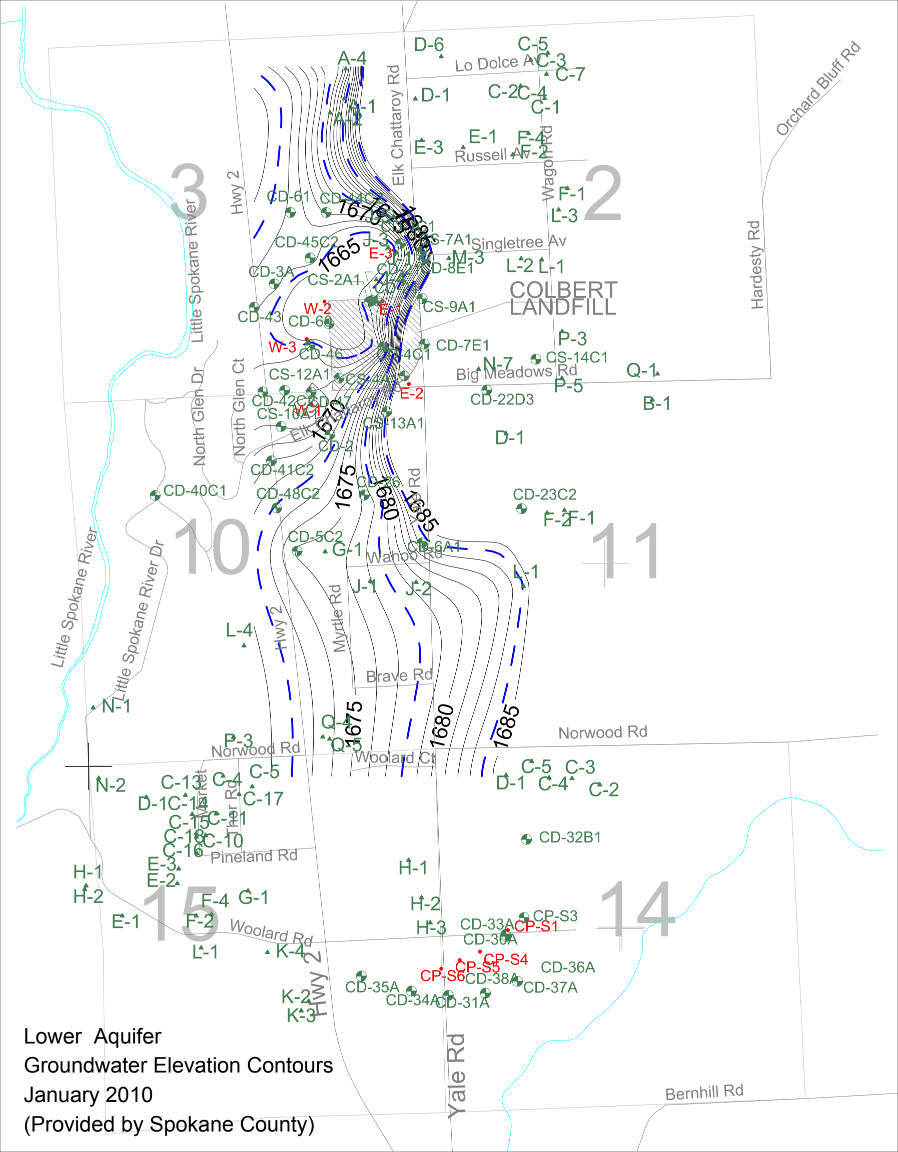
Figure 8. Groundwater Monitoring Locations

From Fourth Five-Year Review (September 2009)



Upper Aquifer
Groundwater Elevation Contours
January 2010
(Provided by Spokane County)

Upper Aquifer
Groundwater Elevation Contours

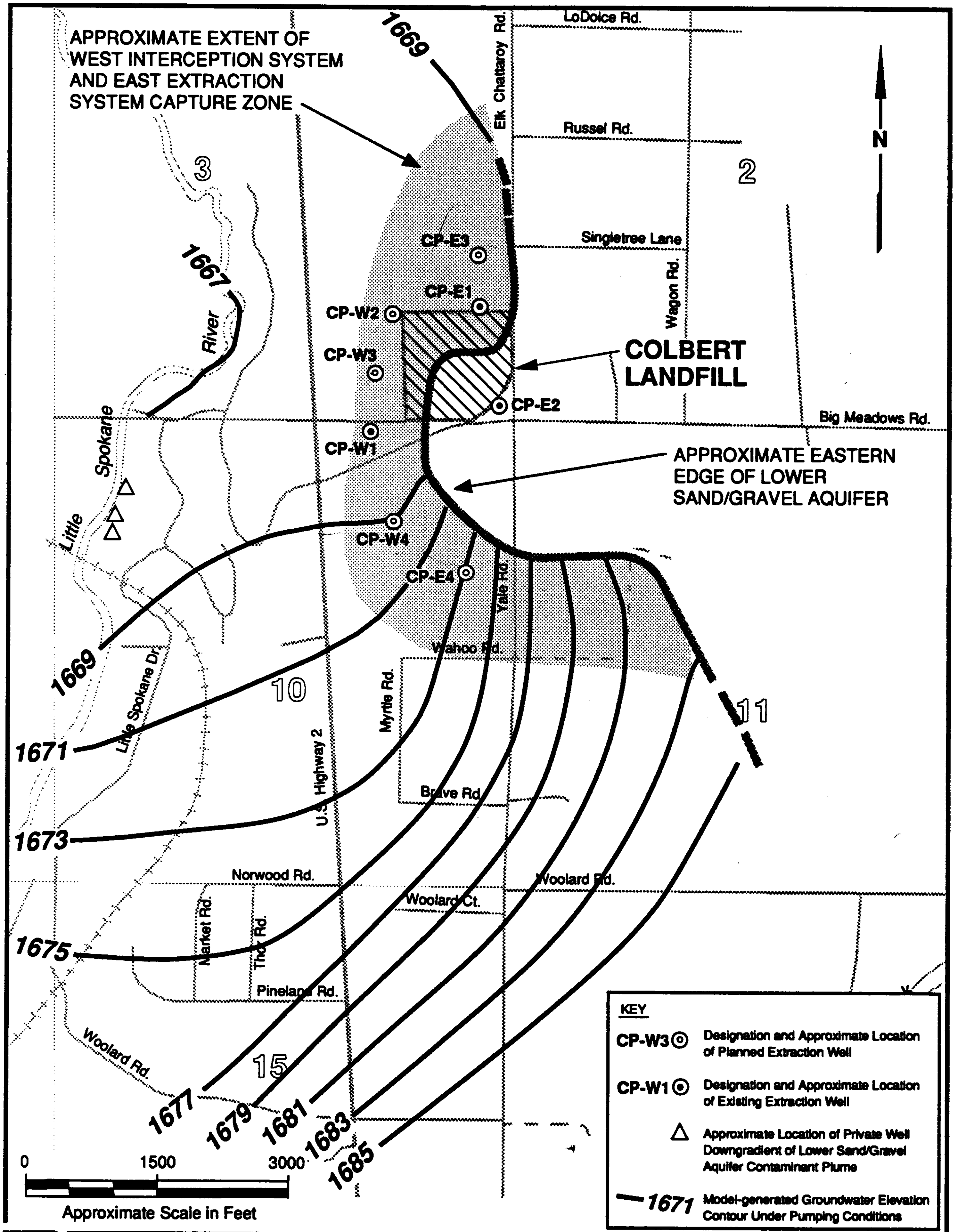


Lower Aquifer

Groundwater Elevation Contours

January 2010

(Provided by Spokane County)

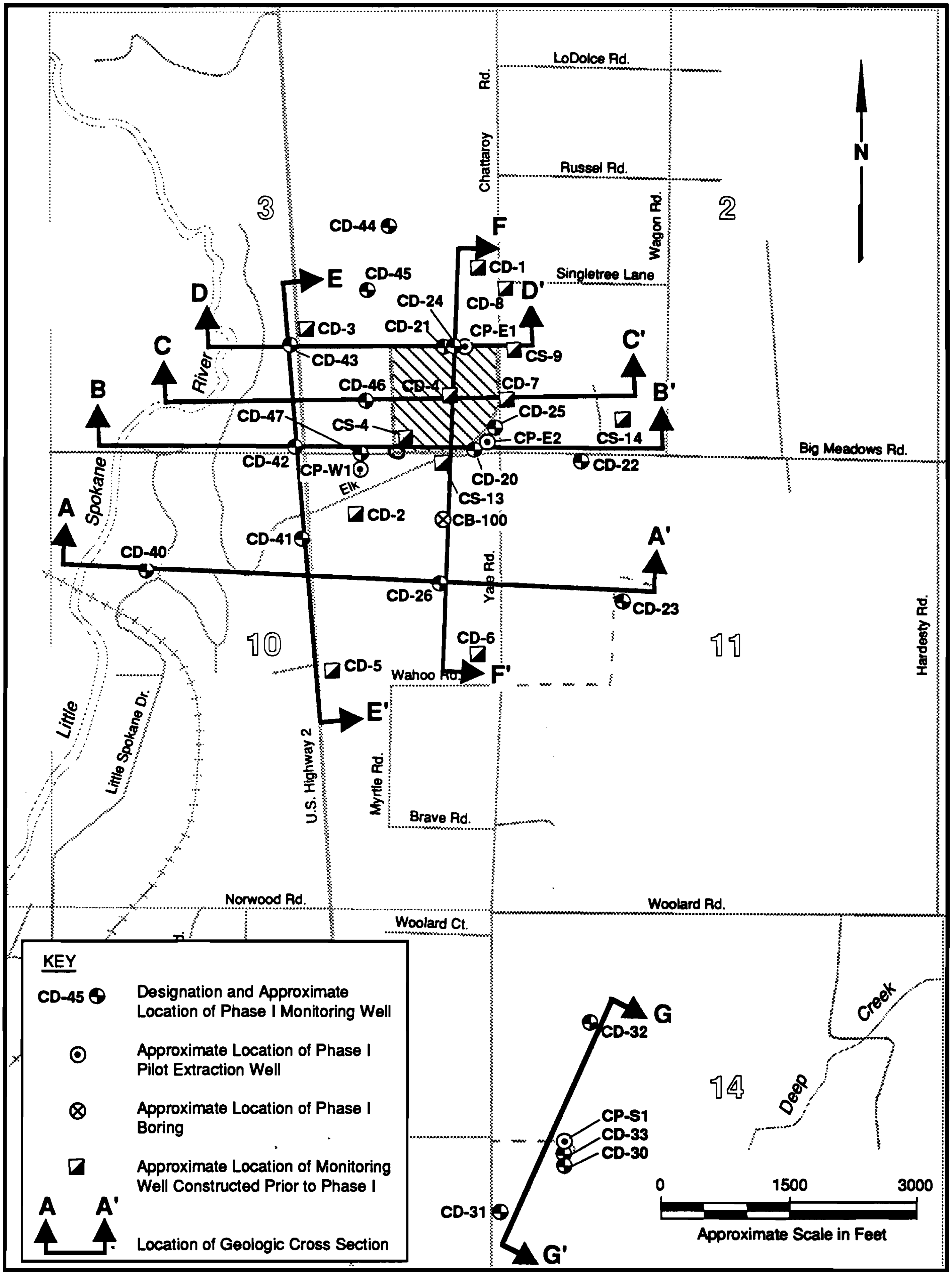


124001.72 Spokane Co./Colbert Landfill/ RD/RA Phase II /Final Extraction Well Plan 8/92

Combined West Interception and East Extraction System Capture Zone

Figure 2-7

From Final Extraction Well Plan (Landau Associates, 1992)



124-01.61 Spokane Co./Colbert Landfill/RD/RA Phase I /Final Engineering Report 12/91

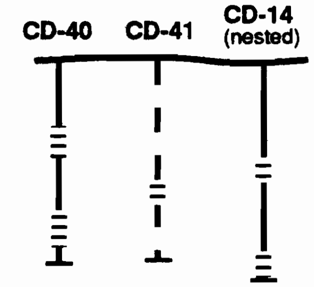
LANDAU ASSOCIATES, INC.	Geologic Cross Section Location Map

Figure ER-4.1

From Final Phase 1 Engineering Report (Landau Associates, 1991)

KEY TO GEOLOGIC CROSS SECTIONS

▨	Fluvial sands, silts and gravels
▓	Upper Sand/Gravel Unit (Unit A), composed of gravelly, fine to coarse sand
▨ Sand Silt/Clay	Lacustrine Unit (Unit B), composed of silt and clay with interbedded fine sand
░	Lower Sand/Gravel Unit (Unit C), composed of gravelly, fine to coarse sand
▓	Weathered Latah Subunit (Unit D_1), composed of gravelly (basalt) silt and clayey silt
■	Latah Formation (Unit D), composed of silt, clayey silt and fine sand
▧	Basalt Unit (Unit E), composed of highly fractured to massive Basalt rock
⊞	Granite Unit (Unit F), composed of Pre-Tertiary granitic rock, highly weathered with zones encountered during Phase I



Approximate location and number of monitoring well cluster, with screen intervals shown for individual monitoring wells. Projected boring logs have dashed lines. Nested wells are noted, and screen intervals shown.

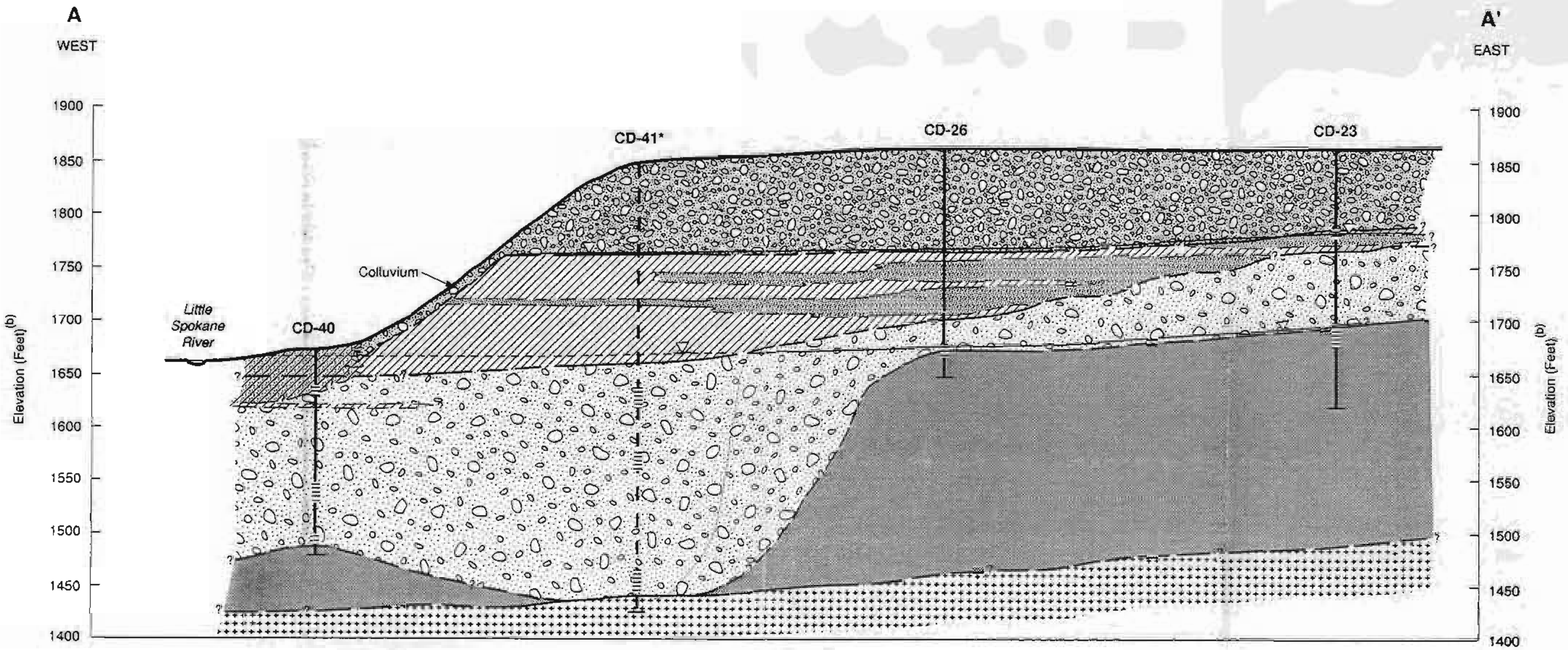
——— ▽ - - - - - -	Ground water elevation line, dashed when representing a piezometric surface in a confined aquifer
? ——— ——— ? ———	Contact between stratigraphic units; question marks indicate contact projection based on limited data

124-01.61 Spokane Co./Colbert Landfill/RD/RA Phase I/Final Engineering Report 12/91

LANDAU ASSOCIATES, INC.	Key to Geologic Cross Sections

Figure ER-4.2

From Final Phase 1 Engineering Report (Landau Associates, 1991)



Notes: a) Subsurface profiles shown have been generalized from data obtained during Phase I and other Site investigations. Variations between this profile and the actual soil conditions may be encountered. The boring logs and the discussion in the text of this Report must be referenced for a proper understanding of the nature of subsurface materials.

b) All elevations in feet above mean sea level (MSL) based on 1929, National Geodetic Vertical Datum.

* Well drilled by air rotary; detailed geology not identified in Lacustrine Aquitard Unit.

0 600 1200

Approximate Scale in Feet

Vertical Scale Exaggeration: 6x

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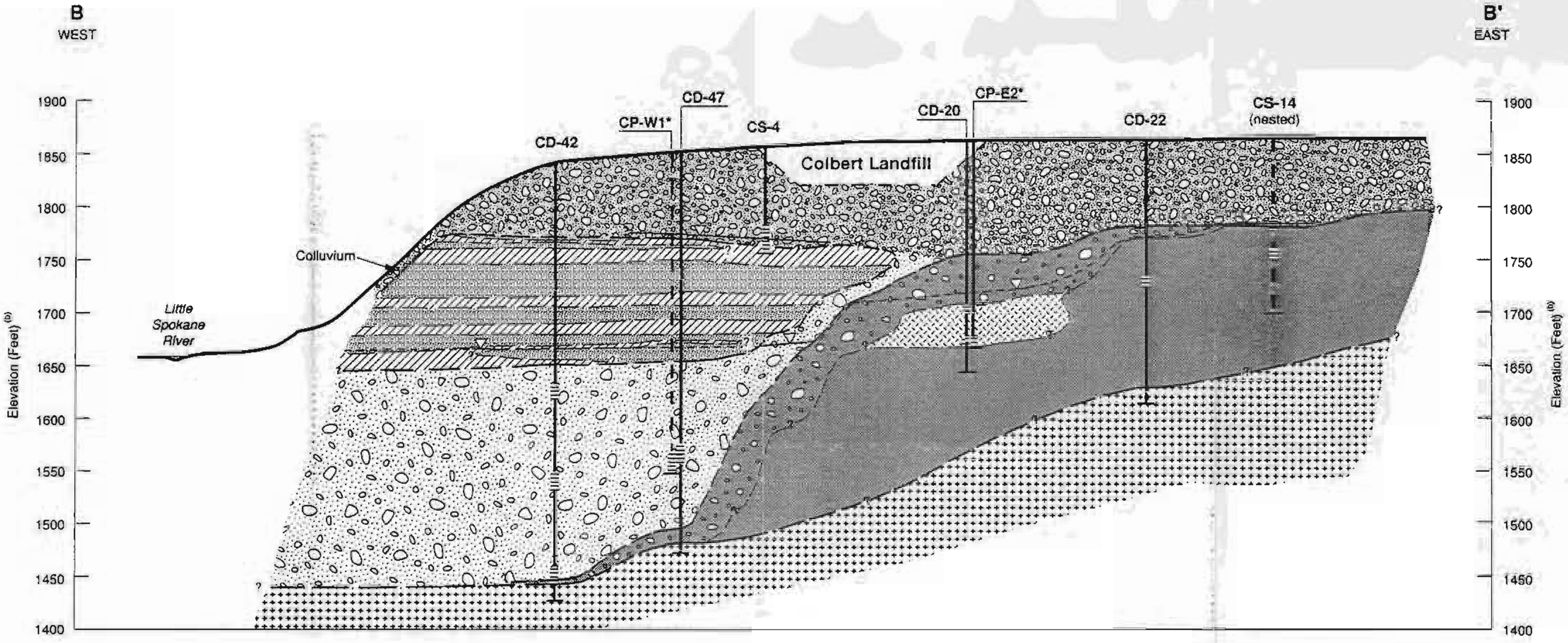
LANDAU ASSOCIATES, INC.

Geologic Cross Section A-A'

From Final Phase 1 Engineering Report (Landau Associates, 1991) Figure ER-4.3



Notes: a) Subsurface profiles shown have been generalized from data obtained during Phase I and other Site investigations. Variations between this profile and the actual soil conditions may be encountered. The boring logs and the discussion in the text of this Report must be referenced for a proper understanding of the nature of subsurface materials.

b) All elevations in feet above mean sea level (MSL) based on 1929, National Geodetic Vertical Datum.

* Pilot Well included in cross section to show screen interval, geologic information is based on adjacent monitoring well boring data.

0 600 1200

Approximate Scale in Feet

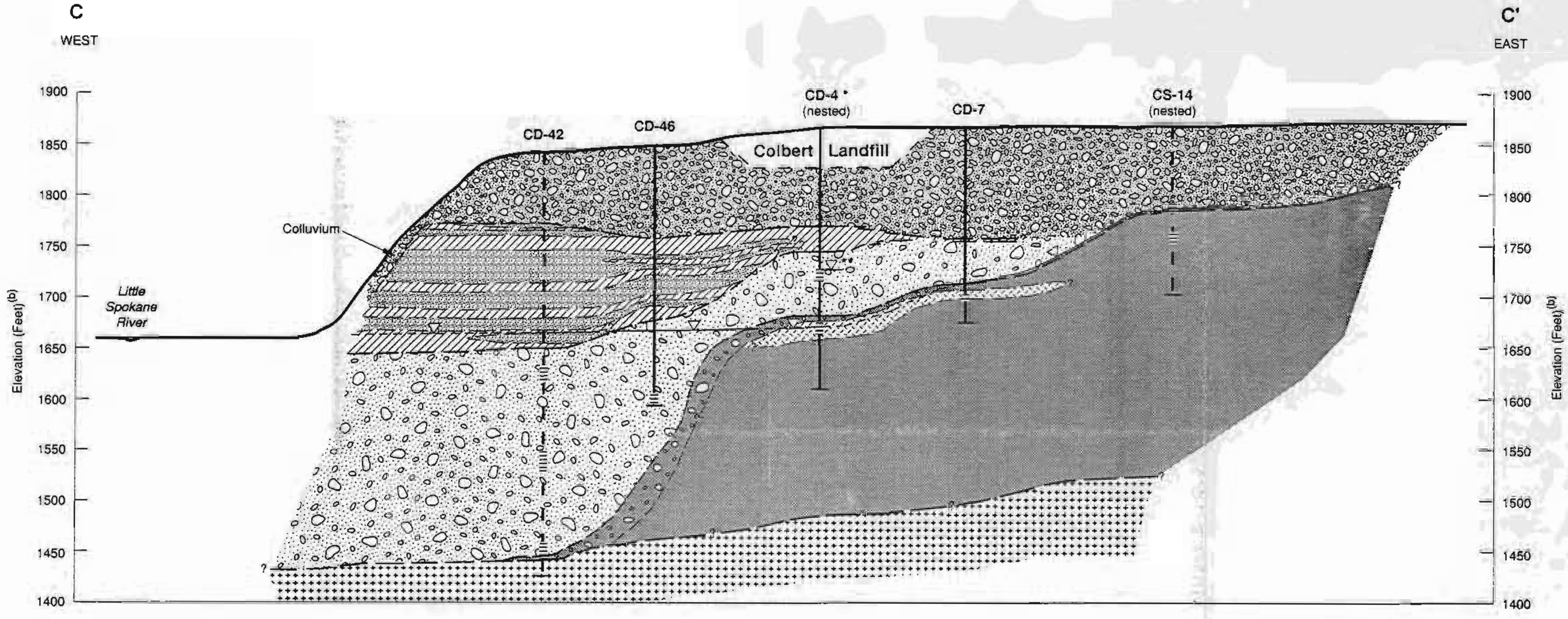
Vertical Scale Exaggeration: 6x

124-01.61 Spokane Co./Colbert Landfill/RD/RA Phase I/Final Engineering Report 12/91

LANDAU ASSOCIATES, INC.

Geologic Cross Section B-B'

From Final Phase 1 Engineering Report (Landau Associates, 1991) Figure ER-4.4



0 600 1200

Approximate Scale in Feet

Vertical Scale Exaggeration: 6x

Notes:
a) Subsurface profiles shown have been generalized from data obtained during Phase I and other Site investigations. Variations between this profile and the actual soil conditions may be encountered. The boring logs and the discussion in the text of this Report must be referenced for a proper understanding of the nature of subsurface materials.

b) All elevations in feet above mean sea level (MSL) based on 1929; National Geodetic Vertical Datum.

* Well drilled by air rotary; detailed geology not identified in Lacustrine Aquitard Unit.

** Ground water in CD-4(U) appears to be perched. However, an underlying aquitard is not identified on the boring log.

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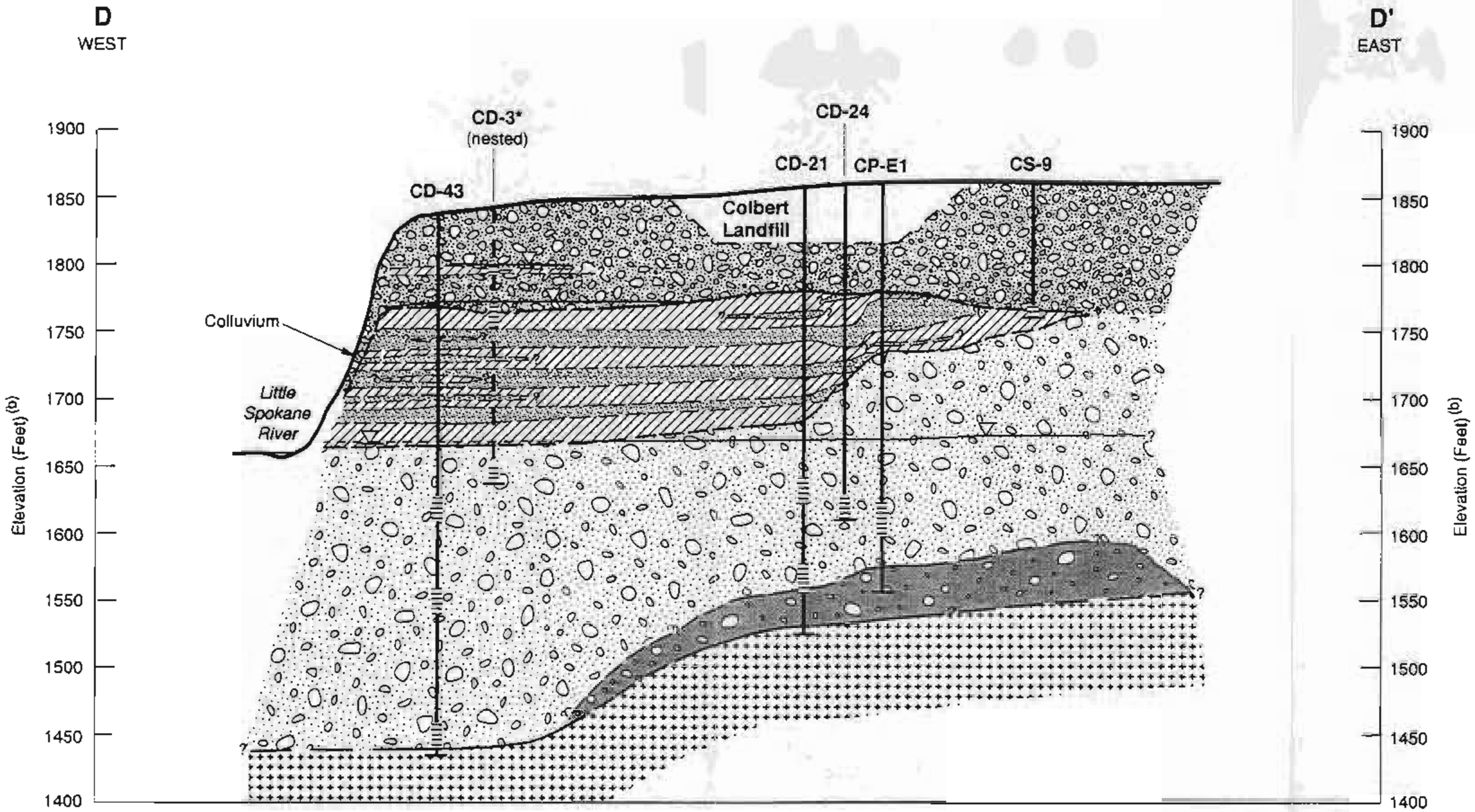
LANDAU ASSOCIATES, INC.

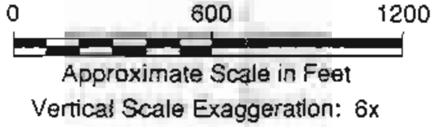
Geologic Cross Section C-C'

From Final Phase 1 Engineering Report (Landau Associates, 1991) Figure ER-4.5



Notes: a) Subsurface profiles shown have been generalized from data obtained during Phase I and other Site investigations. Variations between this profile and the actual soil conditions may be encountered. The boring logs and the discussion in the text of this Report must be referenced for a proper understanding of the nature of subsurface materials.

b) All elevations in feet above mean sea level (MSL) based on 1929, National Geodetic Vertical Datum.



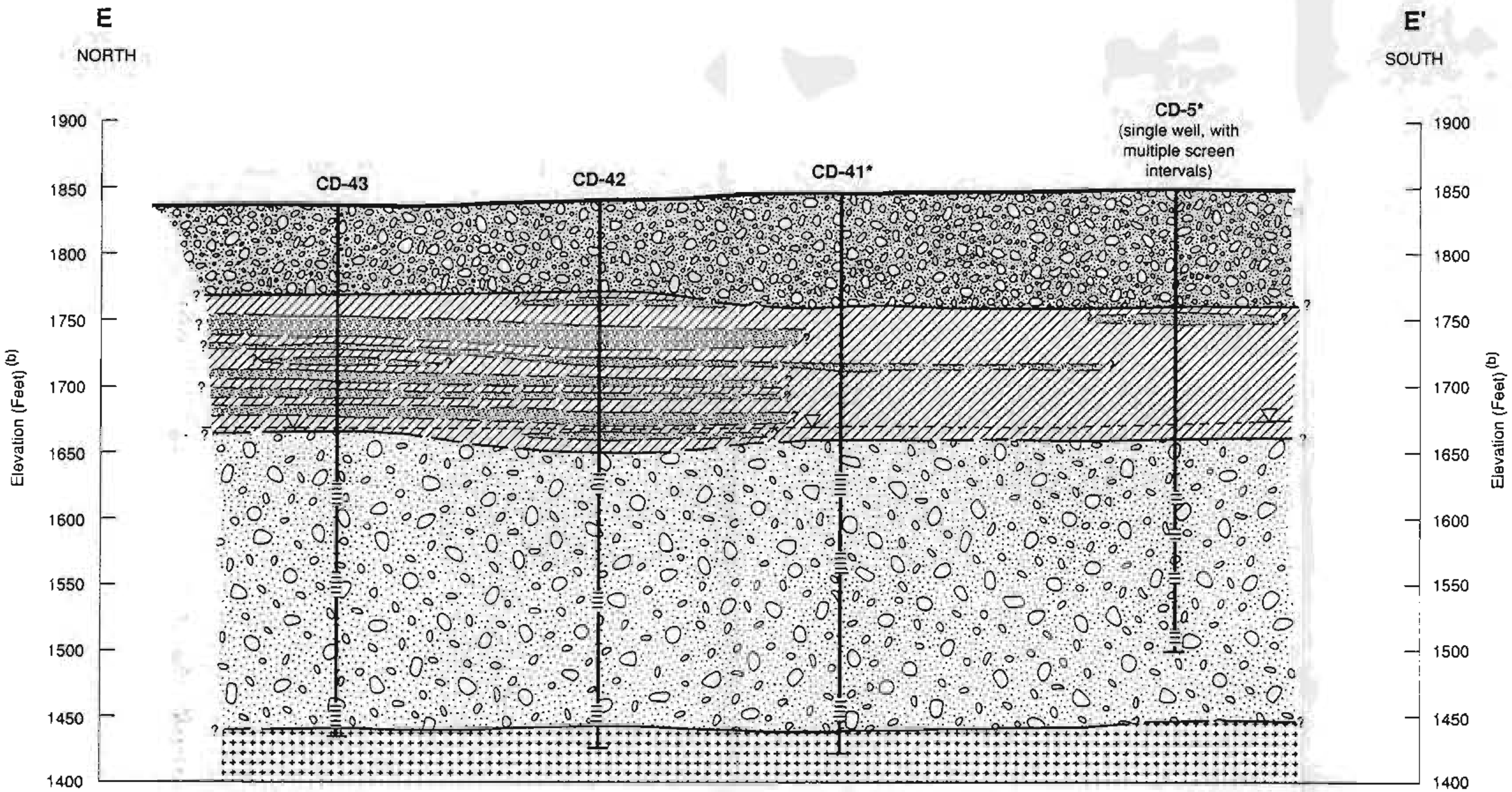
* Well drilled by air rotary; detailed geology in Lacustrine Aquitard Unit based on CD-43 boring data.

124-01.61 Spokane Co./Colbert Landfill/RD/RA Phase I/Final Engineering Report 12/91

LANDAU ASSOCIATES, INC.

Geologic Cross Section D-D'

From Final Phase 1 Engineering Report (Landau Associates, 1991) Figure ER-4.6



Notes: a) Subsurface profiles shown have been generalized from data obtained during Phase I and other Site investigations. Variations between this profile and the actual soil conditions may be encountered. The boring logs and the discussion in the text of this Report must be referenced for a proper understanding of the nature of subsurface materials.

b) All elevations in feet above mean sea level (MSL) based on 1929, National Geodetic Vertical Datum.

0 600 1200

Approximate Scale in Feet

Vertical Scale Exaggeration: 6x

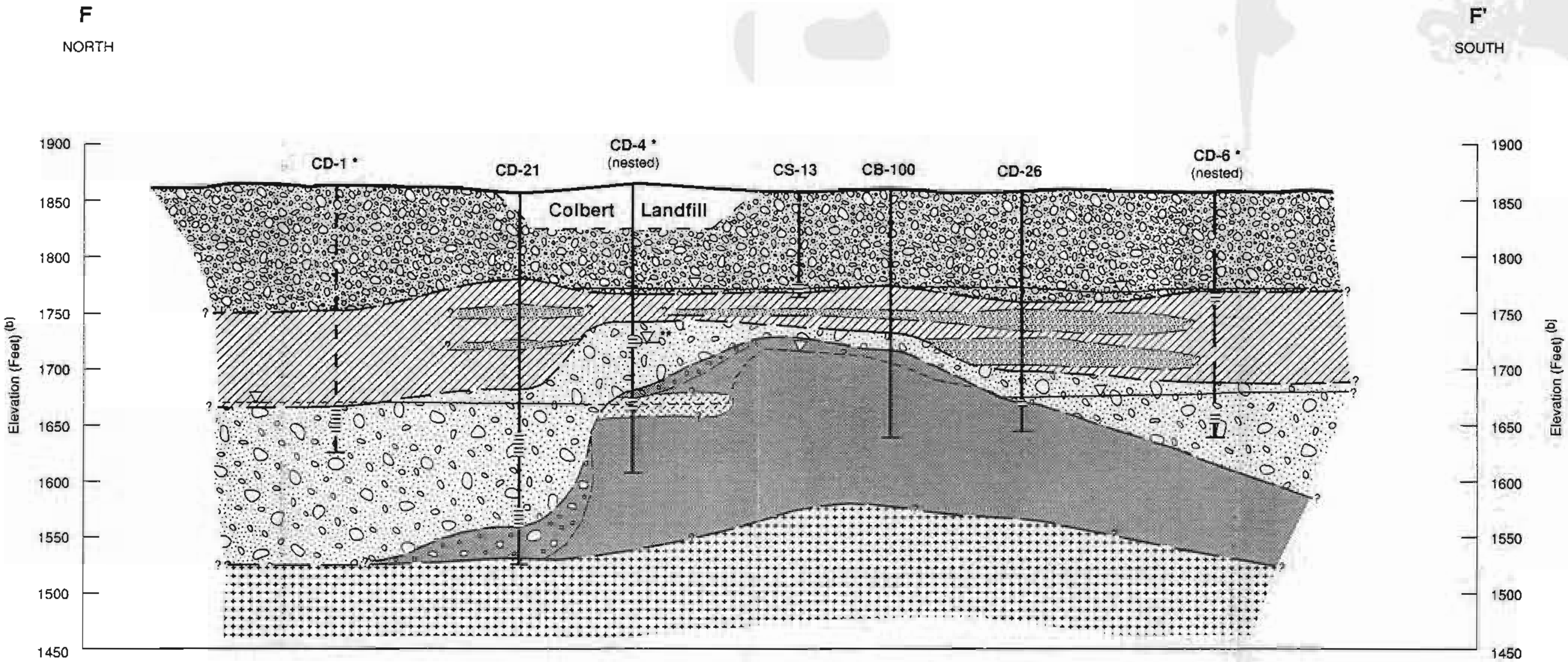
* Well drilled by air rotary; detailed geology not identified in Lacustrine Aquitard Unit.

124 01 61 Spokane Co./Colbert Landfill RD/RA Phase I/Final Engineering Report 12/91

LANDAU ASSOCIATES, INC.

Geologic Cross Section E-E'

From Final Phase 1 Engineering Report (Landau Associates, 1991) Figure ER-4.7



Notes: a) Subsurface profiles shown have been generalized from data obtained during Phase I and other Site investigations. Variations between this profile and the actual soil conditions may be encountered. The boring logs and the discussion in the text of this Report must be referenced for a proper understanding of the nature of subsurface materials.

b) All elevations in feet above mean sea level (MSL) based on 1929, National Geodetic Vertical Datum.

0 600 1200
Approximate Scale in Feet
Vertical Scale Exaggeration: 6x

* Well drilled by air rotary; detailed geology not identified in Lacustrine Aquitard Unit.
** Ground water in CD-4(U) appears to be perched. However, an underlying aquitard is not identified on the boring log.

124-01-61 Spokane Co/Colbert Landfill/RD/RA Phase VI Final Engineering Report 12/91

LANDAU ASSOCIATES, INC.

Geologic Cross Section F-F'

From Final Phase 1 Engineering Report (Landau Associates, 1991) Figure ER-4.8

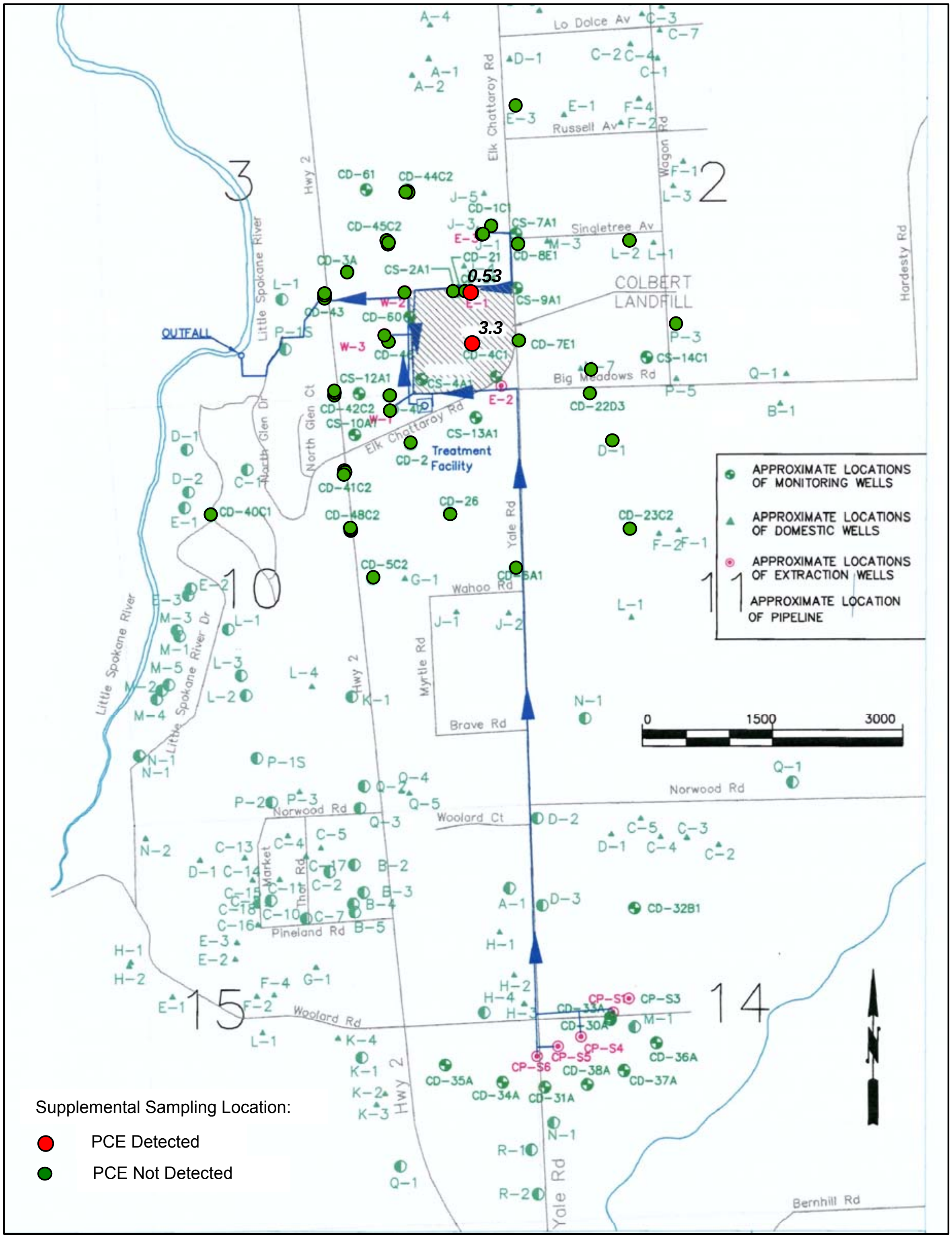


Figure 25. PCE concentrations detected in Lower Aquifer during Supplemental Sampling

From Fourth Five-Year Review (September 2009)

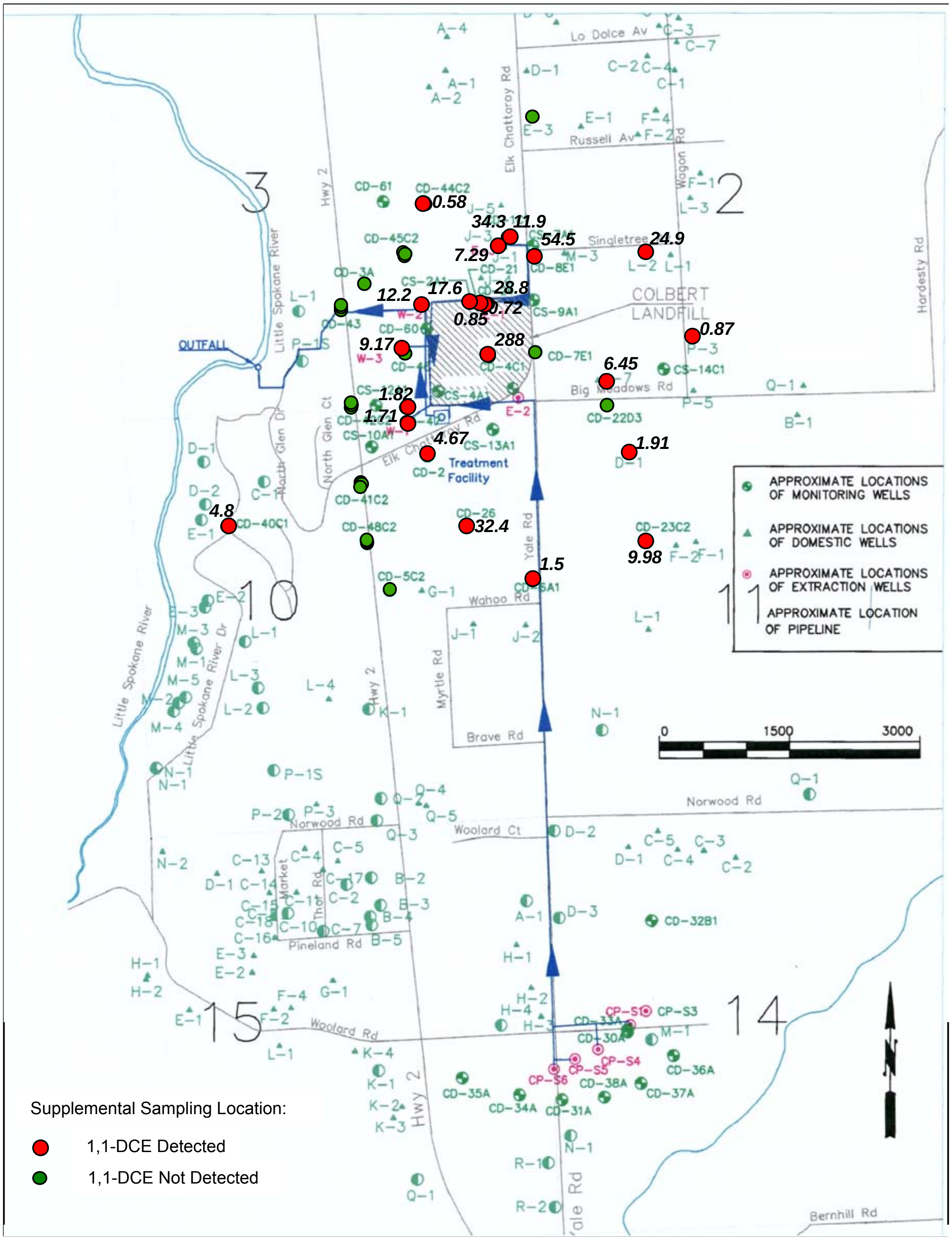


Figure 26. 1,1-DCE concentrations detected in Lower Aquifer during Supplemental Sampling

From Fourth Five-Year Review (September 2009)

Note: It was stated to the RSE team that the TCE concentrations for CD-7E1 and CD-4E1 indicated on this figure are incorrect and should be "swapped".

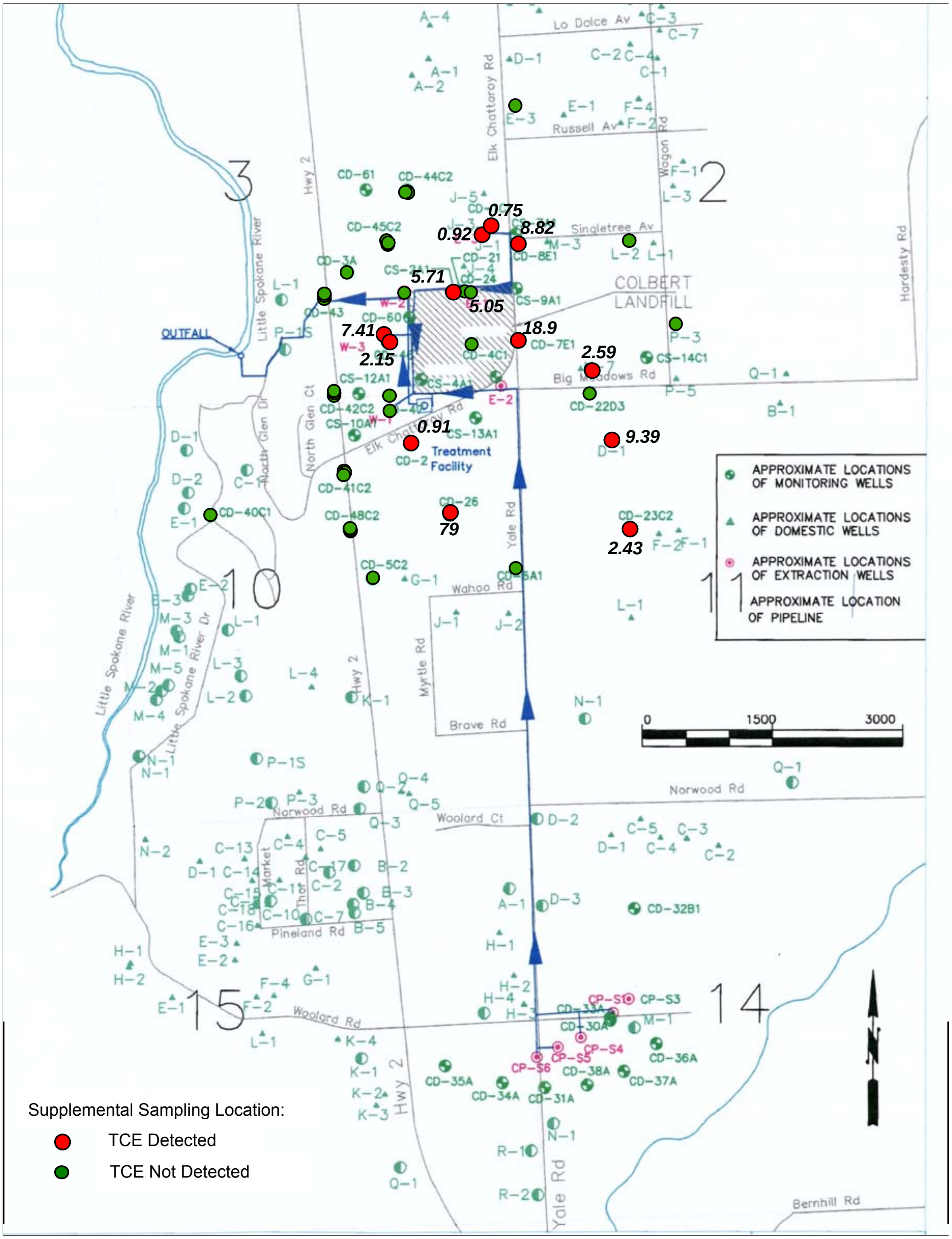


Figure 27. TCE Concentrations detected in Lower Aquifer during Supplemental Sampling

From Fourth Five-Year Review (September 2009)

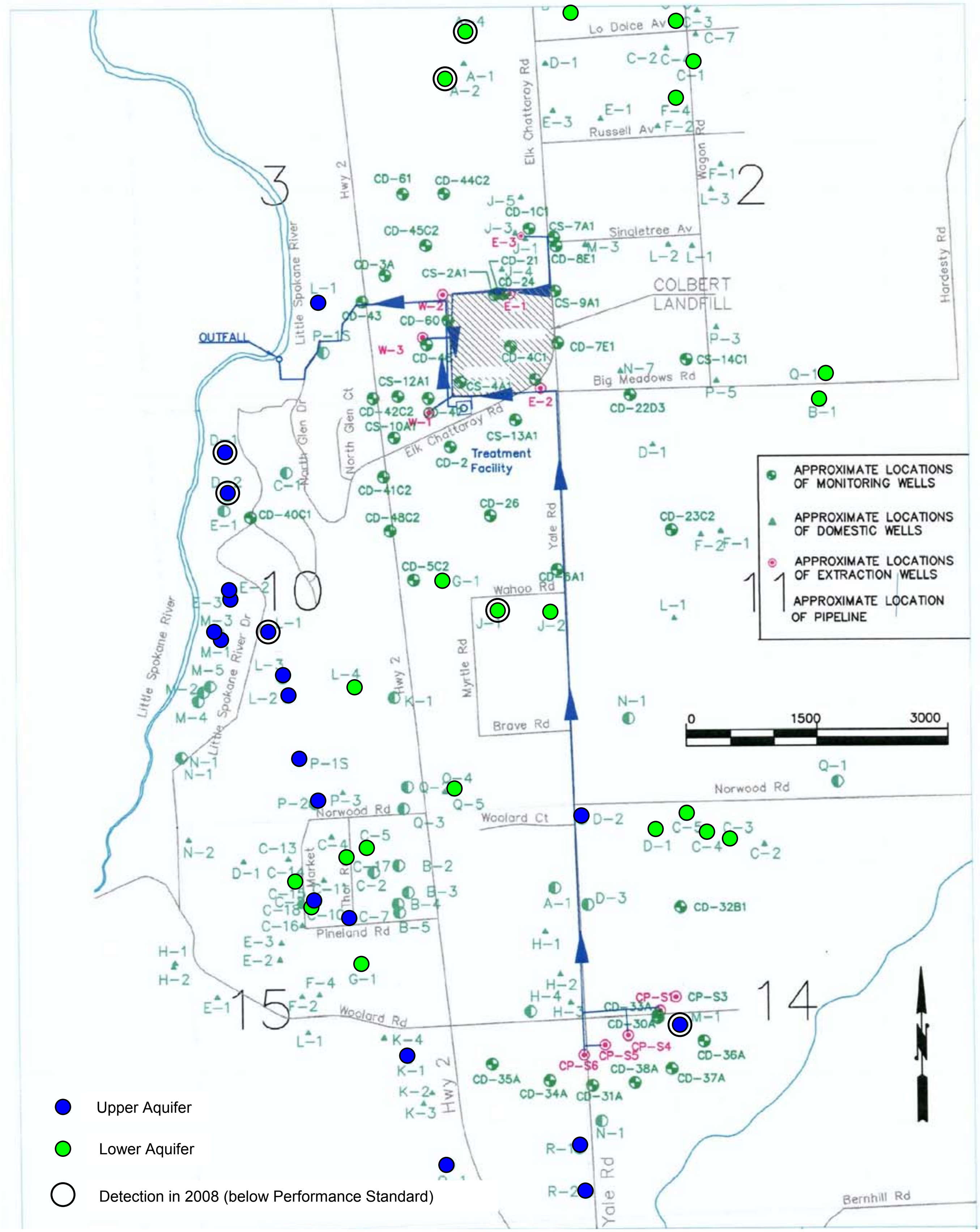


Figure 28. Domestic well monitoring locations (2004 – 2008)

From Fourth Five-Year Review (September 2009)

Note:"system shutdown" on this figure refers to shutdown of the southern extraction well system.

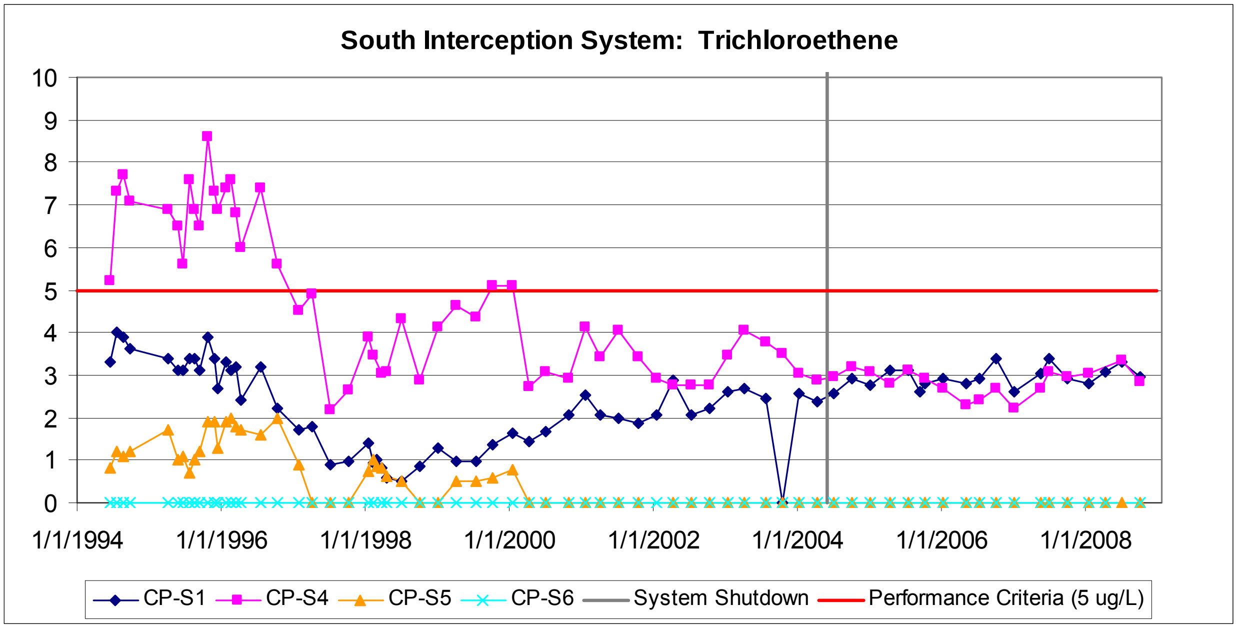


Figure 9. Concentration of TCE in South Interception System Extraction Wells

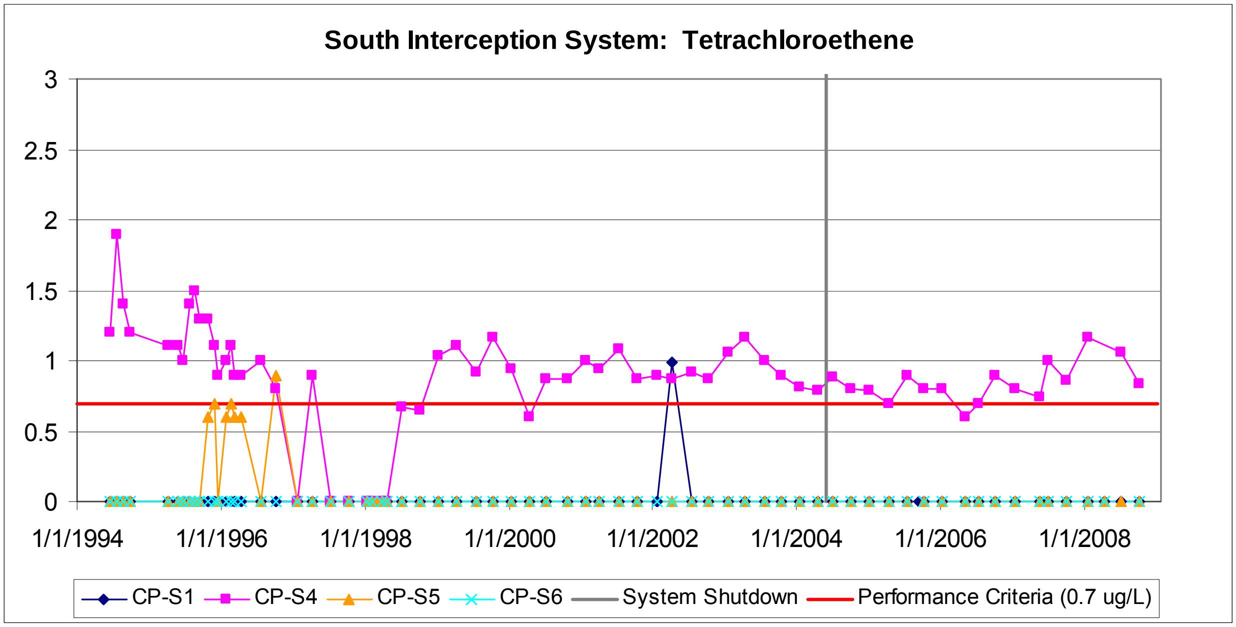


Figure 10. Concentration of PCE in South System Extraction Wells

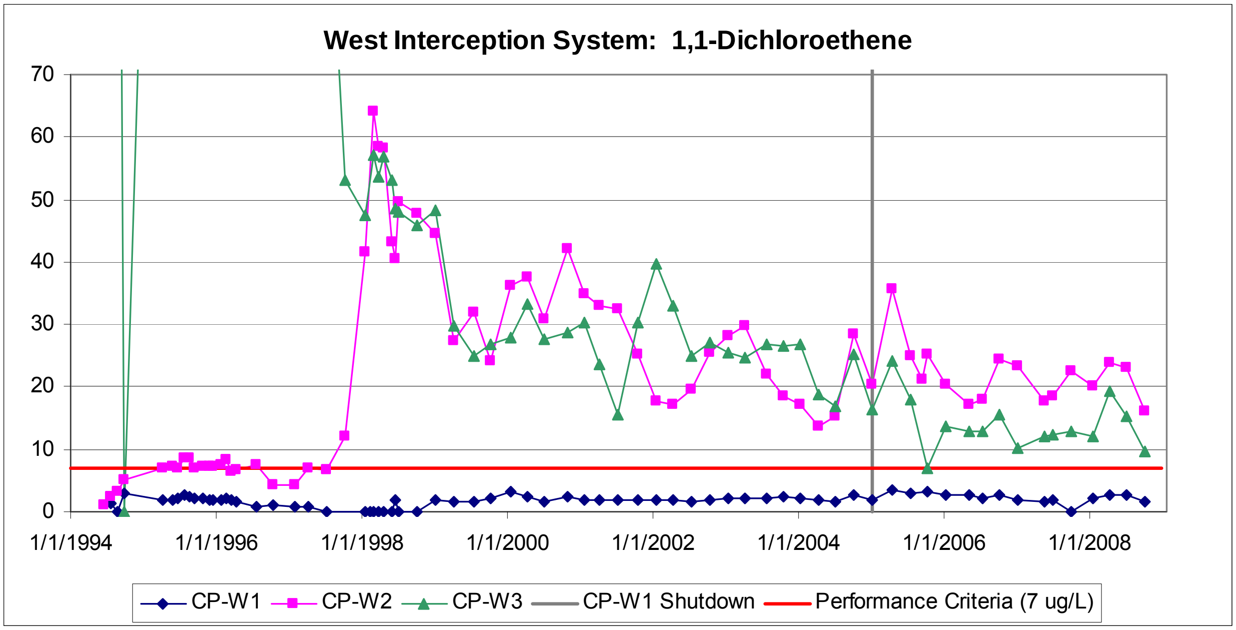


Figure 11. Concentration of 1,1-DCE in West System Extraction Wells

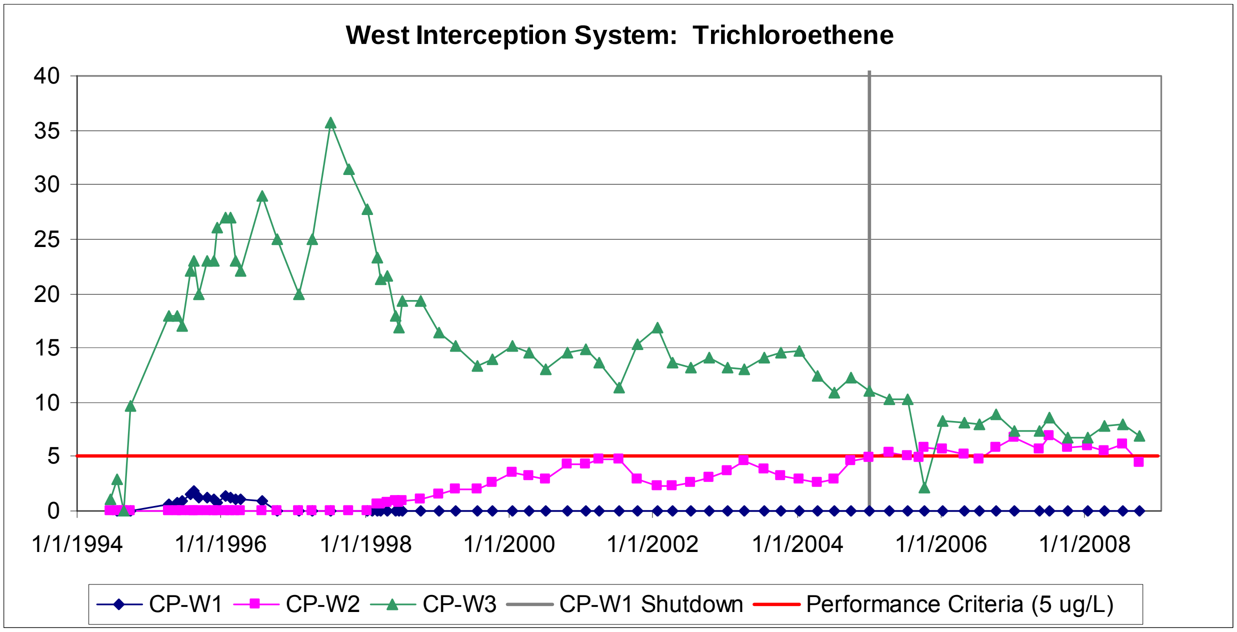
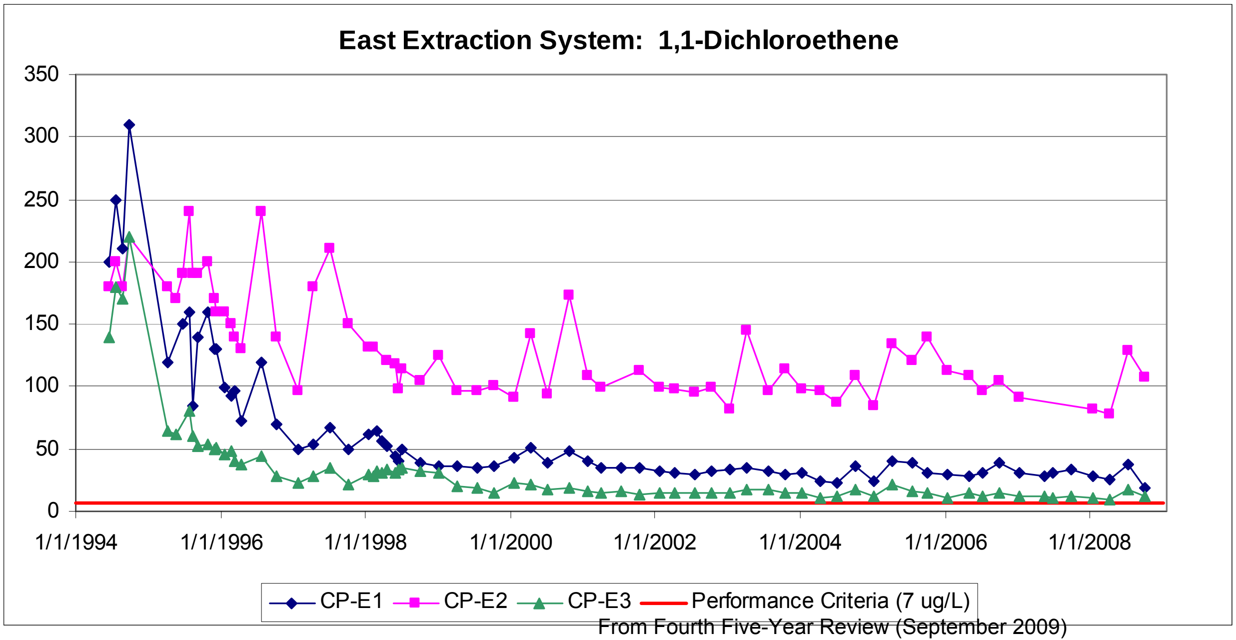


Figure 12. Concentrations of TCE in West System Extraction Wells



From Fourth Five-Year Review (September 2009)

Figure 13. Concentrations of 1,1-DCE in East System Extraction Wells

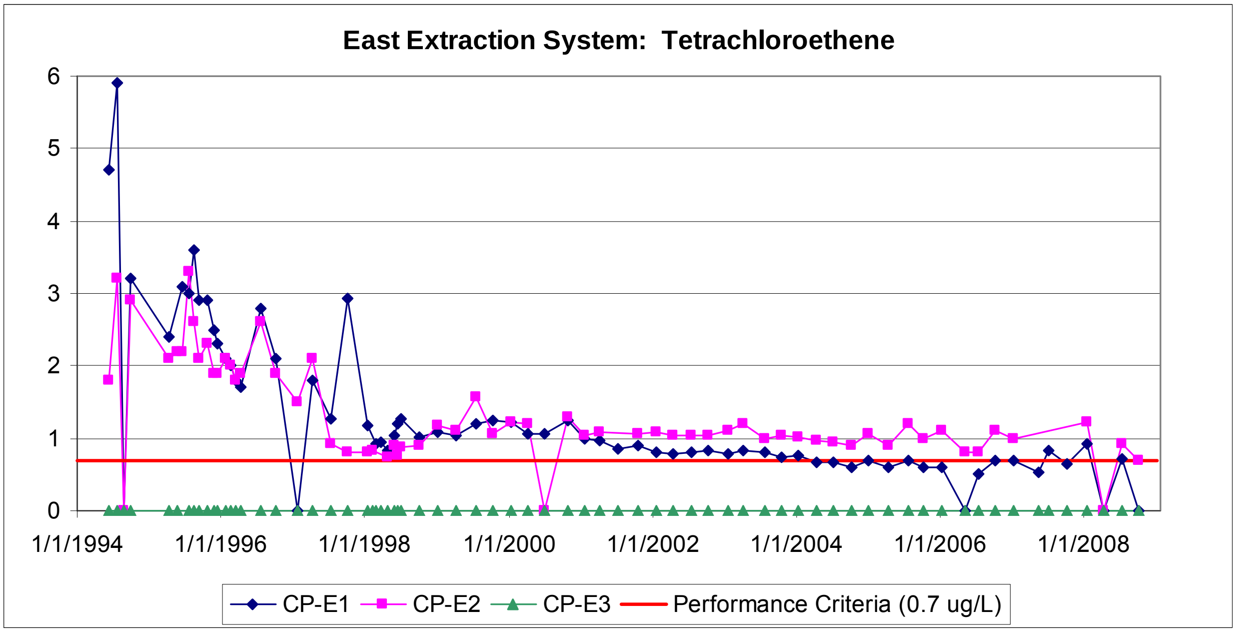


Figure 14. Concentrations of PCE in East System Extraction Wells

From Fourth Five-Year Review (September 2009)

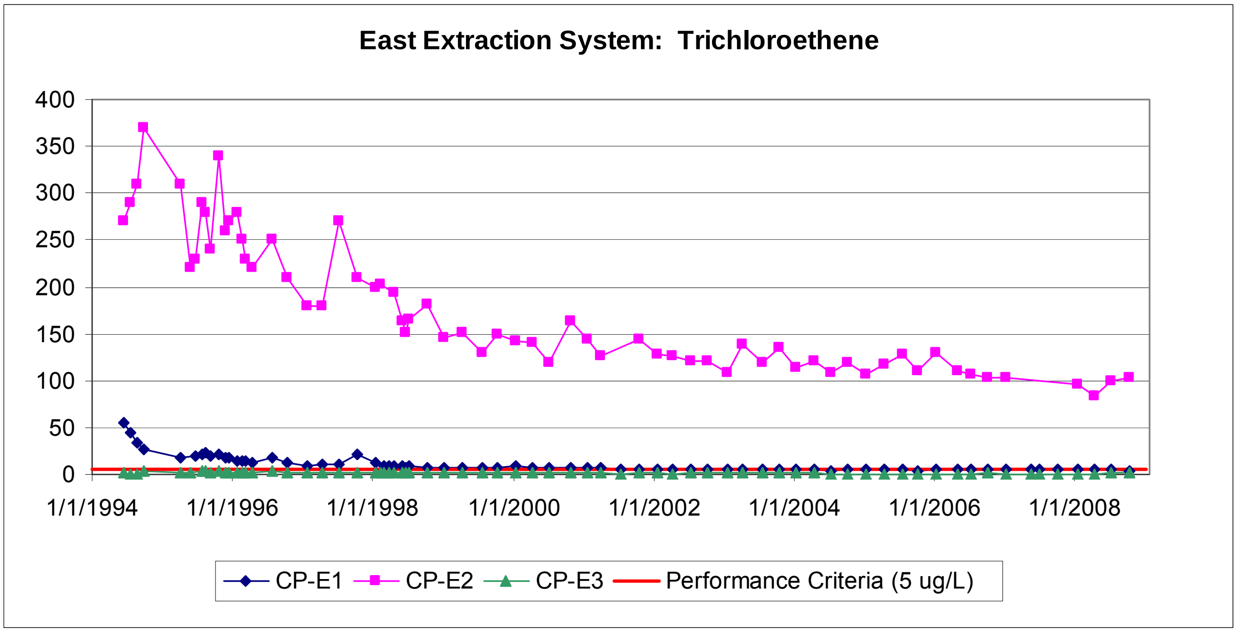
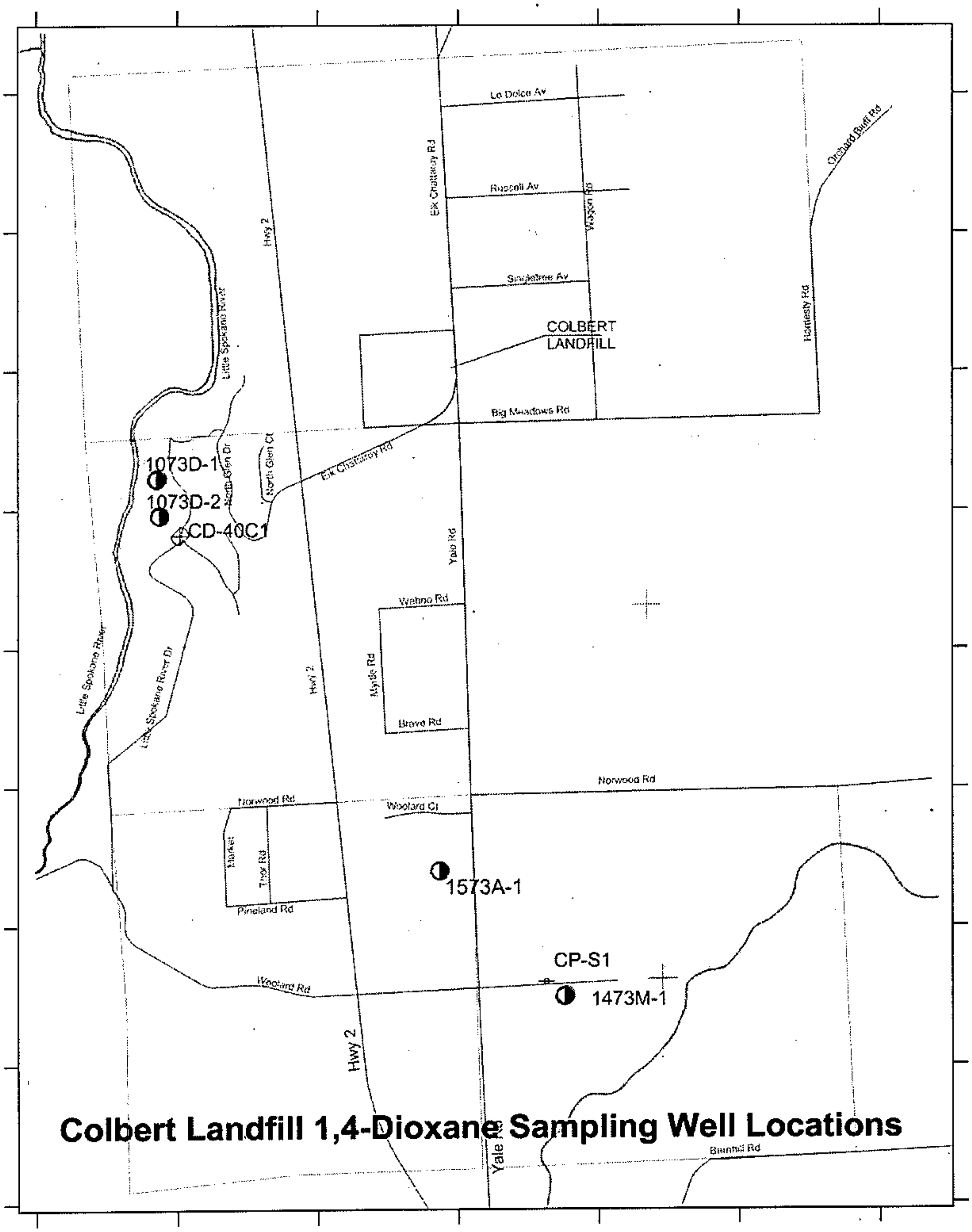


Figure 15. Concentrations of TCE in East System Extraction Wells

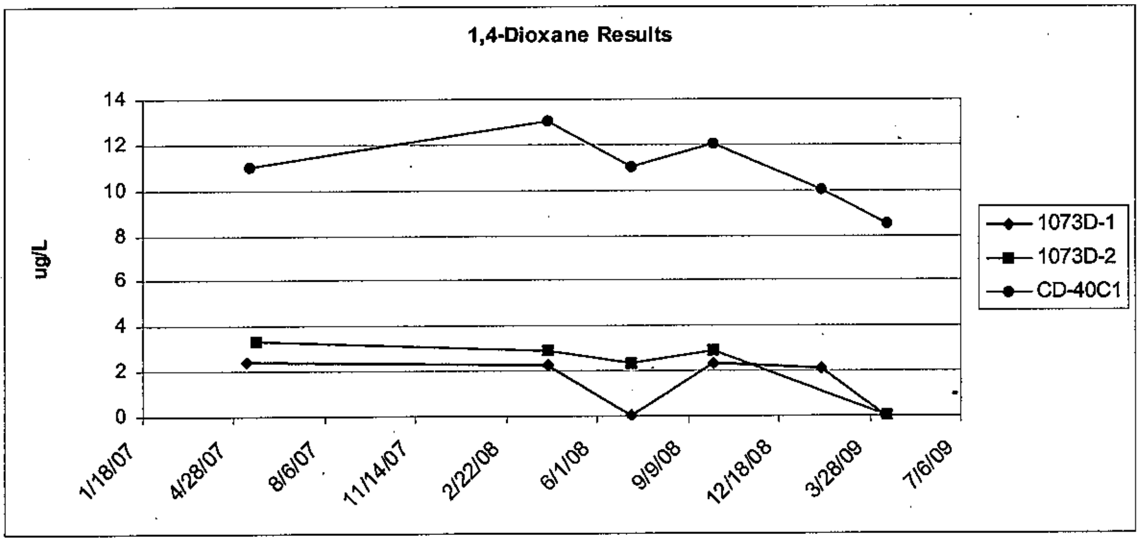
From Fourth Five-Year Review (September 2009)

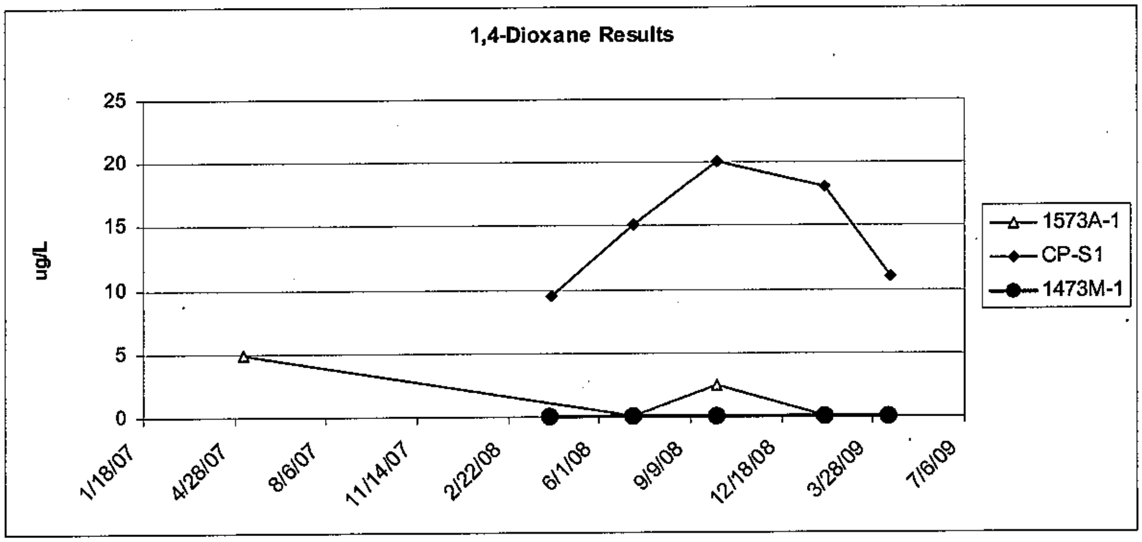
Figure 6-1 Colbert Landfill 1,4-Dioxane Sampling Locations April 2008



From Quarterly Progress Report, Second Quarter 2009 (Spokane County)

Figure 6-2 Colbert Landfill 1,4-Dioxane Concentrations vs. Time





From Quarterly Progress Report, Second Quarter 2009 (Spokane County)

Table 6-2 1,4-Dioxane Sampling Field and Analysis Results

(April 2008 through April 2009)

StationID	SampleDate	Analyte	Result	Qualifier	Units	Temperature	pH	Conductivity	Turbidity	Depth to Water
1073D-1	4/8/2008	1,4-Dioxane	2.2		ug/L	9.2	8.01	412		1.79
1073D-1	7/8/2008	1,4-Dioxane	2	U	ug/L	13	7.92	396	0.08	2.76
1073D-1	10/7/2008	1,4-Dioxane	2.3		ug/L	11.1	8.01	389	0.19	2.89
1073D-1	2/3/2009	1,4-Dioxane	2.1		ug/L	10.6	8.04	372	0.23	2.99
1073D-1	4/14/2009	1,4-Dioxane	2	U	ug/L	10.9	8.02	393	0.36	1.76
1073D-2	4/8/2008	1,4-Dioxane	2.9		ug/L	10.3	7.94	411		
1073D-2	7/8/2008	1,4-Dioxane	2.3		ug/L	11.9	8.01	397	0.09	2.11
1073D-2	7/8/2008	1,4-Dioxane	2.1		ug/L					
1073D-2	10/7/2008	1,4-Dioxane	2.9		ug/L	11.9	8.01	394	0.73	3.11
1073D-2	4/15/2009	1,4-Dioxane	2	U	ug/L	10.2	7.91	404	0.49	1.25
1473M-1	4/8/2008	1,4-Dioxane	2	U	ug/L	10.3	7.61	535		
1473M-1	7/8/2008	1,4-Dioxane	2	U	ug/L	11.9	7.55	504	0.2	
1473M-1	10/7/2008	1,4-Dioxane	2	U	ug/L	11.2	7.62	451	0.17	
1473M-1	2/3/2009	1,4-Dioxane	2	U	ug/L	10	7.6	497	0.18	
1473M-1	4/14/2009	1,4-Dioxane	2	U	ug/L	10.4	7.52	502	0.15	90
1573A-1	7/8/2008	1,4-Dioxane	2	U	ug/L	12.9	7.52	521	0.19	93.03
1573A-1	10/7/2008	1,4-Dioxane	2.4		ug/L	11.3	7.54	515	0.12	92.87
1573A-1	2/3/2009	1,4-Dioxane	2	U	ug/L	8.1	7.52	525	1.1	93.31
1573A-1	4/14/2009	1,4-Dioxane	2	U	ug/L	10.7	7.49	500	0.9	93.26
CD-40C1	4/8/2008	1,4-Dioxane	12		ug/L	9.6	7.8	531	0.34	8.75
CD-40C1	4/8/2008	1,4-Dioxane	13		ug/L					
CD-40C1	7/8/2008	1,4-Dioxane	11		ug/L	10.2	7.8	503	0.16	9.81
CD-40C1	10/7/2008	1,4-Dioxane	12		ug/L	9.9	7.65	510	0.12	10.01
CD-40C1	10/7/2008	1,4-Dioxane	12		ug/L					
CD-40C1	2/3/2009	1,4-Dioxane	10		ug/L	9.9	7.72	519	0.3	10.01
CD-40C1	2/3/2009	1,4-Dioxane	9.9		ug/L					
CD-40C1	4/15/2009	1,4-Dioxane	8.5		ug/L					
CD-40C1	4/15/2009	1,4-Dioxane	8.3		ug/L	9.4	7.69	518	0.29	8.55
CP-S1	4/9/2008	1,4-Dioxane	9.4		ug/L	10.5	7.27	665	0.25	84.56
CP-S1	7/8/2008	1,4-Dioxane	15		ug/L	11.1	7.22	486	0.15	90.78
CP-S1	10/7/2008	1,4-Dioxane	20		ug/L	11.6	7.18		0.32	87.06
CP-S1	2/3/2009	1,4-Dioxane	18		ug/L	9.5	7.21	722	0.69	79.96
CP-S1	4/16/2009	1,4-Dioxane	11		ug/L	11	7.29	735		89.7
						(degrees C)		(umhos/cm)	(NTU)	(FT)

From Quarterly Progress Report, Second Quarter 2009 (Spokane County)

ATTACHMENT B

REFERENCE VALUES FOR SUSTAINABILITY FOOTPRINT CALCULATIONS

Input for Pump and Treat System

General Scope	***Typical Scope Items***	***Useful Information***
- Air stripper operation and off-gas emissions - Landfill gas extraction, exhaust treatment, and emissions - Laboratory analysis for process sampling and groundwater monitoring - Commute for labor not included because staff is assumed to be on-site for other related activities		

Labor, Mobilizations, Mileage, and Fuel

Participant	**Crew Size**	**Number of Days**	**Hours Worked Per Day**	**Total Hours Worked**	**Trips to Site**	**Roundtrip Miles to Site**	**Mode of Transport.**	**Fuel Type**	**Total Miles Traveled**	**Miles Per Gallon**	**Total Fuel Used**	**Activity or Notes**

Equipment Use, Mobilization, and Fuel Usage

Equipment Type	**HP**	**Load Factor**	**Equip. Fuel Type**	**Gallons Fuel Used per Hour**	**Total Hours Operated**	**Gallons Fuel Used On-Site**	**Trips to Site**	**Distance to Site**	**Total Miles Traveled**	**Transport Fuel Type**	**Miles per Gallon**	**Gallons Fuel Used for Transport.**	**Activity or Notes**
Other	2	0.5	Gasoline	0.054	56	3.024							**Generator use for well sampling (2hours per well)**

Electricity Usage

Equipment Type	**HP**	**% Full Load**	**Efficiency**	**Electrical Rating (kW)**	**Hours Used**	**Energy Used (kWh)**	**Notes**
	N/A						
	N/A						
	N/A						
			Totals	0		703000	Total electricity usage from bills

Natural Gas Usage

Equipment Type	**Heat Load (btu/hr)**	**Power Rating (btu/hr)**	**Effiency**	**Total Hours Used**	**Btus Required**	**Total Therms Used**	**Activity or Notes**
			Totals				

Input for Pump and Treat System

Materials Usage

Material Type	Unit	Quantity	Trips	Total Miles Transported	Mode of Transport.	Fuel Type	Fuel Use Rate	Total Fuel Use	Notes
GAC: regenerated	lbs	4400	1	1000	Truck B (5-15 tons)	Diesel	7.2	138.9	Assumed roundtrip distance
Sequestering agent	lbs	2000	1	2400	Truck A (< 5 tons)	Diesel	8.5	282.4	Round trip from Carson, CA

gptm = gallons per ton-mile

Laboratory Analysis

Parameter and Notes	Unit Cost	Number of Samples	Total Cost
Total analytical cost			$22,000
Other			
Other			
Other			
Other			
Other			
Other			
Other			
Other			
Other			
Totals		**0**	**22000**

Waste Generation

Waste Type	Unit	Quantity	Trips	Total Miles Transport.	Mode of Transport.	Fuel Type	Fuel Use Rate	Total Fuel Use	Notes
Non-hazardous	tons								
Hazardous	tons								
Recyclable oil	tons								
Hauled to POTW	tons								
For incineration	tons								

gptm = gallons per ton-mile

On-Site Water Usage

Resource Type	Quantity	Use of Resource
Public water (1000 x gal.)		
Extracted GW #1 (1000 x gals)	341640000	P&T water extracted
Extracted GW #2 (1000 x gals)		
Surface water (1000 x gals)		
Reclaimed water (1000 x gals)		
Stormwater (1000 x gals)		

Fate of On-Site Water Usage

Discharge Location	Quantity	Activity or Notes
Discharge to surface water	341640000	treated P&T water
Reinjected to aquifer		
Discharge to POTW		
Discharge to atmosphere		
Public Use		
Irrigation		
Industrial process water		
Other beneficial use		

Other

Item	Quantity	Activity or Notes
On-site HAP emissions	200	emissions from air stripper and LFG off-gas (all VOCs emitted assumed to be HAPs)
On-site GHG emissions	822206.071	Methane emitted in extracted landfill gas
On-site GHG reductions		(CO2 not included in GHG emissios because waste would degrade to CO2 if not landfilled)
On-site NOx reductions		
On-site SOx reductions		
On-site PM reductions		

Landfill Gas Emissions

Compound Emitted	Ext. Rate (cfm)	Conc. by Volume	Mass Emitted (lbs/yr)	Global Warming Potential (lbs CO2e/lb)	Total CO2e* Emitted (lbs)
methane MW= 16	20	9%	39153	21	**822206**
			0		**0**
			0		**0**
			0		**0**
			0		**0**
			0		**0**
			0		**0**
Total greenhouse gas emissions (GHGs)					**822206.1**

Notes:

$$M_e = C \times Q \times \frac{28.3\,L}{ft^3} \times \frac{1\,mole}{24.1\,L} \times \frac{1440\,min}{day} \times \frac{365\ days}{year} \times MW \times \frac{1\,pound}{454\ grams}$$

where

M_e = mass emitted (pounds per year)

Q = flow rate (cfm)

C = concentration by volume

MW = molecular weight (grams / mole)

divide ppmv by 10^6 to obtain C

divide ppbv by 10^9 to obtain C

		Quantity Used	Parameters Used, Extracted, Emitted, or Generated for P&T											
			Energy		CO2e		NO x		SO x		PM		Air Toxics	
			Conv. Factor	Used	Conv. Factor	Emitted	Conv. Factor	Emitted	Conv. Factor	Emitted	Conv. Factor	Emitted	Conv. Factor	Emitted
				Mbtu		lbs		lbs		lbs		lbs		lbs
Totals				***8,471,922.***		***990,775.***		***617.***		***971.***		***82.***		***235.0446***
ON-SITE														
Energy														
Diesel (on-site)	gal	0	139	0	22.5	0	0.17	0	0.0054	0	0.0034	0	5E-06	0
Gasoline (on-site use)	gal	3.024	124	375.	19.6	59.	0.11	0	0.0045	0	0.0005	0	4E-05	0.0001
On-site electricity use	MWh	703	3400	2,390,200.	0	0	0	0	0	0	0	0	0	0
Other														
On-site process emissions (HAPs)	lbs	200	0	0	0	0	0	0	0	0	0	0	1	200.
On-site process emissions (GHGs)	lbs CO2e	822206.07	0	0	1	822,206.	0	0	0	0	0	0	0	0
ON-SITE TOTAL				**2,390,575.**		**822,265.**		**0**		**0**		**0**		**200.0001**
ELECTRICITY GENERATION														
Electricity production	MWh	703	7800	5,483,400.	150	105,450.	0.36	253.	1	703.	0.088	62.	0.0393	27.6279
TRANSPORTATION														
Diesel (off-site use)	gal	421.3	139	58,561.	22.5	9,479.	0.17	72.	0.0054	2.	0.0034	1.	5E-06	0.0022
Gasoline (off-site use)	gal	0	124	0	19.6	0	0.11	0	0.0045	0	0.0005	0	4E-05	0
Electricity transmission	MWh	703	410	288,230.	18	12,654.	0.0432	30.	0.12	84.	0.0106	7.	0.0047	3.3153
TRANSPORTATION TOTAL				**346,791.**		**22,133.**		**102.**		**86.**		**8.**		**3.3175**
OFF-SITE OTHER														
Materials														
Diesel Produced	gal	421.3	18.5	7,794.	2.7	1,138.	0.0064	3.	0.013	5.	0.0003	0	0.0001	0.0506
GAC: regenerated	lbs	4400	9.6	42,240.	2	8,800.	0.025	110.	0.015	66.	0	0	0	0
Gasoline Produced	gal	3.024	21	64.	4.4	13.	0.008	0	0.019	0	0.0005	0	0.0002	0.0005
Sequestering agent	$	6600	8.83	58,278.	1.36	8,976.	0.0065	43.	0.0049	32.	0.0005	3.	0.0002	1.188
Off-Site Services														
Laboratory Analysis	$	22000	6.49	142,780.	1	22,000.	0.0048	106.	0.0036	79.	0.0004	9.	0.0001	2.86
OFF-SITE OTHER TOTAL				251,156.		40,927.		262.		182.		12.		4.0991

Power Sources and Global Emissions Factors for Electricity Provided by
State of Washington Department of Commerce, 2010 Utility Fuel Mix Report for Inland Power & Light

Type	Percentage Used*	Water (gal/kWh)		CO2e (lbs/kWh)		NOx (lbs/kWh)		SOx (lbs/kWh)		PM (lbs/kWh)		HAPs (lbs/kWh)		Lead (lbs/kWh)		Mercury (lbs/kWh)		Dioxins (lbs/kWh)	
		Full Load	**Adjusted**	**Full Load**	**Adjusted**	**Full Load**	**Adjusted**	**Full Load**	**Adjusted**	**Full Load**	**Adjusted**	**Full Load**	**Adjusted**	**Full Load**	**Adjusted**	**Full Load**	**Adjusted**	**Full Load**	**Adjusted**
Biomass	0%	55	0	0	0	0.0015	0	0.00060	0	0.000084	0	0	0	0	0	0	0	0	0
Coal	5%	0.63	0.0315	2.4	0.12	0.0067	0.000335	0.015	0.00075	0.0017	0.000085	0.0007	0.000035	0.00000024	0.000000012	0.000000042	2.1E-09	3.8E-13	1.197E-14
Geothermal	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	82%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	2%	0.57	0.0114	1.4	0.028	0.0012	0.000024	0.012	0.00024	0.000088	0.00000176	0.000193	0.00000386	1.31E-08	2.62E-10	2.9E-09	5.8E-11	0	0
Nuclear	8%	0.55	0.044	0.024	0.00192	0.000056	0.0000045	0.000131	0.00001048	0.0000126	0.000001008	0.0000053	0.000000424	5.2E-09	4.16E-10	4.6E-10	3.68E-11	2.9E-15	1.276E-16
Oil	0%	0.55	0	1.9	0	0.0036	0.0000000	0.0041	0	0.00029	0	0.0000902	0	0.00000129	0	1.01E-08	0	1.04E-12	0
Solar	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wind	3%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total based on kWh at plant	**100%**		**0.1**		**0.15**		**0.00036**		**0.001**		**0.000088**		**0.0000393**		**0.00000001**		**0.000000002**		**1E-14**

Notes:

- *Water consumption for thermoelectric power plants U.S. Average - 0.47 gallons per kWh**
- *Water consumption for hydroelectric power assumed to be 0 gallons per kWh (i.e., considers evaporation from reservoir as non-additive)*
- *Water consumption for coal resource extraction and fuel processing - 0.16 gallons per kWh***
- *Water consumption for uranium resource extraction and fuel processing - 0.082 gallons per kWh***
- *Water consumption for natural gas resource extraction and fuel processing - 0.10 gallons per kWh***
- *Water consumption for biomass based on 55 gallons per kWh****
- *CO2e, Nox, SOx, and PM emissions from NREL LCI for each fuel type *****

** Consumptive Water Use for U.S. Power Production, December 2003 • NREL/TP-550-33905*

*** Gleick PH. Water and energy. Annu. Rev. Energy Environ. Vol 19, 1994. p 267-99.*

**** The Water Footprint of Energy Consumption : an Assessment of Water Requirements of Primary Energy Carriers, Winnie Gerbens-Leenes, Arjen Hoekstra, Theo an der Meer, ISESCO Science and Technology Vision, Volume 4 - Number 5, May 2008*

***** "NREL LCI" refers to the U.S. Dept. of Energy, National Renewable Energy Laboratory (NREL), Life-Cycle Inventory Database (www.nrel.gov/lci) maintained by the Alliance for Sustainable Energy, LLC.*

Electricity and Energy Used for the Production, Transmission, and On-Site Use of Electricity

For the purpose of this study, the sum of the "energy used" for "electricity production", "electricity transmission", and "on-site electricity use" equals the total amount of energy used to generate the 1 MWh used by the consumer. According to the U.S. Dept. of Energy (GridWorks: Overview of the Electric Grid http://sites.energetics.com/gridworks/grid.html) approximately power plants have a thermal efficiency of approximately 33% and the transmission of electricity results in a loss of approximately 10% of the electricity produced. In addition, the National Renewable Energy Laboratory (Consumptive Water Use for U.S. Power Production December 2003 • NREL/TP-550-33905) states that thermoelectric plants use approximately 5% of the gross electricity produced for on-site demand (i.e., parasitic loads).

This study assumes that the 33% thermal efficiency includes the 5% parasitic load.

For use of 1 MWh of electricity on-site, the following calculations illustrate the electricity and energy used.

$$G = P + T + U$$
$$G = 5\%G + 10\%G + 1$$
$$G(1 - 15\%) = 1$$
$$G = 1.18$$

where

$G = \mathit{electricity\ generated}\ (MWh)$

$P = \mathit{parasitic\ load}\ (MWh){:}\ 5\%\ \mathit{of}\ G$

$T = \mathit{transmission\ loss}\ (MWh){:}\ 10\%\ \mathit{of}\ G$

$U = \mathit{energy\ used\ onsite}\ (MWh)$

$$P = 5\% \times 1.18 = 0.06\ MWh$$
$$T = 10\% \times 1.18 = 0.12\ MWh$$

$$E_I = E_P + E_T + E_U$$
$$E_U + E_T = \eta \times E_I$$

$$E_U = 1\ MWh \times \frac{3{,}413 btu}{MWh} = 3{,}413 btu$$
$$E_T = 0.12\ MWh \times \frac{3{,}413 btu}{MWh} = 410 btu$$

$$E_I = \frac{(3{,}413 + 410)}{33\%} = 11{,}584 btu$$

$$E_P = 11{,}584 - 3{,}413 - 410 = 7{,}761 btu$$

where

$E_I = \mathit{energy\ input}\ (btu)$

$E_P = \mathit{energy\ lost\ electricity\ production}$
$(\mathit{thermal\ loss\ and\ parasitic\ load})\ (btu)$

$E_T = \mathit{energy\ lost\ electricity\ transmission}\ (btu)$

$E_U = \mathit{energy\ used\ onsite\ in\ the\ form\ of}$
$\mathit{electricity}\ (btu)$

$\eta = \mathit{thermal\ efficiency}\ (33\%)$

Default Environmental Footprint Conversion Factor References

Material/Fuel/Service	Green Indicator	Value	Units	Assumptions	Information Source
Gasoline (on-site use)	Energy Used	124	Mbtu/gal	The reference provides the higher heating value of gasoline as 5.218 MMBTU per barrel and defines a barrel as 42 gallons. This converts to approximately 124 Mbtu/gallon.	Climate Leader GHG Inventory EPA-430--K-08-004, May 2008
	Electricity Used		MWh/gal	not applicable -- no electricity used when gasoline is combusted on-site or in transportation	
	All Water Used		gal x 1000/gal	not applicable -- no water used when gasoline is combusted on-site or in transportation	
	Potable Water Used		gal x 1000/gal	not applicable -- no water used when gasoline is combusted on-site or in transportation	
	Groundwater Extracted		gal x 1000/gal	not applicable -- no water used when gasoline is combusted on-site or in transportation	
	CO2e Emitted	19.6	lbs/gal	The reference provides CO2e emitted as 8.81 kg of CO2 per gallon. This converts to 19.4 pounds per gallon. Additionally, N2O and CH4 emissions are provided as g/gal. Values are converted to lbs/gal using a global warming potential (GWP) of 1 for carbon dioxide, 21 for methane, and 310 for nitrous oxide.	Climate Leader GHG Inventory EPA-430--K-08-004, May 2008
	NO x Emitted	0.11	lbs/gal	NREL LCI reported the amount of gasoline in liters required to transport one ton-kilometer (tkm) and provided outputs to nature in kg. The output (nitrogen oxides) generated from transporting 1 tkm was divided by the amount of gasoline required to transport 1 tkm, and the units of the result were converted from kg/L to lbs/gallon.	NREL LCI File: SS_Transport, single unit truck, gasoline powered.xls
	SO x Emitted	0.0045	lbs/gal	NREL LCI reported the amount of gasoline in liters required to transport one ton-kilometer (tkm) and provided outputs to nature in kg. The output (sulfur oxides) generated from transporting 1 tkm was divided by the amount of gasoline required to transport 1 tkm, and the units of the result were converted from kg/L to lbs/gallon.	NREL LCI File: SS_Transport, single unit truck, gasoline powered.xls
	PM Emitted	0.00054	lbs/gal	NREL LCI reported the amount of gasoline in liters required to transport one ton-kilometer (tkm) and provided outputs to nature in kg. The output (Particulates, > 2.5 um, and < 10um) generated from transporting 1 tkm was divided by the amount of gasoline required to transport 1 tkm, and the units of the result were converted from kg/L to lbs/gallon.	NREL LCI File: SS_Transport, single unit truck, gasoline powered.xls
	Solid Waste Generated		tons/gal	not applicable -- no waste generated when gasoline is combusted on-site or in transportation (solid waste and waste oil from maintenance would be tracked separately)	
	Haz. Waste Generated		tons/gal	not applicable -- no waste generated when gasoline is combusted on-site or in transportation (solid waste and waste oil from maintenance would be tracked separately)	
	Air Toxics Emitted	0.000039	lbs/gal	Not available in NREL LCI transport files. Summed hazardous air pollutants emitted from combusting gasoline in industrial equipment. NREL LCI provides results in kg per L combusted. Converted this to pounds per gallon by multiplying by 3.785 and multiplying by .2.2	NREL LCI File: SS_gasoline combusted in industrial equipment.xls
	Mercury Released	0	lbs/gal	EUROPA ELCD - Reference does not indicate a release of mercury.	EUROPA file location: Lorry transport; Euro 0, 1, 2, 3, 4 mix; 22 t total weight, 17,3 t max payload (excluding fuel supply): http://lca.jrc.ec.europa.eu/lcainfohub/datasets/elcd/processes/b444f4d2-3393-11dd-bd11-0800200c9a66_02.00.000.xml
	Lead Released	0	lbs/gal	EUROPA ELCD - Reference does not indicate a release of lead	
	Dioxins Released	0	lbs/gal	EUROPA ELCD - Reference does not indicate a release of dioxins.	

"NREL LCI" refers to the U.S. Dept. of Energy, National Renewable Energy Laboratory (NREL), Life-Cycle Inventory Database (www.nrel.gov/lci) maintained by the Alliance for Sustainable Energy, LLC.

Default Environmental Footprint Conversion Factor References

Material/Fuel/Service	Green Indicator	Value	Units	Assumptions	Information Source
Diesel (off-site use)	Energy Used	139	Mbtu/gal	The reference provides the higher heating value of diesel as 5.825 MMBTU per barrel and defines a barrel as 42 gallons. This converts to approximately 139 Mbtu/gallon.	Climate Leader GHG Inventory EPA-430--K-08-004, May 2008
	Electricity Used		MWh/gal		
	All Water Used		gal x 1000/gal		
	Potable Water Used		gal x 1000/gal		
	Groundwater Extracted		gal x 1000/gal		
	CO2e Emitted	22.5	lbs/gal	The reference provides CO2e emitted as 10.15 kg of CO2 per gallon. This converts to 22.3 pounds per gallon. Additionally, N2O and CH4 emissions are provided as g/gal. Values are converted to lbs/gal using a global warming potential (GWP) of 1 for carbon dioxide, 21 for methane, and 310 for nitrous oxide.	Climate Leader GHG Inventory EPA-430--K-08-004, May 2008
	NO x Emitted	0.17	lbs/gal	NREL LCI reported the amount of diesel in liters required to transport one ton-kilometer (tkm) and provided outputs to nature in kg. The output (nitrogen oxides) generated from transporting 1 tkm was divided by the amount of diesel required to transport 1 tkm, and the units of the result were converted from kg/L to lbs/gallon.	NREL LCI File: SS_Transport, single unit truck, diesel powered.xls
	SO x Emitted	0.0054	lbs/gal	NREL LCI reported the amount of diesel in liters required to transport one ton-kilometer (tkm) and provided outputs to nature in kg. The output (sulfur oxides) generated from transporting 1 tkm was divided by the amount of diesel required to transport 1 tkm, and the units of the result were converted from kg/L to lbs/gallon.	NREL LCI File: SS_Transport, single unit truck, diesel powered.xls
	PM Emitted	0.0034	lbs/gal	NREL LCI reported the amount of diesel in liters required to transport one ton-kilometer (tkm) and provided outputs to nature in kg. The output (Particulates, > 2.5 um, and < 10um) generated from transporting 1 tkm was divided by the amount of diesel required to transport 1 tkm, and the units of the result were converted from kg/L to lbs/gallon.	NREL LCI File: SS_Transport, single unit truck, diesel powered.xls
	Solid Waste Generated		tons/gal	not applicable -- no waste generated when diesel is combusted on-site or in transportation (solid waste and waste oil from maintenance would be tracked separately)	
	Haz. Waste Generated		tons/gal	not applicable -- no waste generated when diesel is combusted on-site or in transportation (solid waste and waste oil from maintenance would be tracked separately)	
	Air Toxics Emitted	0.0000052	lbs/gal	Not available in NREL LCI transport files. Summed hazardous air pollutants emitted from combusting diesel in industrial equipment. NREL LCI provides results in kg per L combusted. Converted this to pounds per gallon by multiplying by 3.785 and multiplying by .2.2	NREL LCI File: SS_diesel combusted in industrial equipment.xls
	Mercury Released	0	lbs/gal	EUROPA ELCD - Reference does not indicate a release of mercury.	EUROPA file location: Lorry transport; Euro 0, 1, 2, 3, 4 mix; 22 t total weight, 17,3 t max payload (excluding fuel supply): http://lca.jrc.ec.europa.eu/lcainfohub/datasets/elcd/processes/b444f4d2-3393-11dd-bd11-0800200c9a66_02.00.000.xml
	Lead Released	0	lbs/gal	EUROPA ELCD - Reference does not indicate a release of lead	
	Dioxins Released	0	lbs/gal	EUROPA ELCD - Reference does not indicate a release of dioxins.	

EUROPA ECLD refers to the European Reference Life Cycle Database (ELCD core database), version II compiled under contract on behalf of the European Commission - DG Joint Research Centre - Institute for Environment and Sustainability with technical and scientific support by JRC-IES from early 2008 to early 2009. (http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm)

Default Environmental Footprint Conversion Factor References

Material/Fuel/Service	Green Indicator	Value	Units	Assumptions	Information Source
Diesel Produced	Energy Used	18.5	Mbtu/gal	EUROPA ELCD - All forms of energy summed and converted to Mbtus per gallon of product.	Primary NREL LCI File: -SS_crude oil, in refinery.xls Secondary NREL LCI File: -SS_crude oil, at production.xls EUROPA file location: Diesel at refinery: http://lca.jrc.ec.europa.eu/lcainfohub/datasets/html/processes/244524ed-7b85-4548-b345-f58dc5cf9dac_02.00.000.html
	Electricity Used	0.00059	MWh/gal	Not provided by EUROPA ELCD. NREL LCI includes electricity usage for crude oil, in refinery with an allocation to diesel. Electricity from crude oil, in refinery (allocated to diesel) and crude oil, at production are included.	
	All Water Used	0.00077	gal x 1000/gal	EUROPA ELCD - Sum of "water", "surface water", "groundwater", and "river water". Negative values (indicating return of water to the hydrosphere) were not included. Sea water was also not included. Result converted to thousands of gallons per gallon of product	
	Potable Water Used		gal x 1000/gal	Not applicable -- no local potable water used during diesel production.	
	Groundwater Extracted		gal x 1000/gal	Not applicable -- no local or on-site ground water extracted during diesel production.	
	CO2e Emitted	2.7	lbs/gal	EUROPA ELCD - Sum of total global warming potential for carbon dioxide, methane, and nitrous oxide released to atmosphere. A global warming potential of 21 is used for methane and a global warming potential of 310 is used for nitrous oxide. Results converted to pounds of carbon dioxide equivalents per gallon of product.	
	NO x Emitted	0.0064	lbs/gal	EUROPA ELCD - Sum of nitrogen oxides emitted to atmosphere. Results converted to pounds of NO x per gallon of product.	
	SO x Emitted	0.013	lbs/gal	EUROPA ELCD - Sum of sulfur oxides emitted to atmosphere. Results converted to pounds of SO x per gallon of product.	
	PM Emitted	0.00034	lbs/gal	EUROPA ELCD - Sum of particulate matter (PM 10 and smaller) emitted to atmosphere. Results converted to pounds of PM per gallon of product.	
	Solid Waste Generated	0.00000036	tons/gal	EUROPA ELCD - Sum of all listed wastes (demolition debris) except for radioactive wastes, slag, and mining wastes, which would likely not be disposed of in a landfill.	
	Haz. Waste Generated	0	tons/gal	EUROPA ELCD - "Chemical waste, toxic" converted into tons per pound of product. No hazardous waste is listed in EUROPA for diesel production, suggesting that little or no hazardous waste is produced as a result of these activities.	
	Air Toxics Emitted	0.00012	lbs/gal	EUROPA ELCD - Sum of all hazardous air pollutants and groups of contaminants as defined by EPA (HAPs) emitted to atmosphere. Reported as pounds per gallon of product.	
	Mercury Released	0.000000048	lbs/gal	EUROPA ELCD - Sum of all mercury and mercury compounds released to air or water. Reported as pounds per gallon of product.	
	Lead Released	0.0000015	lbs/gal	EUROPA ELCD - Sum of all lead and lead compounds released to air or water. Reported as pounds per gallon of product.	
	Dioxins Released	3E-14	lbs/gal	EUROPA ELCD - Sum of all dioxins released to air or water. Reported as pounds per gallon of product.	

Default Environmental Footprint Conversion Factor References

Material/Fuel/Service	Green Indicator	Value	Units	Assumptions	Information Source
GAC: regenerated	Energy Used	9.6	Mbtu/lbs	Calculated using information from the cited reference. See support file for calculations.	Use of Adsorbents for the Removal of Pollutants from Wastewaters, by Gordon McKay, published by CRC Press, 1995, ISBN 0849369207
	Electricity Used	0.00044	MWh/lbs	Calculated using information from the cited reference. See support file for calculations.	
	All Water Used	0.0064	gal x 1000/lbs	Calculated using information from the cited reference. See support file for calculations.	
	Potable Water Used		gal x 1000/lbs	Not applicable -- no local potable water used.	
	Groundwater Extracted		gal x 1000/lbs	Not applicable -- no local or on-site ground water extracted.	
	CO2e Emitted	2	lbs/lbs	Calculated using information from the cited reference. See support file for calculations.	
	NO x Emitted	0.025	lbs/lbs		
	SO x Emitted	0.015	lbs/lbs		
	PM Emitted	0	lbs/lbs	Not calculated	
	Solid Waste Generated	0	tons/lbs	Information not available. To be added when additional information becomes available.	
	Haz. Waste Generated	0	tons/lbs	Information not available. To be added when additional information becomes available.	
	Air Toxics Emitted	0	lbs/lbs	Information not available. To be added when additional information becomes available.	
	Mercury Released	0	lbs/lbs	Information not available. To be added when additional information becomes available.	
	Lead Released	0	lbs/lbs	Information not available. To be added when additional information becomes available.	
	Dioxins Released	0	lbs/lbs	Information not available. To be added when additional information becomes available.	

Default Environmental Footprint Conversion Factor References

Material/Fuel/Service	Green Indicator	Value	Units	Assumptions	Information Source
Gasoline Produced	Energy Used	21	Mbtu/gal	EUROPA ELCD - All forms of energy summed and converted to Mbtus per gallon of product.	Primary NREL LCI File: -SS_crude oil, in refinery.xls Secondary NREL LCI File: -SS_crude oil, at production.xls EUROPA file location: Gasoline at refinery: http://lca.jrc.ec.europa.eu/lcainfohub/datasets/html/processes/5f62ed77-85d0-4c99-8d2c-be56951d8fb3_02.00.000.html
	Electricity Used	0.00059	MWh/gal	Not provided by EUROPA ELCD. NREL LCI includes electricity usage for crude oil, in refinery with an allocation to diesel. Electricity from crude oil, in refinery (allocated to diesel) and crude oil, at production are included.	
	All Water Used	0.00079	gal x 1000/gal	EUROPA ELCD - Sum of "water", "surface water", "groundwater", and "river water". Negative values (indicating return of water to the hydrosphere) were not included. Sea water was also not included. Result converted to thousands of gallons per gallon of product	
	Potable Water Used		gal x 1000/gal	Not applicable -- no local potable water used during gasoline production.	
	Groundwater Extracted		gal x 1000/gal	Not applicable -- no local or on-site ground water extracted during gasoline production.	
	CO2e Emitted	4.4	lbs/gal	EUROPA ELCD - Sum of total global warming potential for carbon dioxide, methane, and nitrous oxide released to atmosphere. A global warming potential of 21 is used for methane and a global warming potential of 310 is used for nitrous oxide. Results converted to pounds of carbon dioxide equivalents per gallon of product.	
	NO x Emitted	0.008	lbs/gal	EUROPA ELCD - Sum of nitrogen oxides emitted to atmosphere. Results converted to pounds of NO x per gallon of product.	
	SO x Emitted	0.019	lbs/gal	EUROPA ELCD - Sum of sulfur oxides emitted to atmosphere. Results converted to pounds of SO x per gallon of product.	
	PM Emitted	0.00052	lbs/gal	EUROPA ELCD - Sum of particulate matter (PM 10 and smaller) emitted to atmosphere. Results converted to pounds of PM per gallon of product.	
	Solid Waste Generated	0.00000042	tons/gal	EUROPA ELCD - Sum of all listed wastes (demolition debris) except for radioactive wastes, slag, and mining wastes, which would likely not be disposed of in a landfill.	
	Haz. Waste Generated	0	tons/gal	EUROPA ELCD - "Chemical waste, toxic" converted into tons per pound of product. No hazardous waste is listed in EUROPA for diesel production, suggesting that little or no hazardous waste is produced as a result of these activities.	
	Air Toxics Emitted	0.00016	lbs/gal	EUROPA ELCD - Sum of all hazardous air pollutants and groups of contaminants as defined by EPA (HAPs) emitted to atmosphere. Reported as pounds per gallon of product.	
	Mercury Released	0.000000085	lbs/gal	EUROPA ELCD - Sum of all mercury and mercury compounds released to air or water. Reported as pounds per gallon of product.	
	Lead Released	0.0000022	lbs/gal	EUROPA ELCD - Sum of all lead and lead compounds released to air or water. Reported as pounds per gallon of product.	
	Dioxins Released	3.1E-14	lbs/gal	EUROPA ELCD - Sum of all dioxins released to air or water. Reported as pounds per gallon of product.	

Default Environmental Footprint Conversion Factor References

Material/Fuel/Service	Green Indicator	Value	Units	Assumptions	Information Source
Sequestering agent	Energy Used	8.83	Mbtu/$	Based on the cited reference, approximatley 1.36 lb of CO2 is emitted per dollar of output in the manufacturing sector. In the absence of other information, it is assumed that the chemical manufacturer also has an emission profile of approximately 1.36 lb of CO2 emitted per dollar of product. Conversion factor estimates assume that 50% of this 1 lb of CO2 per dollar of sample cost results from electricity use (U.S. average fuel blend) and 50% is due to diesel use. A pound of product can then be converted into electricity and diesel usage. The conversion factors result from this electricity and diesel usage.	U.S. CARBON DIOXIDE EMISSIONS AND INTENSITIES OVER TIME: A DETAILED ACCOUNTING OF INDUSTRIES, GOVERNMENT AND HOUSEHOLDS, APRIL 2010
	Electricity Used	0.00048	MWh/$		
	All Water Used	0.0009	gal x 1000/$		
	Potable Water Used		gal x 1000/$		
	Groundwater Extracted		gal x 1000/$		
	CO2e Emitted	1.36	lbs/$		
	NO x Emitted	0.0065	lbs/$		
	SO x Emitted	0.0049	lbs/$		
	PM Emitted	0.00052	lbs/$		
	Solid Waste Generated	0	tons/$		
	Haz. Waste Generated	0	tons/$		
	Air Toxics Emitted	0.00018	lbs/$		
	Mercury Released	0.000000011	lbs/$		
	Lead Released	0.00000012	lbs/$		
	Dioxins Released	1.1E-13	lbs/$		

Default Environmental Footprint Conversion Factor References

Material/Fuel/Service	Green Indicator	Value	Units	Assumptions	Information Source
Laboratory Analysis	Energy Used	6.49	Mbtu/$	Based on the cited reference, approximatley 1 lb of CO2 is emitted per dollar of GDP. Conversion factor estimates assume that 50% of this 1 lb of CO2 per dollar of sample cost results from electricity use (U.S. average fuel blend) and 50% is due to diesel use. A pound of product can then be converted into electricity and diesel usage. The conversion factors result from this electricity and diesel usage.	U.S. CARBON DIOXIDE EMISSIONS AND INTENSITIES OVER TIME: A DETAILED ACCOUNTING OF INDUSTRIES, GOVERNMENT AND HOUSEHOLDS, APRIL 2010
	Electricity Used	0.00035	MWh/$		
	All Water Used	0.00066	gal x 1000/$		
	Potable Water Used		gal x 1000/$		
	Groundwater Extracted		gal x 1000/$		
	CO2e Emitted	1	lbs/$		
	NO x Emitted	0.0048	lbs/$		
	SO x Emitted	0.0036	lbs/$		
	PM Emitted	0.0004	lbs/$		
	Solid Waste Generated	0	tons/$		
	Haz. Waste Generated	0	tons/$		
	Air Toxics Emitted	0.00013	lbs/$		
	Mercury Released	8.4E-09	lbs/$		
	Lead Released	0.000000085	lbs/$		
	Dioxins Released	7.9E-14	lbs/$		