Final Feasibility Study

STERICYCLE KENT FACILITY

KENT, WASHINGTON

June 21, 2017

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ACRONYMS & ABBREVIATIONS

µg/L	micrograms per liter
Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
AOCs	areas of concern
ARARs	applicable or relevant and appropriate regulations
AST	aboveground storage tank
bgs	below ground surface
cis-1,2-DCE	*cis*-1,2-dichloroethene
CLARC	Cleanup Levels and Risk Calculation
COCs	constituents of concern
COPCs	constituents of potential concern
CPOC	conditional point of compliance
CSM	conceptual site model
CUL	cleanup level
DNAPL	dense nonaqueous phase liquid
DOF	Dalton Olmsted & Fuglevand Inc.
Ecology	Washington State Department of Ecology
EPA	Environmental Protection Agency
EZVI	emulsified zero-valent iron
FS	feasibility study
FSWP	feasibility study work plan
ISCO	in situ chemical oxidation
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MTCA	Model Toxics Control Act
NPV	net present value
O&M	operation and maintenance
PAHs	polycyclic aromatic hydrocarbons
POC	point of compliance
PQL	practical quantitation limit
PRB	permeable reactive barriers
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
SPOC	standard point of compliance
SVOC	semivolatile organic compound
TCE	trichloroethene
TPH	total petroleum hydrocarbons
TPH-D	total petroleum hydrocarbons diesel range
TPH-G	total petroleum hydrocarbons gasoline range
TPH-O	total petroleum hydrocarbons lube oil range
USTs	underground storage tanks
VOCs	volatile organic compounds
WAC	Washington Administrative Code
ZVI	zero-valent iron

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Final Feasibility Study

Stericycle Kent Facility
Kent, Washington

June 21, 2017
Project STRCL-004

This report was prepared by the staff of Dalton, Olmsted, & Fuglevand, Inc., under the supervision of the engineer whose seal and signature appear hereon.

The findings, recommendations, specifications, or professional opinions have been prepared in are presented within the limits described by the client, in accordance with generally accepted professional engineering and geologic practices in Western Washington for the nature of services authorized by the client at the time the services were provided. No warranty is expressed or implied.

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Stericycle Kent Facility
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Project STRCL-004

This report was prepared by the staff of Dalton, Olmsted, & Fuglevand, Inc., under the supervision of the hydrogeologist whose seal and signature appear hereon.

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FINAL FEASIBILITY STUDY REPORT
Stericycle Kent Facility
Kent, Washington

1.0 INTRODUCTION

Dalton, Olmsted, and Fuglevand, Inc. (DOF), prepared this Final Feasibility Study (FS) on behalf of Burlington Environmental, LLC, a wholly-owned subsidiary of PSC Environmental Solutions, LLC (PSC), which is a wholly-owned subsidiary of Stericycle Environmental Solutions, Inc. (Stericycle), for approval by the Washington State Department of Ecology (Ecology). Stericycle owns and operates a hazardous waste treatment, storage, and disposal facility on the Stericycle property located at 20245 77th Avenue South in Kent, Washington (Figure 1). The facility operates under Resource Conservation and Recovery Act (RCRA) Part B permit No. WAD 991 281 767. The Stericycle Kent property is referred to in this report as “the site,” while the RCRA-regulated waste management facility that covers the eastern 3 acres of the site is referred to as “the facility” (Figure 2).

A Final Remedial Investigation (RI) Report (AMEC Geomatrix, 2007) was prepared to summarize environmental conditions at the Stericycle site. A Revised Feasibility Study Work Plan (FSWP) (Amec Foster Wheeler, 2015) was prepared and approved by Ecology in 2015. The FSWP also presented an update to the nature and extent of contamination presented in the Final RI Report and outlined the process that would be used to conduct this FS. A draft FS was submitted in April 2016 (Amec Foster Wheeler and DOF, 2016) and conditionally approved by Ecology in a letter dated October 18, 2016 (Ecology, 2016). This final FS includes revisions and additional information requested by Ecology for inclusion in the FS.

The purpose of this FS is to evaluate potential cleanup options for the site and select the most appropriate alternative. This FS will address the constituents of concern (COCs), affected media, and migration pathways identified during the RI phase of work at the site. This FS is designed to comply with requirements of the facility’s RCRA Permit, applicable Model Toxics Control Act (MTCA) regulations, and appropriate state and federal guidance in selecting the cleanup alternative.

1.1 ORGANIZATION AND SCOPE

Information is provided in the following sections of this FS report:

- Section 2 – Site Description and Background
- Section 3 – Cleanup Standards
- Section 4 – Site Characterization
- Section 5 – Remediation Considerations and Objectives
- Section 6 – Potentially Applicable Remedial Technologies
- Section 7 – Remedial Alternative Evaluation Criteria
- Section 8 – Development and Evaluation of Remedial Alternatives
- Section 9 – Report Limitations
- Section 10 – References

2.0 SITE DESCRIPTION AND BACKGROUND

This section summarizes information provided in the Final RI Report about the facility setting, including site layout, geology and hydrogeology, COCs, previous interim remedial measures, the nature and extent of contamination, and the conceptual site model (CSM) of potential exposure pathways. A more detailed description of the site setting and background is provided in the Final RI Report (Geomatrix, 2007).

2.1 LOCATION AND DESCRIPTION

The site is located at 20245 77th Avenue South, Kent, in King County, Washington, in the southeastern 1/4 of Section 1, Township 22 North, Range 4 East. The site lies within the Green River valley, about 2 miles north of downtown Kent and about 4 miles south of Renton. The site location is shown in Figure 1. The site is located on a 6.25-acre parcel of land that can be divided into two areas, the waste management facility on the eastern 3 acres of the site, and the 10-day hazardous waste transfer yard on the western 3.25 acres of the site (Figure 2). The RCRA-regulated waste management facility is subdivided into five areas of concern (AOCs), which are described in Section 2.2. The facility consists of an office, a process containment building, container storage areas, a tank farm with aboveground storage tanks, and a treatment and stabilization building. Container storage areas include the north and south container storage pads and the process containment building, which has storage areas for flammable waste, laboratory packs, and household waste. Existing facility operations include wastewater treatment, stabilization/solidification, labpacking, lab-scale treatment, and waste processing (e.g., consolidation, can crushing, shredding, baling, etc.).

The surface of the facility is entirely covered by asphalt or concrete. The facility is surrounded by an earthen berm constructed about 2 feet above the lot elevation to retain spills and rainwater falling within the facility area. Rainwater falling within the facility area is collected in an underground drainage system and, if necessary, directed to an oil-water separator located on the northwest corner of the facility. Stormwater is treated on site and discharged to the King County publicly owned treatment works (SEE, 1990).

The 10-day RCRA hazardous waste transfer yard is located on the western 3.25 acres of the site and was undeveloped until 2001, when the transfer yard was constructed. The transfer yard includes concrete pads and containment for transfer trailers and roll-off boxes, a fully lined stormwater retention pond, and a bio-filtration swale. The swale drains to a drainage ditch running along the northern edge of the site. Flow through the ditch is diverted into a culvert along the northern edge of the facility.

A 6-foot-high chain-link fence restricts access to the site. A similar fence surrounds the stormwater containment pond on the western half of the site.

A detailed operational history of the site was presented in the RI.

2.2 PREVIOUS INVESTIGATION ACTIVITIES AND CLEANUP ACTIONS

The FSWP identified five AOCs based on previous studies and evaluations of RCRA solid waste management units:

- AOC-1: Former Underground Storage Tanks (USTs);
- AOC-2: Tank Farm Area;
- AOC-3: Stabilization Area;

- AOC-4: Stormwater Drainage System; and
- AOC-5: Process and Storage Area.

These AOCs are shown on Figure 2. In addition, some previous investigations occurred in the 10-day hazardous waste transfer yard on the western half of the site.

2.2.1 AOC-1: Former USTs

AOC-1 is the area where three underground storage tanks (USTs) (16,000-gallon gasoline, 10,000-gallon diesel, and 5,000-gallon gasoline) were located between the current north and south container storage pads. In 1989, investigations were conducted at AOC-1 to evaluate the soil conditions adjacent to the USTs. Three soil borings (MW-9, MW-10, and MW-11), subsequently converted to monitoring wells, were completed in this area.

The USTs were removed in January 1991. After removal of the 5,000-gallon UST, petroleum contamination was noted on the groundwater surface approximately 10 feet below ground surface (bgs). Following the excavation of approximately 705 cubic yards of contaminated soil, 13 confirmation samples (labelled Kent Plant 15 through 27) were collected from the sidewalls and bottom of the excavation.

2.2.2 AOC-2: Tank Farm

AOC-2, the tank farm, is located in the northeastern corner of the site and consists of aboveground storage tank (AST) units containing petroleum products, various solvents, caustics, and treatment operations. The ASTs are located within containment structures. Investigations were conducted in the tank farm area in June 1989 (SEE, 1989) and March 1990 (SEE, 1990). Multiple soil and groundwater samples have been collected during the various phases of the RI to evaluate the extent of constituents of potential concern (COPCs) in this area.

Additional soil sampling was conducted in October 2015, after three ASTs T-2, T-6B, and T-8 were removed as a part of capital improvements at the facility in 2016. Stericycle excavated approximately two to four feet of soil from beneath these tank footprints prior to their replacement. Another tank immediately to the south of T-6 was removed in 2017 where similar methods were used for sampling soil underneath once the tank was removed and excavating underlying soil to three to five feet below ground surface. Sampling results and excavation documentation information were presented to Ecology in a June 2016 memorandum (DOF, 2016), and an April 2017 memorandum (DOF, 2017).

2.2.3 AOC-3: Stabilization Area

AOC-3, the stabilization area, is located south of AOC-2 and consists of a concrete-lined pit. The area also includes aboveground storage tanks T-5305, T-5306, and T-5307. The initial investigation in the stabilization area consisted of a hand auger boring outside of the stabilization building (ADL, 1989).

Two monitoring wells (MW-12 and MW-14) were completed near the building in 1989, and soil samples were collected for analysis (SEE, 1989). Two borings (HA-2 and HA-3) were completed in July 2000 as part of the RI to determine whether sumps associated with the stabilization pit had leaked (PSC, 2000a through c; PSC, 2001a). Additional sampling was conducted in 2010 as part of the data gaps investigation, after a secondary containment failure was documented in this area.

In 2013, soil samples were collected under Tank 5307 as part of the closure process. One single boring was advanced below the base of the pit liner, and two soil samples were collected from the boring.

2.2.4 AOC-4: Stormwater Drainage System

AOC-4 includes the site's stormwater drainage system, the associated catch basins and sumps, underground piping, and the formerly exposed ditch on the north side of the site. In January 1999, an abandoned pipeline was encountered. The abandoned pipeline released approximately 10 to 15 gallons of a diesel and water mixture (PSC, 1999). Confirmation soil samples were collected following the removal of petroleum-affected soils.

In February 1999, Stericycle personnel found another deteriorating pipeline beneath the main driveway. In March 1999, the deteriorating pipeline was removed, visibly contaminated soil was excavated, and confirmation soil samples were collected (PSC, 2000 a through c; PSC, 2001a).

In May 2002 during replacement of the stormwater pipelines just south and east of the process containment building, soil surrounding the pipelines was excavated. Confirmation soil samples were collected from the excavations prior to backfilling the excavations with clean fill.

In 2000, soil samples were also collected near catch basins that are part of the stormwater management system to evaluate the potential for releases.

2.2.5 AOC-5: Process and Storage Area

AOC-5 consists of the current and former process and storage areas, including the current can crush area, the north container loading/unloading pad, the process containment building, the indoor lab pack area, the north and south container storage pads, the check-in pad, and assorted storage areas.

2.2.6 10-Day Hazardous Water Transfer Yard

The 3.25-acre parcel that comprises the 10-day hazardous waste transfer yard on the west side of the property was undeveloped until the transfer yard was completed in 2001. Multiple soil and groundwater samples have been collected in these areas as well, including three new groundwater monitoring wells installed as part of the Data Gaps Investigation.

2.3 LAND USE

The site is located in a heavily industrial area of the city, in an area zoned M3 for general industrial land use by the City of Kent (City of Kent, 2002 and 2006). The properties surrounding the site are other commercial and industrial facilities. The area within a 1-mile radius of the site is zoned almost entirely as M1, M2, or M3, for light to general industrial land use. Consequently, the site meets the MTCA definition of an industrial property (Washington Administrative Code [WAC] 173-340-200). It is expected that the site will continue to meet Ecology's criteria for being "zoned for industrial use" and will continue to qualify as industrial for the purpose of establishing soil and groundwater cleanup levels in the feasibility study based on the City of Kent's Comprehensive Plan. The City of Kent's Comprehensive Plan adopted implementing zoning regulations under the Growth Management Act (Chapter 36.60A. Revised Code of Washington), which designated a manufacturing/industrial center and discourages and limits land uses other than manufacturing, high technology, and warehousing within the boundaries of the center. The facility is located with the City of Kent's designated manufacturing/industrial center.

2.4 PHYSIOGRAPHY, GEOLOGY, AND HYDROGEOLOGY

The physical site setting, including geology, hydrogeology, and surface water, were described in detail in the Final RI Report and FSWP. This section provides a summary of those conditions and additional information collected since the FSWP that is used to refine the decision criteria in this FS.

2.4.1 Geology

The near-surface geology at the site is characterized by alternating sand and silty/clayey layers and was distinguished by the following eight lithologic units, listed in order of increasing depth:

- Fill Unit – The uppermost unit at the site, referred to as the fill unit, consists of poorly sorted sands, gravel, and cobbles. The thickness of the fill unit varies from about 2 feet to 9 feet; however the backfilled area of the former UST location contains as much as 14 feet of fill material.
- Upper Silt and Clay Unit –The silt and clay unit contains varying amounts of silt and clay, with sand and organic material. The thickness of the unit varies from about 1 feet to 9 feet across the site.
- Upper Silty Sand Unit –The sand is typically fine- to medium-grained, with a significant (generally greater than 15 percent) silt content. This unit is locally interbedded with silt or clean sand. The thickness of this unit varies across the site from about 1 to 12 feet.
- Intermediate Silt Unit – The intermediate silt is gray, soft to medium stiff, and contains various amounts of sand and organic material. The silt unit appears to be present in the eastern and southeastern portions of the site, but absent in the north and south central portions of the site. The thickness of this unit varies across the site from 0 to about 7 feet.
- Intermediate Sand Unit –The sand is typically fine- to medium-grained, generally with less than 15 percent silt. The thickness of this unit varies across the site from about 2 to 9 or more feet.
- Lower Silt Unit – A lower silt unit has been encountered in all borings completed to a depth of at least 25 feet The thickness of the lower silt unit varies across the site from about 2 to 10 feet.
- Lower Sand Unit – A sand deposit below the lower silt unit was encountered in all deep borings. The sand is clean, fine- to medium-grained. Discontinuous silt stringers are present within the sand unit. The thickness of this lower sand unit varies from about 5 to at least 10 feet.
- Deep Silt Unit –The deep silt unit consists of firm, gray to brown to black, clayey silt and sandy silt. This is the lowest stratigraphic unit identified at the site. A thickness of more than 10 feet was encountered at MW-16.

2.4.2 Hydrogeology

Eight primary hydrogeologic units have been delineated beneath the site based on analysis of the geologic and hydrogeologic data collected during previous investigations. The eight units consist of layered higher permeability aquifers and lower permeability aquitards:

- Shallow Water-Bearing Unit – The shallow water-bearing unit (fill unit) is hydraulically unconfined, is generally continuous across the site, and becomes unsaturated during the period of low rainfall in summer and early fall. Groundwater elevations have ranged from 22.21 feet to 27.28 Above Mean Sea Level (AMSL) feet since October 2011.
- Upper Aquitard – This aquifer corresponds to the upper silt and clay geologic unit, and appears to be continuous across the site except at the excavated area around monitoring well MW-118-S. Like the shallow water-bearing unit, the upper aquitard is partially unsaturated during the late summer and early fall.
- Intermediate Aquifer Zone A – This aquifer corresponds to the upper silty sand geologic unit and appears to be present throughout the site. The unit is fully saturated year-round and appears to be hydraulically confined by the overlying upper aquitard, except in the vicinity of MW-118-S, where the overlying aquitard was removed during the UST excavation. During summer, parts of Zone A may be semi-confined. Groundwater elevations have ranged from 22.60 feet to 26.96 feet AMSL since October

2011.

- Intermediate Aquitard – This aquitard corresponds to the intermediate silt unit and separates Zone A and Zone B of the intermediate aquifer, where it is present. This aquitard appears to be continuous in the eastern and western parts of the site, but is locally absent in much of the central north and south portions of the site. The thickness of this unit varies across the site from 0 to about 7 feet.
- Intermediate Aquifer Zone B – This aquifer corresponds to the intermediate sand geologic unit. This unit appears to be present throughout the site and hydraulically connected to Zone A of the intermediate aquifer. The unit is fully saturated and is overlain by the intermediate aquitard, where present, or by Zone A of the intermediate aquifer. Where overlain by the intermediate aquitard, the aquifer is confined; those portions in communication with Zone A may be semi-confined during the summer. Groundwater elevations have ranged from 22.43 feet to 26.02 AMSL feet since October 2011.
- Lower Aquitard – This aquitard corresponds to the lower silt geologic unit. The lower aquitard is fully saturated and is bounded above by the intermediate aquifer and below by the deep aquifer.
- Deep Aquifer – This aquifer corresponds to the lower sand geologic unit and has been observed at all deep borings completed to depths of at least 30 feet bgs. The aquifer is hydraulically confined year-round by the overlying lower silt aquitard. Groundwater elevations have ranged from 21.70 feet to 25.35 feet since October 2011.
- Deep Aquitard – This aquitard corresponds to the deep silt unit and lies beneath the deep aquifer. This aquitard appears to be continuous across the site.

The fill unit and the upper aquitard represent important considerations in the hydrogeology and potential hydrogeochemistry of the site. The upper aquitard represents the original ground surface prior to site development, and the aquitard consists of silt and clay related to alluvial floodplain deposits of the Green River Valley. As a result, this aquitard is high in organic carbon content. This high organic carbon content combined with the low permeability of the silt and clay should make the upper aquitard a natural barrier to downward contaminant transport. In addition, the seasonally perched groundwater affects the groundwater chemistry. In particular, the perched groundwater influences the oxidation-reduction potential favoring a tendency toward reducing conditions in the saturated portion of the fill and in Zone A of the intermediate aquifer.

2.4.2.1 Groundwater Flow Directions

Figures 3 through 8 are representative groundwater elevation contour maps for April and October 2014. Because the upper Zone A and lower Zone B portions of the intermediate aquifer are connected hydraulically where the intermediate aquitard is missing, only a single groundwater elevation contour map was drawn for this aquifer unit. The wells shown on these figures have been color-coded to show where the aquitard is or is not present. Table 1 shows the vertical gradients calculated for nested well pairs screened in the three water-bearing or aquifer zones.

Shallow Water-Bearing Unit

In the shallow water-bearing unit during April, the groundwater flow is westerly, veering from the west-southwest to the north-northwest (Figure 3). By October, most of the shallow-zone wells have gone dry, and the flow direction is highly uncertain since most of this unit is dry (Figure 4).

Intermediate Aquifer (Zones A/B)

During April, the groundwater flow directions in the intermediate aquifer are complex, with groundwater flow towards an apparent low that centers around MW-124-I (Figure 5). This is an area where the intermediate aquitard is not present between the two intermediate aquifer zones.

Groundwater elevations in the intermediate aquifer in April are all lower than those in the overlying shallow water-bearing unit, indicating that groundwater will flow vertically from the shallow zone into the intermediate aquifer.

By October, the same area is a mound or ridge centered on MW-124-I and MW-131-I (Figure 6). Groundwater flows away from this mound in several directions. Intermediate aquifer groundwater elevations are consistently lower in October then they are in April. The mound is thought to represent the potentiometric head necessary to re-pressurize zone B of the intermediate aquifer, as confining conditions are present where the intermediate aquitard is present.

Deep Aquifer

In contrast to the shallow water-bearing unit, groundwater elevations in April and October show that the groundwater flow direction in the deep aquifer is uniform and directed to the west. Groundwater elevations in the deep aquifer are lower than those in the shallow water-bearing unit or the intermediate aquifer (Figures 7 and 8). This uniform horizontal flow direction suggests that lower aquitard is apparently continuous.

Summary of Groundwater Flow Directions

The variable conditions near MW-124-I are created by recharge through the window in the aquitard. During the rainy season water levels measured in this well are lower because mounding of groundwater around the edges of the “window” on-top of the intermediate aquitard. By early fall, recharge of the intermediate aquifer from the shallow water-bearing unit has stopped and groundwater is flowing away from the area of MW-124-I. The remnant groundwater mound may be attributable by the greater head necessary to infiltrate groundwater into a confined aquifer. The patterns noted above were back-checked against April and October potentiometric maps from prior years, and found to be consistent.

2.4.2.2 Groundwater Flow Velocities

Table 1 summarizes the hydraulic properties that will be used during development of the remedial alternatives. Average linear groundwater flow velocities were calculated using the following formula:

$$V = Ki/n_e$$

Where: V= average linear velocity (feet/day)
K = hydraulic conductivity (feet/day)
i = hydraulic gradient (feet/feet)
n_e = effective porosity (fraction)

The horizontal groundwater seepage velocities calculated for the different aquifers present at the site are:

- Shallow water-bearing unit: 1.2 to 3.8 feet/day;
- Intermediate aquifer: 0.008 to 0.25 foot/day; and
- Deep aquifer: 0.04 to 0.6 foot/day.

2.4.3 Surface Water

The tributaries of Mill Creek and the Green River are the closest surface water bodies to the site. A drainage ditch runs along the northern border of the western half of the site. The ditch extends from the railroad tracks west of the western site boundary to a culvert along the northern site boundary on the eastern half of the site, as shown on Figure 2. The culvert was constructed in 1991 by the property owner to the north, and consists of 12-inch-diameter polyvinyl chloride piping held in place by concrete blocks. The culvert was constructed to replace a former segment of the same ditch; this segment was filled and culverted at that time. As shown on Figure 9, the culvert drains into another ditch running along 77th Avenue South, which also accepts surface runoff from the property to the north. This ditch runs north along 77th Avenue South and then northwest to Mill Creek, which is a tributary to Springbrook Creek. Several miles north of the site, Springbrook Creek flows into the Black River, which ultimately joins the Duwamish River. A review of potential surface water connectivity between the drainage ditch along the site boundary and Mill Creek was conducted as part of this FS in the context of whether this surface water body may support or have the potential to support fish or shellfish populations. The current pH and dissolved oxygen data and the historical pH data indicate that the ditch would not sustain fish or shellfish and also does not meet the Surface Water Quality standards for Washington, which require a pH above 6.5 and dissolved oxygen values to greater than 6.5 mg/L (Ecology, 2012).

2.4.4 Conceptual Groundwater Model

Although groundwater is present in the wet season within the fill or shallow water-bearing unit, the uppermost true aquifer is considered to be Zone A of the intermediate aquifer in the upper silty sand unit. Groundwater within the fill or shallow water-bearing unit likely perches on the upper aquitard during wet months, and this water drains slowly into Zone A, the upper portion of the intermediate aquifer.

In the intermediate aquifer, groundwater within Zone A is hydrologically connected to Zone B, because the intermediate aquitard is discontinuous. Except for the discontinuities, the intermediate aquifer is separated from the deep aquifer by a relatively thick silt and silty sand aquitard (2 to 10 feet). The sand of the intermediate aquifer is silty in Zone A, with much less silt in Zone B and widely varying hydraulic conductivities due to the variability in percentages of silt present in the unit.

2.5 CONCEPTUAL SITE MODEL OF EXPOSURE PATHWAYS

The CSM for the site was presented in the FSWP. Figure 10 presents a summary of the CSM. The CSM is based on current and assumed future industrial land use at the site and continued industrial and commercial land use in the surrounding area, based on definitions and criteria provided in WAC 173-340-200 and WAC-340-745(1).

The primary sources of COCs at the site are releases from tanks and piping, and constituents spilled at the site. The primary release mechanisms resulting in soil and groundwater impacts from COCs at the facility are leaks and spills. Furthermore, COCs in groundwater at the facility may migrate and affect groundwater in off-site areas. Some of the more volatile constituents detected in soil and groundwater could potentially volatilize into soil gas, which could then migrate to indoor air of nearby buildings. It is assumed that concentrations of volatile compounds migrating from soil gas to outdoor air will be negligible due to rapid mixing and dilution in ambient air under normal working conditions. However, volatile compounds may migrate from soil gas to outdoor air in trenches during excavation activities. As the site is for the most part covered with buildings, concrete, or pavement, constituents detected in surface soil are unlikely to be mobilized in fugitive dust; and constituents detected in soil are also unlikely to leach to groundwater unless the industrial development is removed in the future. Constituents in groundwater in the fill unit, which is seasonally water-bearing, and in the intermediate aquifer potentially may migrate to local surface water bodies via the drainage ditch along the northern border of the facility. This ditch could also be a source of recharge to the fill unit during the winter.

Since the site is zoned industrial, groundwater in the shallow water-bearing unit and intermediate aquifer is not a current or future source of drinking water. The deep aquifer is also not a current or potential future source of drinking water, due to the confining clay layer beneath the deep aquifer. All public groundwater supply wells within 1 mile of the facility are deeper than the deep aquifer and are not a possible receptor of groundwater migrating from the facility (Figure 9).

In 2016, Ecology requested that Stericycle perform a public records review of the wells identified in close proximity to the facility and review available data with Ecology. DOF prepared a memo in February 2017 documenting this review (DOF, 2017) and Ecology responded with several additional records. These documents have been included in this final FS as Appendix H.

3.0 CLEANUP STANDARDS

MTCA regulations require that remedial action alternatives for the site achieve cleanup standards. To determine cleanup standards, screening levels developed during the RI and the FSWP have been evaluated and finalized in the FS to account for updated criteria and points of compliance (POCs) established in accordance with MTCA regulations.

3.1 CLEANUP LEVELS

The screening levels presented in the FSWP were updated to reflect current risk-based values presented in Ecology's Cleanup Levels and Risk Calculation (CLARC) tables and to include consideration of groundwater screening levels protective of indoor air.

3.1.1 Soil Cleanup Levels

Soil cleanup levels developed in the FS constitute MTCA Method C cleanup levels under WAC 173- 340-745 and must be protective of human health and the environment. Soil screening levels developed in the Final RI Report were reviewed and updated in the FS by determining the lower value between the following:

- MTCA Method C - Industrial Cleanup Level based on direct contact/ingestion obtained from the CLARC website (Ecology, 2015a).
- MTCA Method A Soil Cleanup Levels for Industrial Land Use (MTCA Table 745-1) for constituents with no available Method C cleanup levels.
- Soil cleanup levels protective of preliminary groundwater cleanup levels described in Section 3.1.2 (WAC 173-340-747[4]). (Soil cleanup calculations and input parameters were provided in Section 5.2.1.1 of the Final RI Report and are reviewed and updated in this FS.)

The final values were compared to the updated laboratory practical quantitation limits (PQLs) and adjusted upward in accordance with WAC 173-340-707 if they were below the PQL. The soil cleanup levels used to evaluate the soil conditional POCs (COPCs) during the FS are presented in Table A-1 of Appendix A and the calculations for soil cleanup levels protective of groundwater are shown in Table A-2.

3.1.2 Groundwater Cleanup Levels

Groundwater cleanup levels were developed in the FS to be protective of drinking water, surface water and indoor air. Groundwater screening levels were developed in the RI and reviewed and updated in the FS by determining the lower of the value between the following:

- MTCA groundwater table values obtained from the CLARC website (Ecology, 2015a):
    - MTCA Method A levels for constituents that do not have a Method B level available; and
    - MTCA standard Method B levels based on drinking water beneficial use, which include Federal maximum contaminant levels.
- Surface water applicable or relevant and appropriate regulations (ARARs):
    - Water Quality Standards for Surface Waters of the State of Washington (WAC 173-201A) – Acute and Chronic effects, Aquatic Life, Freshwater;
    - National Recommended Water Quality Criteria (Clean Water Act §304) – Freshwater, Acute and Chronic effects, Aquatic Life and for the Protection of Human Health, Consumption of Water and Organisms and Consumption of Organisms Only; and

  - National Toxics Rule (40 Code of Federal Regulations 131) – Freshwater, Acute and Chronic effects, Aquatic Life, and Human Health, Consumption of Water and Organisms.

- MTCA Method B Surface Water levels, calculated using CLARC tables if a federal or local surface water value is not found in the ARARs (Ecology, 2015); and
- MTCA groundwater values protective of indoor air obtained from the CLARC website (Ecology, 2015a).

The determined values were compared to the laboratory screening levels and were adjusted upward in accordance with WAC 173-340-707 if they were below the PQL. The groundwater cleanup levels used to evaluate groundwater COPCs during the FS are presented in Table A-3 of Appendix A.

3.1.3 Area Background

Area background calculations were conducted as part of this FS for COPCs that were sporadically detected within the groundwater data set and for which a historical source of contamination was not identified: arsenic, manganese, and iron. This assessment was done to distinguish site-related concentrations from non-site-related concentrations. Consistent with WAC 173-340-709, the values were calculated as follows:

- WAC 173-340-709(2) Background Concentrations – Data was used from the most upgradient well at the site, MW-129-I, located on the east side of 77the Avenue South, immediately across the street (77th Avenue South) from the facility.
- WAC 173-340-709(3) Statistical Analysis – The Ecology software program MTCAStat was used to determine data distribution for each COPC, and to calculate the upper 90th percentile and four times the 50th percentile (unless normally distributed, in which case the 80th percentile was assessed). The lower of these values was selected as the area background value. MTCAStat printouts are included as Appendix B.
- WAC 173-340-709(4) Sample Size – The sample set included all available data since 2005.
- WAC 173-340-709(5) Procedures – Non-detect values were assigned a value equal to one-half of the method detection limit.

The calculated area background levels, (updated from those presented in the FSWP to include data collected through 2015), are:

- Arsenic – Data from MW-129-I yield a background value of 11.74 micrograms per liter (μg/L).
- Iron – Data from MW-129-I yield a background value of 84.43 milligrams per liter (mg/L).
- Manganese – Data from MW-129-I were insufficient to yield a satisfactory data distribution, so data from well MW-114-I were added to the assessment. This well is also located on the east side of the site, just outside the fenceline of the facility, south of MW-129-I. Using the combined data set yields a background value of 10.59 mg/L.

The area background levels were then used in developing cleanup levels consistent with the requirements of WAC 173-340-706(1)(a)(i). Consistent with WAC 173-340-706(1)(a)(i) the cleanup levels for arsenic, iron, and manganese were set to the MTCA C values because the calculated background values were greater than the MTCA C values (Table A-3).

Proposed final cleanup levels (CULs) for the FS are reported in Tables 2 and 3 for soil and groundwater, respectively. The final FS CULs will be evaluated for total risk in accordance with WAC 173-340-705(4) (multiple hazardous substances or pathways) in the Cleanup Action Plan. CULs will be adjusted, if necessary, so that the total combined excess cancer risk potential (calculated in accordance with MTCA methods) for the carcinogenic substances does not exceed one in 100,000 (1 x 10^{-5}), and that the hazard index calculated in accordance with MTCA methods does not exceed 1. The CULs applicable at the POC must be adjusted to meet these two total risk criteria.

3.2 POINTS OF COMPLIANCE

As defined in the MTCA regulations, the POC is the point or points at which CULs must be attained and may be a standard POC (SPOC) or a CPOC.

The relevant regulatory provisions for establishing a CPOC for affected groundwater at the site are presented in WAC 173-340-720(8). For groundwater, a CPOC is proposed near the site boundary. The location of a possible CPOC is shown on Figure 11. Under MTCA (WAC 173-340-720[8][c]), a CPOC for groundwater is permissible when:

1. It is not practicable to attain the SPOC within a reasonable restoration time frame,
2. The CPOC is as close as practicable to the source of the release, and
3. All practicable methods of treatment are used in the site cleanup.

Highly disruptive remediation technologies would likely be the only way to completely remove COCs to allow for an SPOC within a short restoration time frame. However, highly disruptive remediation technologies (i.e., excavation) beneath AOC-2, the tank farm area, would likely fail a cost/benefit analysis because (1) the site is an active waste handling facility, (2) the extent of the source area is small, and (3) effects on groundwater are limited. Since other remedial technologies exist that would allow industrial activities to continue, highly disruptive remediation costs would be disproportionately high relative to the potential incremental benefit.

For soil, the POC is established under WAC 173-340-740(6) and generally requires establishment of a POC for soils throughout the site to a depth of 15 feet bgs. However, for cleanup actions that involve containment of contamination, WAC 173-340-740(6)(f) establishes the following provisions for the cleanup to comply with the cleanup standards:

> *"…for those cleanup actions selected under this chapter that involve containment of hazardous substances, the soil cleanup levels will typically not be met at the points of compliance specified in (b) through (e) of this subsection. In these cases, the cleanup action may be determined to comply with cleanup standards, provided:*
>
> *(i) The selected remedy is permanent to the maximum extent practicable…*
>
> *(ii) The cleanup is protective of human health…*
>
> *(iii) The cleanup action is demonstrated to be protective of terrestrial ecological receptors…*
>
> *(iv) Institutional controls are put in place…that prohibit or limit activities that could interfere with the long-term integrity of the containment system;*
>
> *(v) Compliance monitoring…and periodic reviews…are designed to ensure the long- term integrity of the containment system; and*
>
> *(vi) The types, levels and amounts of hazardous substances remaining on-site and the*

> *measures that will be used to prevent migration and contact with those substances are specified in the draft cleanup action plan."*

Based on the site conditions presented in the RI and subsequent documents, this FS assumes that soil CULs will not be met at the SPOC and that the provisions of WAC 173-340-740(6)(f) will apply to the site. It is not practicable to attain the CULs at the SPOC for soil because buildings and the tank farm on the site limit access to some portions of the subsurface, and the presence of shallow groundwater limits the practicable depth at which many remediation technologies could be employed.

Assuming the provisions in WAC 173-340-740(6)(f) are applicable for the facility, Stericycle plans to comply with the requirements of this subsection as follows:

(i) Practicable, permanent treatment methods will be used to remove the source area. Treatment methods that may be applicable are described and evaluated as part of this FS and adhere to the requirements specified under WAC 173-340-360.

(ii) Cleanup levels have been established to protect human health; in those locations where cleanup levels will not be achieved, the receptor pathways will be evaluated and suitable institutional controls will be included in the final remedy to protect human health.

(iii and iv) Institutional controls that maintain the integrity of the containment system and protect plants and wildlife from being exposed to any residual contamination will be part of the selected final remedy.

(v) Compliance monitoring and long-term controls necessary for the remedy will be defined in the design of the final remedy.

4.0 SITE CHARACTERIZATION

This section describes how the proposed CULs presented in Section 3 were used in this FS to refine the understanding of the nature and extent of contamination at the site and identify the areas to be targeted for cleanup.

4.1 CONSTITUENTS OF CONCERN

COPCs were developed in the RI and FSWP, and the same approach was used in the FS to refine the list of COPCs and establish COCs based on cleanup levels established in Section 3 of this FS. Primary soil COPCs previously identified in the RI and FSWP are:

- Limited areas of petroleum hydrocarbon fractions, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and naphthalene;
- Limited areas of pesticides including 4,4’-DDD and 4,4’-DDE; and
- Inorganics, including cyanide, antimony, arsenic, copper, cadmium, silver, thallium, zinc, and mercury.

Table A-4 in Appendix A shows the evaluation process by which the FS COCs were selected.

As part of the FS, COPCs identified in soil were evaluated to determine if they are also present in groundwater at the site, and if so, whether concentrations exceed CULs established in Section 3. Several of the COPCs were not detected in groundwater at concentrations greater than the CUL in the last five years and therefore, consistent with the empirical demonstration method for deriving soil concentrations for groundwater protection in WAC 173-340-747(3)(f), the soil CULs for these COPCs were re-evaluated, removing the groundwater protection-based screening level, and the resultant soil CUL was adjusted upward in many cases. This affected several compounds, as summarized in Table A-5 in Appendix A, and reduced the soil COCs identified at the site to:

- VOCs – benzene and vinyl chloride;
- PAHs – benzo(a)pyrene, benzo(b)fluoranthene, and chrysene;
- Total petroleum hydrocarbons (TPH) – diesel, lube oil, and gasoline range; and
- Inorganics – arsenic and cyanide.

These are the only compounds detected in soil above the revised CULs summarized in Table 2. The COCs in soil for each AOC are summarized in Table 4.

In groundwater, the primary COPCs previously identified were arsenic, hexavalent chromium, cyanide, iron, and vinyl chloride. All of these COPCs have been detected above CULs in groundwater recently and are considered indicators of contamination at the site, as described in Section 4.2, and are therefore carried forward as groundwater COCs. The groundwater CULs are summarized in Table 3 and the COCs are summarized in Table 5 for each AOC.

4.2 NATURE AND EXTENT OF CONTAMINATION

This section summarizes the nature and extent of contamination at the facility. This summary, combined with the CSM presented in Section 2.5 and the discussion in Section 4.1, will form the basis for evaluating alternative remediation technologies at the facility. The distribution of COCs in soil and groundwater at the site was reviewed in detail in the RI (Geomatrix, 2007) and the Revised FSWP (Amec Foster Wheeler, 2015).

The sampled locations with indicator COCs exceeding FS CULs in soil are shown on Figures 12 and 13. Maximum concentrations of COCs in groundwater from 2010 through 2015 are shown on Figure 14 for the shallow water-bearing unit, Figure 15 for the intermediate aquifer, and Figure 16 for the deep aquifer. The maximum and average concentrations of the COCs in groundwater from 2010-2015 are also presented in Table 6. Additional figures showing the maximum concentration of COCs during 2015 in all the water-bearing units are provided on cross sections located in Appendix C, and figures showing the trends of COCs in all the monitoring wells are located in Appendix D.

4.2.1 Soil

The primary migration pathway of concern is the migration of COCs in soil to groundwater. The potential for completion of this migration pathway is currently minimized by the asphalt, concrete, and buildings that cover most of the soil on the site. These coverings severely limit the infiltration of rainwater into the underlying soil. Many of the soil COCs are not detected in groundwater above CULs and therefore their main residual threat relates to risk scenarios for direct contact or inhalation exposure, which may be more easily mitigated via institutional controls.

Since arsenic is one of the most wide-spread COCs at the site, a closer look at the dataset was taken using Ecology’s MTCAStat site evaluation tool for calculating compliance statistics (http://www.ecy.wa.gov/programs/tcp/tools/toolmain.html), based on the recommendations in Ecology’s Statistical Guidance, Figure 13 (Ecology, 1992) as well as MTCA. All soil data from the site were entered into the workbook tool. This includes 69 detected values and 21 non-detect values (“censored”) values. The results are presented in Appendix E and showed a 95 percent upper confidence limit or 6.08 milligrams per kilogram (mg/kg) for arsenic at the site, below the cleanup level of 7.4 mg/kg. However, there were three samples in AOC-2 and one sample in AOC-3 that had values that were more than twice the CUL. Based on the Ecology's 1992 guidance document, those drive a finding that the site is still considered contaminated. Therefore, the areas of those samples will be targeted for cleanup in the alternatives described in this FS.

In 2016, Ecology requested that an additional summary of the available TPH data be included in the revised FS. Charts of the TPH data collected at the site were provided to Ecology in 2016 and are now included in the FS as Appendix I. Since most samples were not necessarily collected close in space, a scatter plot of all the soil data back to the late 1990s was produced. Excavation and sampling performed beneath ASTs during construction work in 2016 and 2017 detected TPH in the Tank Farm Area, but also confirmed concentrations declined with depth – generally below cleanup levels by 3 to 5 feet bgs.

AOC-1: Former USTs

Soil sampling in the area of the former USTs was conducted during tank removal in 1991 and during installation of groundwater monitoring wells MW-9, MW-10, and MW-11 in 1989. However, no COCs were detected at concentrations exceeding cleanup levels in these samples.

AOC-2: Tank Farm Area

A review of available soil data indicates that the tank farm may be the primary source for releases to the soil and groundwater. Compounds that have been detected in soil from the tank farm area at concentrations exceeding the soil cleanup levels include benzene; benzo(b)fluoranthene; chrysene; arsenic; cyanide; and TPH in the gasoline range (TPH-G), diesel range (TPH-D), and lube oil range (TPH-O). Higher concentrations of petroleum constituents have been detected in near-surface soil than in deeper soil in petroleum-impacted areas, suggesting a surficial release.

Several sampling events conducted in 2015, 2016, and 2017 also identified cyanide, TPH-G, TPH-D, and TPH-O above cleanup levels in soil samples collected underneath four ASTs that were replaced, as described in Section 2.2.2.

AOC-3: Stabilization Area

Compounds that have been detected in soil at concentrations exceeding the cleanup levels are benzene, vinyl chloride, arsenic, and TPH-G.

AOC-4: Stormwater Drainage System

Compounds that have been detected in soil at concentrations exceeding the cleanup levels include benzene, benzo(a)pyrene, benzo(b)fluoranthene, chrysene, TPH-G, TPH-D, and arsenic.

AOC-5: Process and Storage Area

Several soil samples were collected from the process and storage areas of the site. However, no COCs were detected at concentrations exceeding cleanup levels in these samples.

10-Day RCRA Hazardous Waste Transfer Yard

A number of soil samples were collected from the 10-day RCRA hazardous waste transfer yard prior to the construction of the yard in 2001, and then again in 2007. Arsenic was detected in soil samples from this area at concentrations exceeding cleanup levels. Arsenic may be associated with fill material used across the site during construction.

4.2.2 Groundwater

Five COCs (vinyl chloride, arsenic, cyanide, hexavalent chromium, and iron) continue to be detected at concentrations exceeding cleanup levels at the site. The Final RI Report concluded that these COCs, with the exception of cyanide, appear to be related to a release from AOC-2. However, the lateral and vertical extent of these COCs appears to be limited, and they do not appear to be migrating from the site at concentrations exceeding groundwater cleanup levels.

4.2.2.1 Vinyl Chloride

As presented in the FSWP, concentrations of related compounds trichloroethene (TCE), *cis*-1,2- dichloroethene (*cis*-1,2-DCE) and vinyl chloride are all decreasing, as illustrated in Figure D-1 in Appendix D. Biodegradation appears to be reducing the concentrations of chlorinated ethenes in groundwater. TCE and *cis*-1,2-DCE are no longer detected at concentrations exceeding cleanup levels, and vinyl chloride is detected in groundwater samples above the cleanup level at only a few wells, all located in AOC-2 and AOC-3. In 2015, vinyl chloride was only detected in wells MW-120-I and MW-124-I1, near AOC-2.

The current vinyl chloride concentrations are lower than those in the Final RI Report, which indicates that the areas where vinyl chloride are present and the continued evidence of biodegradation are consistent with the conclusions in the Final RI Report. TCE, *cis*-1,2-DCE, and vinyl chloride concentrations in soil were evaluated to attempt to identify any residual source areas of chlorinated ethenes that could contribute to groundwater concentrations. Vinyl chloride was detected in only one sample, located beneath Tank 5307 in AOC-3, with a concentration of 140 µg/kg, which is above the cleanup level of 0.94 µg/kg. This location could be the source area for the remaining elevated vinyl chloride concentration seen downgradient of the location.

Given the current trend in groundwater concentrations, vinyl chloride would be anticipated to be below the cleanup level by around 2020 (Figure 17).

4.2.2.2 Arsenic

As presented in the FSWP, arsenic concentrations in groundwater at the site have not exhibited any significant increasing or decreasing trends over time (Figures D-2 through D-4 in Appendix D), as opposed to the generally decreasing trends observed for VOCs. Historically, the highest concentrations have been associated with the shallow water-bearing unit in AOC-2, and are likely associated with soil concentrations in this area combined with reducing conditions in groundwater in the same area. Results of groundwater sampling conducted in 2015 continues to show the highest arsenic concentrations in AOC-2, with the highest detected concentration at well MW-123-S (71.7 µg/L in April 2015). The concentrations of arsenic detected in groundwater throughout the remainder of the site appear to represent background conditions in the area.

As discussed in Section 3.1.3, an area background concentration was calculated using the data from the upgradient well MW-129-I which yielded a background value of 10.5 µg/L. These values are in the range of a 2015 background study performed by Ecology, which found statewide average natural background values to range from 1.4 to 14.1 µg/L, with a value of 6.6 µg/L assigned to the Puget Sound Basin (Ecology, 2015b).

Groundwater geochemistry was also evaluated as part of this FS to look for trends that might influence arsenic concentrations. Figures F-1 and F-2 in Appendix F show the relative values for pH, redox potential, dissolved oxygen, and specific conductivity over time at several wells in the vicinity of AOC-2 and AOC-3. The most discernable trend is a decline in redox potential at each of these wells. However, arsenic concentrations have remained relatively steady during this same period, offering no indication that a more reducing environment will lead to decreasing concentrations of detectedarsenic in the future.

Iron oxides containing arsenic can be dissolved in groundwater in the presence of total organic carbon, whether from naturally-occurring organic matter (as in the case of former wetlands) or from anthropogenic sources of organic carbon, such as releases of chlorinated compounds or TPH. In areas with high total organic carbon concentrations (whether natural or anthropogenic), background arsenic concentrations may appear elevated due to arsenic becoming more mobile in the resulting reducing conditions (Welch et al., 2000). The upper sandy fill unit on site overlays a silt and clay unit high in total organic carbon (as described in Section 2.4.1), and significant dissolved iron concentrations are present on site. While anthropogenic releases of carbon sources have occurred on site (TPH and VOCs), the elevated levels of arsenic that are ubiquitous across the site are most likely due to this local geology.

Overall, current arsenic distribution in groundwater at the site can be summarized as follows:

- Concentrations in the shallow water-bearing unit tend to be under 10 µg/L, but do vary between 1 and 20 µg/L. The exception is well MW-123-S, which consistently shows the highest concentrations, generally between 60 and 80 µg/L (Figure D-2).
- Concentrations in the intermediate aquifer (hydraulically connected to the shallow water-bearing unit) show similar trends, with most wells following a pattern of concentrations in the 1 to 20 µg/L range, with most under 10 µg/L (Figure D-3). The exceptions are wells MW-102-I, MW-117-I2, and MW-126-I, which consistently show detections above 20 µg/L.
- Concentrations in the deep aquifer are steady and tend to be under 5 µg/L, and generally below 2 µg/L (Figure D-4).

4.2.2.3 Cyanide

Cyanide has been detected sporadically at the site, as illustrated in Figures D-5 through D-9 in Appendix D.

Cyanide concentrations in soil were also evaluated to attempt to identify a potential source of groundwater concentrations. Cyanide was historically detected above the cleanup level of 0.2 mg/kg in eight soil samples, ranging from 0.203 mg/kg in sample MW-21 (7.5 feet bgs) to 0.84 mg/kg in sample T-8SS-0.5 (0.5 foot bgs). All eight soil samples were located in AOC-2. An additional 32 soil samples were analyzed for cyanide, and all results were below the cleanup level. No obvious source of cyanide that may be contributing to groundwater has been identified. The majority of cyanide concentrations in groundwater above the cleanup level also occurred in samples collected in AOC-2. There does not appear to be a release mechanism or a plausible source for the high concentrationsof cyanide in the groundwater from the deep aquifer.

As part of this FS, additional samples were collected from wells that historically had higher total cyanide concentrations (MW-117-I2, MW-123-I2, and MW-126-I) during the October 2015 event. These samples were analyzed for total, free, and weak acid dissociable cyanide to evaluate if the cyanide detected in the groundwater from these wells was in strong metal bound forms or if it was more biologically available. Unfortunately, the total cyanide results in October 2015 showed concentrations below the sensitivity for the free and weak acid dissociable methods, making a valid conclusion difficult to draw with the available data. Additional samples for total, free, and weak dissociable cyanide were collected during the April and October 2016 sampling events. These results are summarized in Table 6A. The recent results show:

- Total cyanide concentrations continued to be sporadic, with concentrations as high as 0.0261 mg/L (MW-24D in October 2016).
- Free cyanide was never detected at any well during the same sampling periods.
- Weak dissociable cyanide was either not detected or detected at much lower concentrations than total cyanide, with the highest concentration being 0.003 mg/L.

These results indicate that the cyanide present in groundwater at the site is not free cyanide that is biologically available, and therefore total cyanide concentrations do not warrant action as part of the selected remedy.

Total cyanide concentrations measured in groundwater were also evaluated during the FS against the available total iron concentrations and turbidity measurements. Cyanide in groundwater in the presence of iron is not likely to be mobile and dissolved solids may cause interferences with the analytical method. There was no correlation observed between the total iron or turbidity measurements and the total cyanide concentrations measured in groundwater historically[1]. However, iron is present in groundwater at the site, as discussed in Section 4.2.2.4.

For the purposes of the draft FS, the results of historical total cyanide were used to define the area required for treatment. The recent results appear to contradict the conservative presumption that total cyanide results from the site represent free cyanide that is biologically available, and therefore cyanide will not be carried forward for treatment at the site as part of the Cleanup Action Plan.

4.2.2.4 Iron

Iron concentrations in groundwater at the site have not exhibited any significant increasing or decreasing trends over time; however, iron was only analyzed from 2006 to 2009 and then again in 2015. The Final RI Report concluded that historical releases of organic constituents in the vicinity of AOC-2 could have contributed to reducing conditions and solubilization of iron, leading to higher concentrations of organic constituents in AOC-2.

The highest concentrations of iron appear to be limited to AOC-2; the concentrations detected throughout the remainder of the site appear to represent area background conditions.

Analytical results support the conclusions in the Final RI Report. Concentrations at MW-129-I, the most upgradient well in the Stericycle network, ranged from 49.1 to 86.7 mg/L. As discussed in Section 3.1.3, an area background concentration was calculated using the data from this upgradient well. The resultant adjusted cleanup level is 24.5 mg/L for iron. Groundwater sampling conducted in 2015 continued to show the highest iron concentrations in AOC-2, with wells MW-102-I-1 and MW-123-I having concentrations of 94.5 mg/L and 109 mg/L, respectively, above the area background-based cleanup level.

4.2.2.5 Hexavalent Chromium

The highest recent concentrations of hexavalent chromium are observed in AOC-2 at wells MW-124- I1 and MW-24D, as shown in Figures D-10 through D-12 in Appendix D. Historically elevated concentrations have been observed at other wells, primarily surrounding AOC-2 both east and generally upgradient (MW-114-I1 and MW-126-S) and west (MW-122-I2 and MW-102-S), and show a high degree of variability. Hexavalent chromium has not been detected at monitoring wells near the site boundary in recent data; thus, hexavalent chromium is not expected to be migrating from AOC-2.

As part of the FS, historical hexavalent chromium results were reviewed in comparison to total and dissolved chromium results. These results are summarized in Table 7, though total/dissolved chromium has not been analyzed since 2003. The historical data show that total and dissolved chromium concentrations were generally lower than those reported during the same event as hexavalent chromium, and current hexavalent chromium results are reported at higher concentrations than total/dissolved chromium were generally detected historically. By definition, the fraction of chromium reported as hexavalent chromium should always be equal to or lower than total/dissolved chromium, indicating there may be data quality issues with the hexavalent chromium results. In fact, many of the older hexavalent chromium results were qualified or rejected as part of data validation.

Recent results still show issues with the quantification of hexavalent chromium. For example, matrix spike and matrix spike duplicate results routinely show very low recoveries (10 percent or less), indicating unreliable quantification of hexavalent chromium even at known concentrations.

Since recent data sets had not included the analysis of total/dissolved chromium, Stericycle collected additional samples in 2016 for analysis of total/dissolved chromium at locations analyzed for hexavalent chromium to further validate the reported concentrations ranges for hexavalent chromium at the site. Table 7a summarizes these results, which show that total/dissolved chromium has not been detected at any location above the cleanup level and is consistently lower than the reported hexavalent chromium fraction, further confirming the assessment made in the draft FS.

Since historical results were variable and no obvious source area had been determined, hexavalent chromium was reviewed in the draft FS based on 2015 reported results. Since 2016 results yield information that indicates hexavalent chromium is not as high as earlier reported, the 2016 results will be used in the Cleanup Action Plan as the site remedy is designed.

4.2.2.6 TPH

While TPH has been detected in soil, it has not been detected in groundwater above cleanup levels. Charts of the TPH data (soil and groundwater) collected at the site were provided to Ecology in 2016 and are now included in the FS as Appendix I. The groundwater data for the past 10 years were evaluated as trends over time, plotting results of wells that had a detected concentration more than once in the time period. These results show the past decline and current low levels of TPH present in groundwater at the site.

4.2.3 2015 Surface Water Sampling

Surface water in the drainage ditch that runs along the northern border of the western half of the site was sampled during the fourth quarter groundwater sampling event. Samples were collected from three locations (shown on Figure 14) on October 27, 2015. A peristaltic pump and clean, disposable tubing was used to collect each sample. The tubing intake was placed approximately 2 inches below the surface of the water present in the drainage ditch at the time of the sampling. Between 5 and 6 liters of water were initially purged and used to record field parameters before filling bottles for laboratory analyses at each location. Water quality parameters are summarized below:

- Dissolved oxygen ranged from 1.71 to 2.38 mg/L.
- Turbidity was generally low, ranging from 2.38 to 7.95 Nephelometric Turbidity Units.
- Specific conductivity ranged from 0.093 to 0.117 microSiemens per centimeter.
- Redox ranged from 46 to 93 millivolts.
- pH ranged from 5.52 to 6.04.

The data are summarized and compared to historical sampling results in Table 8. The 2015 results showed the following:

- The concentrations of COCs detected in the drainage ditch in 2015 are generally comparable in concentration range to the historical data that was collected between 1988 and 2000.
- The highest concentrations were observed at the easternmost sampling location.
- The only COCs detected above site groundwater cleanup levels were copper, silver, and zinc, though concentrations were orders of magnitude below the MTCA Method B surface water criteria (Ecology, 2015a).

The current concentrations of constituents detected in surface water do not appear to be significantly different than those evaluated during earlier investigations, and do not warrant further consideration as part of the FS.

4.2.4 Summary of Nature and Extent of COCs

The potential for exposure to contaminated soils or the migration of the COCs identified in soil and groundwater at concentrations exceeding cleanup levels is unlikely under both current and future land use scenarios. The surface of the facility and most of the transfer yard is entirely covered with asphalt, concrete, or buildings. This surface cover effectively minimizes the leaching of soil COCs to groundwater, except where groundwater is in direct contact with COCs, which occurs only during the wettest periods of the year. As long as this low-permeability cover remains in place on most of the site, leaching of COCs is assumed to be low. The only area on the site where COCs in soil have also affected groundwater is in AOC-2. However, the COCs in groundwater are a much smaller subset of those found in soil, the concentrations are generally very low, and the areal extent of groundwater impacts is limited.

The assessment of current groundwater COC concentrations are summarized in the following key findings:

- Vinyl chloride concentrations above the cleanup level are generally limited to the AOC-2 area. One soil sample, 5307-SB-1-2013101011-2, showed an elevated vinyl chloride concentration (140 µg/kg) that could indicate a historical source. However, the vinyl chloride concentrations have declined over time, indicating a continuing source is not present.

- Arsenic is an area-wide concern and concentrations at the site have remained fairly steady. Arsenic levels may be related to seasonal variability in the geochemistry of groundwater, as evidenced by seasonally higher concentrations in the shallower groundwater zones.
- Cyanide has been detected sporadically, including the highest concentration observed at an off-site boring GP2010-1 south of the site on South 206th Street collected in 2010 (435 µg/L). However, analytical results from recent groundwater monitoring have shown that the cyanide detected in groundwater is not present in a biologically available form with all tests for free cyanide resulting in non-detect results during multiple sampling rounds in 2016.
- The areal extent of the highest concentrations of iron appears to be limited to the AOC-2 area; the concentrations detected through the remainder of the site appear to represent area background conditions.
- Hexavalent chromium concentrations are highly variable, with detected concentrations occurring only sporadically at most wells. 2016 results show that total and dissolved chromium levels at all wells are consistently below the cleanup level for hexavalent chromium.
- While TPH has been detected in soil, it has not been detected in groundwater above cleanup levels.

5.0 REMEDIATION CONSIDERATIONS AND OBJECTIVES

This section presents the remediation objectives for the cleanup action at the site and applicable local, state, and federal laws that will affect the development of remediation alternatives.

The overall objective of this FS is to identify the preferred remediation alternative to reduce the risks to human health and the environment resulting from COCs in soil and groundwater at the site to acceptable levels. All remedial alternatives must address the CSM and the site migration and exposure pathways of concern described in Section 2.5. The remediation considerations and remediation objectives established for the facility will provide the framework for development of remedial alternatives.

The MTCA regulations (WAC 173-340-360) present the general requirements for selecting cleanup actions for a contaminated site. The minimum requirements applicable to all cleanup actions include specific threshold requirements and other requirements that must be met by all cleanup actions.

The threshold requirements specify that the cleanup action should:

- Protect human health and the environment;
- Comply with cleanup standards specified in WAC 173-340-700 through WAC 173-340- 760;
- Comply with applicable state and federal laws; and
- Provide for compliance monitoring.

The other requirements cited in the MTCA regulations specify that the cleanup action should:

- Use permanent solutions to the maximum extent practicable, as determined by the requirements of WAC 173-340-173-340-360(3);
- Provide for a reasonable restoration time, as determined by the requirements of WAC 173-340-360(4); and
- Consider public concerns.

5.1 REMEDIATION OBJECTIVES

General remediation objectives applicable to the site are:

- Prevent direct contact with surface or subsurface soil and inhalation of dust from surface soil affected with COCs at concentrations that exceed industrial CULs (not groundwater protection standards) or reduce the risks associated with these exposure pathways to acceptable levels.
- Reduce subsurface VOC concentrations to levels that will not pose a threat to industrial indoor air quality or reduce risks associated with inhalation of vapors from affected soil or groundwater to acceptable levels.
- Reduce, as practicable, COC mass.
- Protect human and ecological receptors by reducing COC concentrations in affected groundwater at the CPOC within a reasonable time frame.
- Minimize potential disruption of ongoing facility activities and installations.

- Support current and future industrial use of the property.
- Attain remedial objectives as soon as possible and cleanup standards within a reasonable time frame.
- Use all practicable methods of treatment in the site cleanup.
- Comply with applicable state and federal regulations for site cleanup, health and safety, and waste management.

5.2 APPLICABLE LOCAL, STATE, AND FEDERAL LAWS

Cleanup actions conducted under MTCA must comply with applicable state and federal laws. The term "applicable state and federal laws" includes legally applicable requirements and those requirements that Ecology determines to be relevant and appropriate as described in WAC 173-340- 710. Typical ARARs include location-specific, action-specific, and contaminant-specific ARARs.

Location- and action-specific ARARs influence the character and nature of the cleanup standard and/action. Contaminant-specific ARARs are those that affect cleanup standards and were discussed in Section 3.0. This section describes ARARs, in addition to those outlined in Section 3, with which the remedial action must comply.

The facility RCRA Part B permit specifically requires that the FS must comply with Revised Code of Washington Chapter 70.105 (Hazardous Waste Management), Chapter 173-303 (Dangerous Waste Regulations), and Chapter 173-340 (MTCA Cleanup Regulations). Additionally, the site is covered under RCRA as an interim status facility for the purpose of corrective action, requiring compliance with federal RCRA regulations (40 Code of Federal Regulations 240-299). Any remedial action taken at the site must comply with other applicable laws and regulations (42 United States Code Ch. 6901 et seq.). The applicable requirements under the Dangerous Waste Regulations and RCRA pertain primarily to management of remediation wastes and general compliance with the interim status RCRA permit. Corrective action requirements under RCRA and the dangerous waste rules are addressed under the RCRA permit and the MTCA regulations.

Location-specific ARARs include those based on the location of the site, such as:

- Permits from local municipalities as required for activities at the site;
- Shoreline, wetlands, and critical areas criteria; and
- Tribal and cultural protections (archaeological resources).

Action-specific ARARs include those based on acceptable management practices and will depend on the technology selected. They may include:

- Minimum Standards for Construction and Maintenance of Wells;
- Underground Injection Control Program;
- General Occupation Health Standards and Safety Standards for Construction Work;
- State Environmental Policy Act; and
- Clean Air Act.

Depending on the nature of the action selected as the remedial alternative, different ARARs may apply and will be defined as part of the design for implementation. Standard industry practices often address many ARARs, such as construction of wells being performed by a Washington licensed driller and construction work being conducted under site-specific health and safety plans compliant with federal and local safety regulations.

5.3 DISPROPORTIONATE COST ANALYSIS

The MTCA regulations will be followed to determine whether certain types of remediation are warranted at the site following a disproportionate cost analysis 173-340-360(3)(e). A frequently cited example of a disproportionate cost is a landfill where the large volumes of refuse, typically with a wide variety of contaminants, could be cleaned up only by excavating and moving the refuse to another engineered landfill. The costs to remove all refuse to a different landfill are disproportionate to the reduction of risk. The landfill case has been adopted by the U.S. Environmental Protection Agency (EPA) as a presumptive remedy, in that the model remedy assumes that the landfill would be left in place and the appropriate remedy is capping. Ecology follows the EPA presumptive remedy approach for landfills.

MTCA's disproportionate cost analysis can be performed quantitatively or qualitatively. For this FS, the qualitative approach to disproportionate cost analysis is appropriate and further described in Section 7.

6.0 POTENTIALLY APPLICABLE REMEDIAL TECHNOLOGIES

A wide range of potentially applicable technologies were selected for evaluation relative to the specific remediation considerations for the site and the screening criteria. Potentially applicable remediation technologies considered in this FS to address the exposure pathways associated with the concentrations of COCs in soil and groundwater are presented in Sections 6.1 and 6.2, respectively. The applicable technologies retained based on the screening process are presented in Section 6.3.

Since this is a focused FS, only those technologies that show the greatest potential to satisfy the site remediation objectives were retained for development of remedial alternatives. A summary of the remediation technologies considered for the FS and the results of the technology screening are presented in Tables 9 and 10 for soil and in Tables 11 and 12 for groundwater. The retained technologies for both soil and groundwater are presented in Table 13.

The technologies in this FS were screened in the FSWP to identify those technologies best suited for potential use in developing remedial alternatives for the site. The applicability of each technology was considered in light of physical site characteristics and the remediation objectives presented in Section 5.1.

6.1 SOIL REMEDIATION TECHNOLOGIES

Several proven remediation technologies have been considered as appropriate candidates for remediation of soils at the site. Tables 9 and 10 summarize the results of technology screening and lists the areas at the site that would be addressed using each technology.

The retained technologies include both in situ and ex situ processes that would result in destruction, removal, or containment of contaminants.

6.1.1 In Situ Soil Remediation Technologies

In situ technologies for remediation of soil are implemented without excavation and removal of soils and with minimal disturbance to soil. These technologies rely upon techniques to alter subsurface conditions and promote remediation of COCs present in the subsurface. In situ technologies are generally better suited for remediation in highly developed areas, active production facilities, and areas with deep or widely distributed contaminants.

6.1.1.1 Chemical Oxidation

In situ chemical oxidation (ISCO) involves application of a chemical oxidant, such as permanganate, ozone, persulfate, Fenton's Reagent, hydrogen peroxide, or a proprietary formulation of these agents,[1] into the subsurface to react with organic contaminants. By-products of the ISCO reaction are nonhazardous compounds that are more stable, less mobile, and/or inert (Siegrist, 2000). ISCO results in rapid and complete chemical destruction of many toxic organic chemicals and some inorganic constituents; other organic species are amenable to partial degradation as an aid to subsequent bioremediation. In general, the oxidants have been capable of achieving high treatment efficiencies (e.g., > 90 percent) for organic compounds, with rapid reaction rates under ideal conditions and in homogeneous soils. Although typically applied to impacted groundwater, chemical oxidants may also be applied to vadose zone soils through the use of infiltration galleries, vertical or horizontal injection wells, mechanical mixing, or direct-push injection points with forced advection to rapidly

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[1] One such proprietary formulation is RegenOx, which involves combining slow-release hydrogen peroxide and Fenton's Reagent to form radicals that serve to oxidize the COCs.

move the oxidant into the subsurface. The key for ISCO effectiveness in soils is ensuring direct contact with site contaminants.

The rate and extent of oxidation of a targeted COC are dictated by several factors: (1) the properties of the COC itself; (2) susceptibility of the COC to oxidative degradation; and (3) the matrix conditions, most notably the concentration of organic carbon and of other oxidant-consuming substances (including natural organic matter, such as the organic silt layer, reduced minerals, carbonate, and other free radical scavengers). Given the relatively indiscriminant and rapid rate of reaction of the oxidants with reduced substances, the method of delivery and distribution throughout a subsurface region is of paramount importance. Subsurface heterogeneities and preferential flow paths may result in inefficient treatment. Dispersion and groundwater advection assist groundwater ISCO treatment systems in achieving oxidant contact with contaminants. In the vadose zone, however, distribution of the oxidant relies solely on injection under pressure and vertical migration, resulting in the need for more closely spaced injection points.

Oxidation reactions can decrease the soil pH if the system is not adequately buffered. Other potential oxidation-induced effects include mobilization of redox-sensitive and exchangeable sorbed metals, possible formation of toxic by-products, evolution of heat and gas, and interference with biological activity.

This technology would be applied to impacted vadose zone soils located beneath the tank farm. ISCO would target all site COCs with the exception of inorganics. The limited depth of the vadose zone (generally a maximum of 2 to 8 feet) and limited access due to ongoing operations on site would limit the cost-effectiveness of this technology; an extensive subgrade distribution network would be needed to distribute reactant, and the limited depth would result in a high cost for treating a small soil volume. Safety issues from handling hazardous oxidation chemicals would be significant in areas that are actively used for industrial purposes.

Chemical oxidation may result in generation of oxygen in the subsurface, reduction in pH of the soil, and the oxidation of electron donors in the subsurface. In addition, the temporary increase in redox potential of the soil may shift conditions from methanogenic conditions, which are associated with reductive dehalogenation. Reductive dehalogenation of chlorinated VOCs has already been documented at the site and is contributing to decreasing COC concentrations. Chemical oxidation is likely to mobilize inorganic COCs in soil into groundwater.

6.1.1.2 Chemical Reduction

Similar to in-situ chemical oxidation, chemical reduction requires the injection of a reducing agent such as zero-valent iron (ZVI), ferrous sulfide, or hydrogen sulfide to chemically convert site COCs to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. Some products combine reductants like ZVI with a carbon source or electron donor, such as emulsified ZVI (EZVI); EZVI is composed of nano- or micro-scale, ZVI emulsified in biodegradable vegetable oil and a food- grade surfactant (Quinn et al., 2005). The exterior of the oil membrane emulsion droplets have hydrophobic properties similar to dense nonaqueous phase liquid (DNAPL), and are therefore miscible with DNAPL. Chlorinated VOCs diffuse through the oil membrane and undergo reductive dechlorination in the presence of ZVI. In this reaction, the ZVI is essentially consumed; the ZVI becomes oxidized, and has no further reactivity. In addition, the vegetable oil and surfactant in EZVI act as long-term electron donors and promote anaerobic biodegradation. EZVI can be delivered to the subsurface through direct-push injection, or via hydraulic or pneumatic fracturing.

Other chemical reductant formulations are designed for the slow -release of reducing chemicals like sulfides in order to promote long-term reducing conditions, which are also favorable to anaerobic biodegradation. Ferrous iron and ZVI are the most common reducing agents; ferrous iron is already abundant at the site and could be utilized under enhanced groundwater chemistry conditions to stabilize inorganic COCs and accelerate the remediation of vinyl chloride.

This technology presents several drawbacks, including difficulties in obtaining effective distribution in the subsurface, especially at sites with complex hydrostratigraphy (for disperse injections) or groundwater flow patterns (for a reactive barrier configuration).

Chemical reduction would be implemented in AOC-2, AOC-3, and AOC-5 to address vinyl chloride, cyanide, arsenic, and iron at the site in both the shallow fill unit in the areas around the tank farm in AOC-2. This technology would likely enhance biodegradation of chlorinated COCs and decrease the mobilization of soil COCs to groundwater, though thorough bench- and pilot-scale testing may be desirable to verify an effective geochemical response to this treatment.

As part of an enhanced bioremediation program, in situ chemical reduction may speed remediation time frames for VOCs and inorganics by aiding in development of the right geochemistry for organisms to thrive.

6.1.1.3 Cap/Surface Cover

Various caps and surface covers can be used to minimize exposure at the surface to waste materials, to reduce vertical infiltration of surface water into wastes that could generate contaminated leachate, and to control gas emissions from waste that contains VOCs. Caps can also provide a useful surface for various land uses, such as golf courses, parking areas, and warehouses. For many sites, a cap/surface cover is combined with subsurface barrier walls to provide a comprehensive engineered barrier to effectively contain affected soil.

Typical cover designs for industrial facilities include Portland cement concrete, asphalt pavement, and asphalt concrete pavement. These cover systems effectively convey surface water to collection systems and definitively reduce contact with soils, encourage runoff to reduce infiltration, and prevent human exposure to underlying soil or waste. These rigid or semi-rigid caps allow the site to be maintained in productive use by allowing for structures to be constructed and vehicles and equipment to be operated. Flexible membrane liners and compacted clay or bentonite liners are more conventionally applied to landfill caps, where large areas prone to differential settlement must be graded, sloped, covered, vegetated, and managed over the long term with limited use of the area after capping. A variety of subsurface barriers can be combined with caps, including slurry walls, sheet-pile walls, grout curtains, cement-bentonite walls, soil-cement walls, or barrier walls constructed of proprietary materials such as Impermix®.

The site consists of a patchwork of concrete, dirt, and asphalt covering, and is already largely covered by impervious surfaces in all AOCs. A cap/cover system would minimize human exposure to underlying waste materials, limit erosion and runoff of impacted soil, and reduce (but not eliminate) infiltration of surface water (thereby reducing the potential for soil COCs to leach into groundwater).

Either a new cover or restoration of existing cover at the site could be installed to cover areas around the tank farm area in AOC-2, where COCs in soil are most prevalent. Installing a more impermeable cover in areas currently covered only with soil may improve the overall effectiveness of the current cover system. In addition, capping and surface cover may be used in the short term to provide a protective barrier until other technologies can be utilized for future remedial actions.

6.1.2 Ex Situ Remediation Technologies

Remediation of soil using ex situ technologies requires excavation of affected soil and is typically used only for shallow hotspots rather than for widely distributed or deep contamination.

6.1.2.1 Excavation and Off-Site Disposal

Excavation and off-site disposal involves excavation of either all areas of soil that exceed cleanup levels or selected hotspots. Excavation could potentially include removal of soil to target VOCs, semivolatile organic compounds, TPH, and inorganics (metals). The excavated soil would be stockpiled, characterized, and transported and disposed of off site. New clean fill would be placed in the excavation and compacted to restore the site to pre-existing grade. Dewatering would be required to remove the full extent of impacted soils, and a rock ballast layer with geotextile fabric may need to be installed to stabilize the soft, wet bottom of the excavation prior to backfilling. Excavation of the contaminated soil beneath the water table would require extensive dewatering of the area and an associated water treatment system. In addition, excavation of portions of the site would be impossible due to the existing buildings on the site, which are expected to remain staffed during remediation activities.

Excavation with off-site landfill disposal would comprehensively address all soil COCs; however, large scale excavation in active areas of the facility like AOC-2 would require extensive shoring and support systems, additional short term risk of spills with ongoing operations, and some impacted soil would likely remain in place due to the presence of existing structures/buildings. However, targeted excavation used in conjunction with capping and surface cover, may be employed as part of site maintenance and redevelopment activities in the short term. In the long term, once the facility is closed, large scale excavation would be considered as part of closure activities.

Excavation requires the disposal of excavation spoils off site, which can be quite costly. In addition, significant short-term risks would be created due to dust generation, volatilization of COCs, and transportation of impacted soils. Nevertheless, this technology would address all COCs in the excavated areas and may be utilized in smaller specific areas as they become accessible in the future if surface redevelopment provides access to additional soils.

6.2 GROUNDWATER REMEDIATION TECHNOLOGIES

Several general technologies have been considered to address groundwater impacts within the affected groundwater units. Table 11 summarizes the results of the technology screening and lists the areas at the site that would be addressed using each technology. Technologies are categorized by whether they may be implemented in situ or ex situ, and by the method of treatment they encompass (chemical, biological, physical, etc.). Ancillary or support technologies as outlined in Table 11 are technologies used in conjunction with another primary treatment technology as a support measure. A list of the retained remediation technologies for soil and groundwater is presented in Table 13.

6.2.1 Enhanced Anaerobic Biodegradation

Enhanced anaerobic biodegradation involves injecting a carbohydrate electron donor (e.g., molasses, sodium lactate, vegetable oil, or proprietary blend) into the affected groundwater to create reducing conditions and enhance naturally occurring reductive biodegradation processes. This is a proven technology with a substantial history of success in a variety of applications. The carbohydrate could be injected with wells, direct-push probes, or groundwater recirculation systems. Groundwater recirculation systems could use vertical or horizontal wells. This approach could be implemented as either a reactive zone to treat a source area or as a biobarrier to intercept and treat groundwater as it moves downgradient.

This technology would likely address vinyl chloride and its potential sources (Section 4.2.2.1). Anaerobic biodegradation would not directly address inorganics in groundwater, although it may be used in conjunction with in situ chemical reduction to stabilize inorganics (i.e., co-precipitation of arsenic with ferrous sulfide through bio-mediated processes).

Natural bioattenuation of chlorinated VOCs is already occurring at the site, as evidenced by the strong downward trend in concentrations of vinyl chloride (Figure 17). This trend also indicates that indigenous organisms can support reductive dechlorination of chlorinated organic COCs.

This technology would enhance already-occurring biodegradation of vinyl chloride in groundwater and is compatible with ongoing natural biological processes in affected groundwater and in situ chemical reduction technologies (Section 6.1.1.1). This technology will be considered to address vinyl chloride impacted groundwater in AOC-2 and may be used in conjunction with in situ chemical reduction to stabilize inorganics.

6.2.2 Bioaugmentation

Bioaugmentation is an in situ remedial technology in which a biological seed culture, specifically adapted for degradation of the constituents of interest, is introduced to the impacted groundwater. Bioaugmentation could be conducted using anaerobic or aerobic biological seeds.

Under anaerobic conditions, the microorganism *Dehalococcoides ethogenes* must be present for dechlorination of vinyl chloride to ethene. For bioaugmentation technology, a microbial culture containing *Dehalococcoides ethogenes* would be added to the impacted groundwater to promote full reductive dechlorination. Injection wells are typically used for injecting the microorganisms. The culture added to the subsurface would then compete with indigenous organisms for nutrients and substrate. For many bioaugmentation applications, the added organisms do not compete successfully with indigenous organisms. Due to the ongoing natural attenuation of vinyl chloride in affected groundwater units, it is expected that indigenous organisms are present that effectively degrade COCs at the site and that bioaugmentation may not enhance biodegradation in these zones.

Due to the use of oxygen and injection wells, aerobic bioaugmentation technology could encounter issues of iron fouling and biofouling. For either anaerobic or aerobic bioaugmentation technologies, permitting to allow injection would be required and may be complex due to introduction of a non-native biological organism if they are not currently present. The bacterial strain introduced by bioaugmentation processes is typically not fully adapted to the local environment; therefore, the bioaugmentation seed may require periodic or continual addition in order to maintain a viable population and effective bioremediation.

Although biodegradation is already occurring at the site, anaerobic bioaugmentation has been retained for possible use, should future testing show that the degradation of COCs is stalling.

6.2.3 Monitored Natural Attenuation

Monitored natural attenuation relies on the attenuation of groundwater constituents by natural processes, including biodegradation, abiotic degradation, adsorption, and dilution. This technology is combined with a long-term monitoring program designed to be sufficiently robust to monitor the progress of natural attenuation toward meeting cleanup objectives. Due to the passive nature of this remedial technology, it can be readily implemented with a minimum of institutional issues, such as permitting or arranging for access permissions, and also would have minimal potential for implementation problems, such as fouling. The potential drawbacks of sole reliance on this technology include potentially longer remediation periods when compared to active groundwater remediation technologies. Iron, arsenic, and cyanide may not be amenable to monitored natural attenuation.

Biodegradation of chlorinated solvents present at the site is currently observed and accounts for the presence of vinyl chloride in groundwater (Figure 17). Natural attenuation, including biodegradation, is currently occurring throughout the site as is evidenced by the downward trend of concentrations of chlorinated solvents (Appendix D-1), coupled with the evidence of the key attenuation parameters, such as daughter compounds (*cis*-1,2-DCE and vinyl chloride). Monitored natural attenuation may be used either in conjunction with or following implementation of more active groundwater remediation technologies at a site. When implemented following more active remedial technologies, it is often referred to as monitored attenuation. Selection of a remedial strategy for the site will include consideration of processes that have limited negative impact on the natural attenuation process. Natural attenuation may also serve as one component of a comprehensive remedial alternative that includes active treatment. For vinyl chloride, natural attenuation may provide a permanent approach for remediation as it results in transformation of vinyl chloride into a less harmful product (i.e., ethene).

6.2.4 Chemical Reduction

Chemical reduction requires the injection of reducing agent such as ZVI, ferrous sulfide, hydrogen sulfide, or a hydrogen-releasing compound to chemically convert site COCs to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert.

Other chemical reductant formulations are designed for the slow release of reducing chemicals like sulfides in order to promote long-term reducing conditions that are also favorable to anaerobic biodegradation. Ferrous iron, ZVI, and hydrogen-releasing compounds are the most common reducing agents; ferrous iron is already abundant at the site and could be utilized under enhanced groundwater chemistry conditions to stabilize inorganic COCs. Site-specific chemical formulations with sulfides may be used in conjunction with hydrogen-releasing compounds, ZVI or existing iron concentrations to form insoluble precipitates of arsenic and reduce iron concentrations in groundwater as arsenic co-precipitates with ferrous sulfides (i.e., arsenopyrite).

Typical drawbacks include difficulties in obtaining effective distribution in the subsurface, especially at sites with complex hydrostratigraphy (for disperse injections) or groundwater flow patterns (for a reactive barrier configuration).

Chemical reduction could be implemented in AOC-2, AOC-3, and AOC-4 to address vinyl chloride, cyanide, arsenic, and iron in all impacted groundwater units around the tank farm (AOC-2), AOC-3, and AOC-4). This technology would likely enhance biodegradation of vinyl chloride and decrease the mobilization of soil COCs to groundwater. Bench- and pilot-scale testing may be necessary to verify an effective geochemical response to this treatment.

As part of an enhanced bioremediation program, in situ chemical reduction may speed remediation time frames for vinyl chloride and inorganics by aiding in development of the right geochemistry for organisms to thrive.

6.2.5 Chemical Oxidation

Chemical oxidation has been successfully used for in situ treatment of nonchlorinated and chlorinated VOCs and cyanide. Oxidants that have been used include potassium permanganate, hydrogen peroxide, ozone, persulfate, and Fenton’s reagent. This technology is based on injection of the chemical oxidant into the impacted groundwater or addition to excavations (at or below the water table) before backfill. Injection of the chemicals can be accomplished using direct-push techniques, injection wells, or recirculation wells. This technology is typically considered only for treatment of highly impacted source areas; the technology is not well suited for use in dilute groundwater plumes. High doses of reactant chemical would be required, and low utilization efficiencies would be achieved for dilute plumes, thereby resulting in high remediation costs.

Hydrogen peroxide, ferrous sulfate, and permanganate (potassium or sodium) are generally purchased and stored as liquids, which must be metered into the groundwater. However, ferrous sulfate and potassium permanganate can be purchased as solids and dissolved on site prior to injection into the groundwater. Ozone can be generated on site using specialized equipment. In addition, proprietary chemicals, such as Regenox (manufactured by Regenesis), can be purchased. These chemical oxidants are all reactive, hazardous chemicals that require proper design and management to be used safely.

Although chemical oxidation may effectively degrade chlorinated organics in groundwater, it would alter existing subsurface conditions that are necessary for natural biodegradation processes in all areas affected by the oxidant, temporarily suppressing the natural anaerobic biodegradation processes currently occurring in impacted groundwater. In situ chemical oxidation may also result in the mobilization of metals that may migrate downgradient of injection locations. In addition, the technology is effective only when the oxidant is directly in contact with COCs. Delivery of the oxidant within intermediate aquifer Zones A and B would be difficult without inducing groundwater flow, and might limit the potential use of this technology. The organics, background pesticides, and high iron content within the soil would also react with the oxidant, reducing the treatment effectiveness for targeted COCs.

Chemical oxidation could be implemented to address vinyl chloride, iron, and cyanide in both the shallow water-bearing unit and the intermediate aquifer Zones A and B in the areas around the tank farm in AOC-2, AOC-3, and AOC-4; and to address cyanide in the deep aquifer. Risks would include mobilizing metals and would need to be assessed through bench- and pilot-scale testing.

6.2.6 Passive/Reactive Treatment Barriers

Permeable reactive barriers (PRBs) using ZVI or other reagents to chemically reduce chlorinated solvents are proven to be effective for groundwater remediation. This technology is typically implemented as a reactive barrier to destroy COCs migrating away from the source area in impacted groundwater.

In order to make this technology cost-effective for large areas, a ZVI PRB is sometimes implemented as a funnel and gate system, in which a low-permeability barrier wall “funnel” is placed within the flow path of the affected groundwater to direct flow to the zero-valent iron “gate,” where the reaction occurs. ZVI has been proven to reduce arsenic, free cyanide, and chlorinated organics. This approach would require significant, invasive construction to implement the funnel and gate, which is particularly problematic for use of this technology on an active industrial property.

For installation in smaller areas, PRBs may be installed by direct push or through installation of treatment columns, which could still have a significant effect on reducing concentrations of groundwater COCs.

Due to the complex hydrogeology of the intermediate aquifer Zones A and B, PRBs installed by direct push offer flexibility in placement around existing on-site operations. This use of PRBs in strategic locations could be effective in treating contaminated groundwater and prior to migration off site.

6.3 REVIEW OF RETAINED TECHNOLOGIES

The retained remediation technologies for soil and groundwater are listed in Table 13. The technologies discussed in Section 6.1 and 6.2 were screened against the criteria to develop remedial alternatives for soil and groundwater at the site. The technology description and relevant site considerations are summarized in Tables 10 and 12 as well as in Sections 6.1 and 6.2.

7.0 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

This section presents the criteria used to evaluate the potential remedial alternatives identified for the site and to select the preferred alternative(s). The potential remedial alternatives are presented in Section 8 and were developed using the technologies retained during the initial screening of potentially applicable remediation technologies presented in Section 6. The remedial alternatives presented in Section 8 were designed to attain the remediation objectives presented in Section 5.1.

To select the preferred alternative, each of the remedial alternatives presented in this FS was evaluated relative to the criteria specified in the MTCA rules under WAC 173-340-360(3)(f) (evaluation criteria for determining whether a cleanup action uses permanent solutions to the maximum extent practicable). The evaluation criteria used for this FS must address requirements of the MTCA regulations and the RCRA Part B permit. In this FS, remedial alternatives will be evaluated based on the following evaluation criteria:

- Protectiveness and risk reduction (WAC 173-340-360[3][f][i]),
- Permanence (WAC 173-340-360[3][f][ii]),
- Cost (WAC 173-340-360[3][f][iii]),
- Long-term effectiveness (WAC 173-340-360[3][f][iv]),
- Management of short-term risks (WAC 173-340-360[3][f][v]),
- Technical and administrative implementability (WAC 173-340-360[3][f][vi]),
- Public concern (WAC 173-340-360[3][f][vii]), and
- Reasonable restoration time frame (WAC 173-340-360[4]).

The remedial alternatives considered in this FS were designed to attain the remediation objectives to the extent practicable. The FS evaluation criteria are defined and discussed in the following subsections. These criteria are used to evaluate the remedial alternatives presented in Section 8.

7.1 PROTECTIVENESS AND RISK REDUCTION

As described in WAC 173-340-360(3)(f)(i), this criterion involves evaluating “*the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and offsite risks resulting from implementing the alternative, and improvement of the overall environmental quality.*”

Evaluation of protectiveness and risk addresses long-term effects rather than short-term effects, which are evaluated under a different criterion. Alternatives that attain remediation levels and/or cleanup levels are considered as protective under this criterion, and alternatives that meet remediation or cleanup levels in a shorter time are considered to provide a higher level of risk reduction. Alternatives that rely on engineering controls or institutional controls to provide protectiveness and risk reduction are generally ranked lower for this criterion than alternatives that do not rely on these controls.

Factors considered for evaluating this criterion include:

- Potential risks to human health and the environment during and following implementation of the alternative (current site conditions will be used as a baseline to assess the reduction in risks that would result from implementing the remedial alternative);

- Present and future land use for the site;

- Present and potential for future use of any water resources either associated with or affected by the constituents within the site;

- Potential effectiveness and reliability of institutional controls associated with the alternative; and

- The ability of the remedy to reduce site risk, including the capability of the alternative to limit and monitor migration of COCs and the toxicity of COCs.

7.2 PERMANENCE

As described in WAC 173-340-360(3)(f)(ii), permanence is the "*degree to which the alternative permanently reduces the toxicity, mobility or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.*"

Alternatives that actively degrade or destroy COCs would be ranked higher for this criterion than alternatives that utilize on-site or off-site containment. In accordance with MTCA requirements, the alternative providing the greatest degree of permanence is used as the baseline alternative against which other alternatives are compared. The other alternatives will be compared to the baseline alternative to identify the alternative that provides the greatest practicable degree of permanence. For the purposes of this FS, the term *practicable* shall be used as defined in WAC 173-340-200.

7.3 COST

WAC 173-340-360(3)(f)(iii) describes the cost evaluation criteria. Costs of remedial alternatives include implementation costs, operation and maintenance (O&M) costs, monitoring costs, and management/reporting costs. Cost estimates were prepared for each remedial alternative considered in this FS. The costs include both initial implementation costs as well as future costs over the estimated remediation life, as detailed in Appendix G. Future costs are included in the total alternative cost using net present value (NPV) estimates. Cost estimates were prepared in general accordance with EPA guidance for preparing FS cost estimates under the Comprehensive Environmental Response, Compensation, and Liability Act (EPA, 2000).

The costs for implementing a remedial alternative include costs associated with:

- Engineering and permitting,

- Public relations,

- Construction and utility relocation,

- Purchase of facilities and equipment,

- Building and tank demolition,

- Waste transportation and disposal,
- Site restoration (including building and surface restoration), and
- Property access.

Implementation costs typically occur at the beginning of the remedial action implementation program but may also include costs that occur later in the remediation program, such as costs for replacement or major repair of key remedial system components.

Estimated costs for O&M (including minor repairs), monitoring, and routine reporting are generally calculated on an annual basis, commencing after construction has been completed. These costs include longer term, repeating expenses associated with multiyear remediation activities. Reporting costs are incurred to document monitoring, maintenance, and operations activities and provide regulatory information to Ecology. Estimates of these ongoing, recurring, future costs usually include labor, power, utilities, sample analyses, subcontractors, agency oversight, and consumed materials. Future recurring costs are combined with initial implementation costs into a single NPV cost estimate for each remedial alternative. The NPV calculations consider an annual net discount rate (assumed to be 2.5 percent) that addresses the time value of money. The net discount rate is the interest rate that could be obtained from a prudent investment less a reasonable inflation rate. The net discount rate of 2.5 percent was selected in consultation with Ecology on past remediation projects. This NPV cost estimate, including initial implementation costs and future recurring costs, is used to assess the cost criterion and compare the cost of the remedial alternatives.

Conceptual level cost estimates of remedial alternatives are included in Appendix G.

7.4 LONG-TERM EFFECTIVENESS

WAC 173-340-360(3)(f)(iv) states that:

> *"long-term effectiveness includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes."*

In addition, it is recommended that when assessing the relative degree of long-term effectiveness, the following cleanup actions be ranked in descending order as a general guideline:

1. Reuse or recycling;
2. Destruction or detoxification;
3. Immobilization or solidification;
4. On-site or off-site disposal in an engineered, lined and monitored facility;
5. On-site isolation or containment with attendant engineering controls; and
6. Institutional controls and monitoring.

In summary, for this criterion, the certainty that an alternative will be effective is assessed, in addition to the capability of a remedial alternative to reliably maintain its effectiveness over a long period of time. If an alternative includes technologies that are not reliable, have not been used under similar site conditions, or are in developmental stages and are not proven technologies, the alternative would generally be considered to have low long-term effectiveness. In addition, if an alternative results in production of hazardous substance residues, it would have a lower long-term effectiveness than alternatives that do not produce such residues. Permanent alternatives that result in destruction of COCs or that result in the recycling or reuse of waste would provide better long-term effectiveness than alternatives relying on containment using engineering controls.

7.5 MANAGEMENT OF SHORT-TERM RISKS

The short-term risk evaluation criteria is described in WAC 173-340-360(3)(f)(v) as "*the risk to human health and the environment associated with the alternative during construction and implementation, and the effectiveness of measures that will be taken to manage such risks.*" Short-term risks associated with remedial alternatives include potential releases of material, water, particulates, or vapors containing COCs that could occur during implementation of the alternative. These types of releases could occur as a result of dust generation during excavation or handling of excavated materials, loss of affected soil or affected groundwater during treatment, or accidental releases during transport of affected media to a waste disposal or treatment facility. Alternatives with potential risks that cannot be effectively managed would rank lower than those with minimal short-term risks or alternatives in which the short-term risks can be effectively managed.

7.6 TECHNICAL AND ADMINISTRATIVE IMPLEMENTABILITY

As described in WAC 173-340-360(3)(f)(vi), the technical and administrative implementability criterion refers to the capability to effectively implement a remedial alternative. This criterion is based on whether implementation of the alternative is technically possible relative to its complexity, administrative/regulatory requirements, size, access, and integration with existing site conditions.

Technical implementability involves technical and physical factors, such as the presence of existing buildings or storage tanks that may affect implementation of an alternative or the need for specialized equipment for implementation. Simple, proven remedial alternatives would rank high for technical implementability, while complex or unproven (developing) alternatives would rank low, as the implementability of unproven technologies is unknown. Administrative implementability involves factors such as permitting requirements or regulatory approvals needed for implementation.

Administrative factors would most likely affect the implementation schedule, whereas technical factors could make an alternative difficult to implement and not as effective as a simpler remedy. Alternatives with minimal permitting requirements and that are readily accepted by regulatory agencies would rank high for administrative implementability.

Factors considered for evaluation of this criterion include:

- The size and complexity of the remedial alternative;
- The degree to which the remedial alternative can be integrated with existing operations and activities within affected areas;
- Regulatory requirements, including permitting;
- Present and future land use for the area above and adjacent to the project area, including any specific constraints land use may have on the alternative;

- Present and potential for future use of any water resources either associated with or that may be affected by the site; and
- Potential constraints to implementation of institutional controls associated with the alternative.

7.7 PUBLIC CONCERN

Public concern is described in WAC 173-340-360(3)(f)(vii). This criterion considers the concern that the community including individuals, community groups, local governments, tribes, federal and state agencies, or any other organization that may have an interest in or knowledge may have regarding the implementation of the alternative. Remedial alternatives likely to be readily accepted by the public would rank higher than alternatives that may create issues that must be addressed.

Potential public concerns include factors such as:

- Increased truck traffic and adverse traffic impacts,
- Noise,
- Dust and odors,
- Release of vapors,
- Use of hazardous materials,
- Safety, and
- Effects on property values.

In addition, contamination of nearby water bodies and off-site groundwater are potential issues that may be cause for public concern.

7.8 REASONABLE RESTORATION TIME FRAME

A reasonable restoration time frame is not an evaluation criterion included in WAC 173-340-360(3)(f); however, it is included as part of the protectiveness criterion (WAC 173-340-360[3][f][i]) and is a minimum requirement required under WAC 173-340-360(2)(b). Restoration time frame is considered as an additional evaluation criterion to determine if the restoration time frame for each alternative can be considered reasonable. The requirements and procedures for determining whether a cleanup action provides for a reasonable restoration time frame is described in WAC 173-340-360(4).

The restoration time frame is the time required for an alternative to attain remediation objectives. In assessing this criterion, the practicability of attaining the shortest restoration time is assessed.

Additional consideration as summarized in WAC-173-340-360(4)(b) include:

- Potential risks posed by the site to human health and the environment;
- Practicability of achieving a shorter restoration time frame;

- Current use of the site, surrounding areas, and associated resources that are, or may be, affected by releases from the site;
- Potential future use of the site, surrounding areas, and associated resources that are, or may be, affected by releases from the site;
- Availability of alternative water supplies;
- Likely effectiveness and reliability of institutional controls;
- Ability to control and monitor migration of hazardous substances from the site;
- Toxicity of the hazardous substances at the site; and
- Natural processes that reduce concentrations of hazardous substances and have been documented to occur at the site or under similar site conditions.

Alternatives that achieve remediation objectives in a shorter time would rank higher for this criterion than alternatives requiring a longer time. Alternatives that may not achieve remediation objectives for many years would rank lower than those alternatives that attempt to restore the environment, even if there is uncertainty about the ability of the alternative to achieve remediation objectives. A longer period of time may be used for the restoration time frame for a site to achieve cleanup levels at the POC if the cleanup action selected has a greater degree of long-term effectiveness than on-site or off-site disposal, isolation, or containment options. However, extending the restoration time frame cannot be used as a substitute for active remedial measures, when such actions are practicable.

8.0 DEVELOPMENT AND EVALUATION OF REMEDIAL ALTERNATIVES

This section develops and evaluates remedial alternatives that could be implemented to address affected soil and groundwater at the site and selects a preferred alternative. These alternatives are based on remedial technologies identified in the screening of potentially applicable remedial technologies. In order to select the preferred alternative, potentially applicable remedial alternatives are evaluated relative to criteria specified in the MTCA rules.

The remedial alternatives developed for the site are described in detail in Section 8.1. An evaluation of the remedial alternatives relative to the evaluation criteria described in Section 7.0 is presented in Section 8.2. The baseline or most permanent alternative (as defined in MTCA) is identified in Section 8.2.2, and alternatives are evaluated relative to this baseline alternative using the criteria specified in the MTCA rules. This evaluation results in selection of a preferred alternative for the site. A disproportionate cost analysis was conducted to assess the relative costs and benefits of alternatives, and the results are presented in Section 8.3. The preferred remedial alternative is described in Section 8.4.

8.1 REMEDIAL ALTERNATIVES

This section outlines the remedial alternatives that have been developed from the remedial technologies described in Section 6. The evaluation of these alternatives requires that each alternative be designed to attain the remedial objectives specific to the site and the remedial considerations for different portions of the site. Components common to all remedial alternative are described in Section 8.1.1. The conceptual design for each remedial alternative is presented in Sections 8.1.2 through 8.1.4.

Several remediation technologies were retained that will sufficiently reduce total contaminant mass within the source areas such that COC concentrations in groundwater may meet the CULs within a reasonable time frame at the CPOC. These technologies are listed in Table 13.

Three remedial alternatives that incorporate one or more of the retained technologies have been developed for the site. Not all of the technologies that were retained were used to develop the alternatives, but all were considered.

8.1.1 Remedy Components Common to All Alternatives

This section describes the following elements, which are common to all three remedial alternatives:

- Institutional controls (ICs);
- Active treatment of remaining source soils in active areas of the facility as they become accessible or at facility closure;
- Pavement or concrete surface cover;
- Targeted treatment of arsenic in groundwater;
- Compatibility of treatments chosen with hexavalent chromium treatments; and
- Long-term compliance monitoring.

8.1.1.1 Institutional Controls

ICs, as described in WAC 173-340-360(2)(e), are not a remediation technology and do not result in site cleanup; rather, they are commonly used as a component of remedial alternatives to address residual soil and/or groundwater contamination. In addition, ICs may be used to protect human health and the environment during implementation of a remediation program that may require longer time frames to achieve remediation objectives. ICs typically consist of administrative controls, such as deed restrictions, and controls that prohibit actions that may result in the exposure of individuals to soil or groundwater contaminants. They also may include engineering controls that limit exposure to individuals and the environment (e.g., soil cover, hydraulic control, site fencing, etc.).

Deed restrictions protect the health and safety of people who may come in contact with the site in the future. Such restrictions could include preventing or limiting site excavation work and assessing potential vapor exposure pathways prior to ground disturbing activities, requirements to notify future construction workers of the presence and location of affected site soil or groundwater, or precluding future use or redevelopment of the site for certain uses, such as residential, schools, day care centers, or hospitals. Additional ICs can be established to maintain remediation technologies put in place at a site.

Administrative controls also can be non-enforceable restrictions that provide information, notification, or site security. These controls may include warning signs that inform users of the potential site hazards and access requirements. On-site security and containment fencing may be employed in addition to warning signs to prevent unauthorized individuals from entering the site. On an industrial facility operation like this site, administrative controls can be built into site safety plans and in employee and visitor hazard communications.

As discussed in Section 4.2.1, the most frequently detected COC, arsenic, levels in soil are, on average, below the FS cleanup levels for most site areas. For these reasons, Stericycle proposes to use ICs to address remaining low-level soil contamination onsite.

8.1.1.2 Active Treatment of Source Material in Soils

Historical soil sampling results show the majority of elevated concentration COCs detected in samples in AOC-2, and a few locations farther south in AOC-3. It is currently impracticable to remediate source material beneath the active areas of the facility, especially in AOC-2 and in AOC-3, without severely affecting site operations. Remediation would require demolition or temporary removal of existing tanks or structures and/or breaches to existing containment features that are currently necessary to minimize the risk of releases to the subsurface from site operations.

Remediation of the soils above CULs beneath the tank farm in AOC-2 would result in severe impacts to active site operations and would require decommissioning, removing, and replacing/restoring waste storage tanks that are currently in use. Remediation of soils above CULs in AOC-3 southeast of the Treatment Stabilization Building also would severely impact operation. As noted in Section 4.2.1, sample results for arsenic in AOC-3 (5307-SB-1) showed a concentration that is more than two times the FS CUL of 7.4 mg/kg. This sample is from approximately 6 to 11 feet bgs, below the shallow silt layer and underneath a vault. In order to design treatment, additional pre-design sampling and characterization would be necessary which is currently impracticable with the active operations in these areas.

Contamination remaining in soil for the majority of the active areas of the facility could be evaluated and remediated at facility closure or as maintenance on the tanks/structures, and/or as redevelopment activities allow. Since many of the soil sample results are now 15-30 years old and for several COCs that are naturally degradable, resampling prior to remediation of these areas is warranted in order to specifically determine depths and extents of treatment or excavation zones.

Based on the existing data an area encompassing the highest density of samples that showed concentrations above CULs is assumed for future assessment and remediation during facility closure via excavation or other active measures. The areas to be assessed for further remediation at facility closure are shown on Figure 18 and would include approximately 9,000 square feet within the central area of AOC-2 under the tank farm (Source Area 1) and two smaller source areas- an approximately 1,000 square foot area in the northwest corner of AOC-2 (Source Area 2) near sample location S-1, and an approximately 500 square foot area on the east side of the Treatment Stabilization Building in AOC-3 (Source Area 3).

A detailed pre-design would be necessary prior to remediation in order to better delineate the extent of remediation that will be required. Under the July 2015 RCRA Closure Plan (Section Ii of the permit), soil sampling is already required in Source Area 1 and 3 upon facility closure and will aid in determining design of active remediation of soils in that area. Sampling will also be performed in Source Area 2 to aid design of treatment for that remaining soil source area. ICs will be used to prevent worker exposure and any excavation work performed in known or suspected contaminated areas will be coordinated with Ecology.

8.1.1.3 Pavement or Concrete Surface Cover

Surface cover and containment are crucial in support of ongoing facility operations. Maintaining pavement and concrete is necessary for both ongoing operations and to prevent worker exposure to subsurface contaminants. Maintaining existing pavement and concrete surface cover/containment will be a part of all three remedial alternatives.

8.1.1.4 Targeted Treatment of Arsenic in Groundwater

Although arsenic has been measured in soil above screening levels in several areas of the site (Figure 12), arsenic concentrations in groundwater for the majority of the site are consistent with natural organic carbon levels (Section 4.2.2.2). Elevated levels of arsenic in groundwater are likely a result of natural organic carbon creating reducing conditions that result in freeing arsenic from iron oxides that are naturally occurring in the aquifer soils. This combination of background total organic carbon with iron oxides in site soils creates a large source of arsenic with a huge buffering capacity.In situ chemical and biological treatment methods are unlikely to overcome this naturalgeochemistry.

Even if these technologies are initially successful, arsenic concentrations are likely to rebound over time. For these reasons, Stericycle proposes to limit treatment of arsenic in groundwater to areas where anthropogenic sources of carbon have exacerbated the existing arsenic concentrations. The primary areas for treatment are under and around AOC-2, as well as near MW-117-I2. Although no carbon based groundwater COCs are currently above screening levels at MW-117-12, arsenic levels are substantially elevated when compared to the majority of the wells on site (Appendix D, Figure D-3). Low-level detections of some chlorinated VOCs (*cis*-1,2-DCE, vinyl chloride) have been reported in semi-annual progress reports since 2010, indicating the presence of anthropogenic carbon, which may explain the higher arsenic concentrations. Once the anthropogenic contaminants are treated, the previously existing geochemistry should return and arsenic concentrations should return to levels consistent with the natural total organic carbon and iron oxide interactions in the aquifer.

8.1.1.5 Compatibility of Treatments Chosen with Hexavalent Chromium Treatments

Hexavalent chromium concentrations are likely biased high due to interferences in the analytical method. These biases are likely pushing results above screening levels erroneously and Stericycle has proposed additional sampling to further augment the issues raised in Section 4.2.2.5. For these reasons, Stericycle proposes to use technologies compatible with hexavalent chromium treatment, but not to target groundwater that has no concentrations exceeding screening levels except for hexavalent chromium.

All three alternatives assume that hexavalent chromium in groundwater will not be above the CUL once additional analysis have been completed. However, the three alternatives chosen have been chosen for compatibility with hexavalent chromium remediation. Should the additional analysis confirm hexavalent chromium is above the CUL, the alternatives may be re-ranked or expanded to address hexavalent chromium in groundwater (if not already addressed by the preferred alternative).

8.1.1.6 Long-Term Compliance Monitoring

Long-term groundwater monitoring is also proposed as a component of each of the three alternatives discussed below. Long-term groundwater monitoring will consist of regularly scheduled groundwater sampling and analysis for COCs from a network of wells on the site. These data will be used to document and evaluate remedy effectiveness and progress on anticipated remediation timelines to meet CULs. The specific number of wells and timeframes for monitoring are specified for each remedial alternative in the descriptions below.

Stericycle considered the MTCA requirements for sites where natural attenuation may be appropriate aspects of a remedy as part of this FS. These considerations included those specifically cited in WAC 173-340-370(7)(a) through (d), as follows.

a. *Source control has been conducted to the maximum extent practicable.* Sources of contamination that remain at the site are confined to the areas underneath the active portion of the operational facility, and covered by pavement and/or buildings and tanks controlling access and risk of contact with this material. Groundwater and surface water sampling do not show a concern for off-site migration due to remaining sources at the site.

b. *Leaving contaminants on-site during the restoration time frame does not pose an unacceptable threat to human health or the environment.* ICs will be included in the remedy to prevent risks of contact with contaminated media at the site and ongoing monitoring will continue to assess risk of off-site migration, which is currently not expected to occur.

c. *There is evidence that natural biodegradation or chemical degradation is occurring and will continue to occur at a reasonable rate at the site.* The groundwater data trends presented in this FS show large reductions in the COPCs identified in the RI, and continued degradation of remaining organic COCs at the site. Inorganic COCs will continue to be monitored for evidence of their degradation as geochemical conditions change as the remaining the organic COCs attenuate. Current and historical data trends for inorganic COCs support the hypothesis that groundwater concentrations are stable for those compounds, and not increasing, as recommended under Ecology's natural attenuation related guidance (Ecology, 2005).

d. *Appropriate monitoring requirements are conducted to ensure that the natural attenuation process is taking place and that human health and the environment are protected.* The remedy will include ongoing groundwater monitoring under all alternatives.

8.1.2 Alternative 1 Monitored Natural Attenuation

Alternative 1 relies on eventual contaminated soil remediation, maintenance of surface cover over remaining source soils, and monitored natural attenuation to address affected site soil and groundwater. The following elements are included in Alternative 1 (Figure 18):

- Remediation of contaminated soils in AOC-2 and AOC-3 when the areas become accessible;
- Assessing and repairing the existing surface cover, as necessary, in remaining source soil areas in AOCs 2 and 3;
- Long-term monitoring and maintenance of the cover over remaining soil source areas in AOC 2 and 3;
- Monitored natural attenuation of groundwater downgradient of source areas;
- Long term groundwater monitoring; and
- ICs, including a deed restriction.

The existing surface cover would prevent exposure of workers to COCs at the site. The areas on the site where soil exceeds cleanup standards but are technically or administratively impracticable to excavate would be left in place until such time as they are accessible, as noted in Section 8.1.1.2. As a result, ICs, monitored natural attenuation, and maintaining/repairing the existing cover should be adequate to address affected site soil and groundwater and protect downgradient receptors.

Based on the trend plot for concentrations of vinyl chloride over time shown in Figure 17, vinyl chloride will attenuate to below CULs by approximately 2021 in MW-120-I1. In addition, ongoing active natural biodegradation processes at the site would permanently degrade and destroy biodegradable COCs present within the saturated zone. It is expected that inorganic constituents would attenuate in the shallow water-bearing unit and in the intermediate and deep aquifers prior to reaching the CPOC, as anthropogenic carbon from other COCs is consumed. As noted in Section 8.1.1.4, once anthropogenic sources of carbon are degraded, the arsenic concentrations should attenuate to levels typical of natural total organic carbon and iron oxide interactions in the aquifer. The surface cover would be maintained to prevent contact with remaining affected soil and to prevent erosion and runoff of affected soil in areas around AOC-2 and AOC-3.

A groundwater monitoring program employing the existing monitoring well network would be conducted to verify that natural attenuation and degradation of COCs continue to occur, and that COC concentrations are trending toward CULs at the CPOC over time. It is assumed for the purposes of consistent cost comparisons between alternatives that for this alternative, monitoring would take place for 30 years. There are currently 27 wells actively being monitored under the existing monitoring plan. Three new monitoring wells are proposed as part of Alternative 1 (Figure 18). The cost estimate was developed under the assumption that 30 wells will be monitored for five years, decreasing to 20 wells after five years, 15 wells after 10 years, and 10 wells after 20 years.

ICs are included in Alternative 1 so that the cover is maintained, and to restrict future land use and groundwater use at the site. Since potential exposure to COCs above CULs would remain, a deed restriction limiting the site to industrial use would be implemented. The deed restriction would also clearly identify the location of known soil and groundwater contamination. Additional ICs to limit recovery and use of groundwater beneath the site and strict health and safety requirements for conducting subsurface work in impacted areas would also be required. Formal pavement inspections would be performed during groundwater monitoring events. Facility operators would be expected to repair damage or settling in the pavement.

Under this alternative, soil CULs may not be met on site for some time, although the site is expected to ultimately achieve compliance with MTCA compliance monitoring criteria (WAC 173-340-410).

Concentrations of COCs would remain above CULs in affected soil, primarily beneath AOC-2 and AOC-3, with some very low level exceedances in AOC-4 and the 10-day hazardous waste transfer yard. Concentrations of COCs in soil that exceed CULs but that would not be planned for active remediation as part of Alternative 1 are generally less than two times the CUL and do not currently result in significant impacts to groundwater. Groundwater concentrations of COCs are slightly elevated along the north and eastern site boundaries and the groundwater in the site vicinity is not currently used as a drinking water source (Section 2.5).

Although the time frame to meet CULs in groundwater is longer for Alternative 1 than for alternatives using more active remediation technologies, the COCs in soil are not a threat to workers on site and the COC concentrations in groundwater are very low and are unlikely to reach potential receptors.

The site currently poses no known or suspected risk to human health or the environment. ICs would be needed for the site over the long term to protect human health and the environment and meet the criteria under MTCA for sites utilizing Method C CULs.

This alternative meets the threshold requirements established in WAC 173-340-360(2)(a). The alternative would provide short-term protection of human health and the environment through risk reduction (ICs and surface cover), and long-term protection through the permanent destruction, transformation, or immobilization of hazardous chemicals through natural attenuation processes and contaminated soil remediation. This alternative is in compliance with state and federal laws, and provides for long-term compliance monitoring. The other MTCA requirements established in WAC 173-340-360(2)(b), including a reasonable restoration time frame, will be evaluated as part of the alternatives evaluation presented in Section 8.2.

8.1.3 Alternative 2 Permeable Reactive Barriers and Monitored Natural Attenuation

Alternative 2 supplements the source material soil remediation, surface cover, and natural attenuation processes that would occur under Alternative 1 with the installation of PRBs to prevent off-site migration of affected groundwater from all three aquifer zones to protect downgradient receptors.The configuration and layout of the PRBs is shown on Figure 19 and includes:

- Both shallow and intermediate PRBs along the north and northwest side of AOC-2 and the east side of AOC-3 to prevent off-site migration of COC-affected groundwater;
- An intermediate aquifer PRB in the vicinity of the South Gate to prevent off-site migration of arsenic-affected groundwater near MW-117; and
- A deep aquifer PRB to prevent off-site migration of cyanide-affected groundwater downgradient of MW-24D and MW-117D (Figure 19).

Placement of the PRBs is based on observed historical groundwater flow directions (Figures 3 through 8) and observed COC-affected groundwater distribution (Figures 14 through 16). The installation of the PRBs should result in meeting CULs for site COCs in groundwater along the CPOC and protect downgradient receptors.

The following elements are included in Alternative 2 (Figure 19):

- Remediation of contaminated soils from AOC-2 and AOC-3 when the areas become accessible;

- Assessing and repairing the existing surface cover, as necessary, in remaining source soil areas in AOCs 2 and 3;
- Long-term monitoring and maintenance of the cover over remaining soil source areas in AOC 2 and 3;
- Installation of PRBs in the shallow water-bearing unit and the intermediate and deep aquifers to achieve CULs at the CPOC;
- Monitored attenuation of groundwater from other known or suspected source areas;
- Long term groundwater monitoring; and
- ICs, including a deed restriction.

Source material remediation, surface cover, and ICs would be implemented as described in Alternative 1.

Ferrous iron, arsenic, and hexavalent chromium have generally been observed above CULs around in the shallow water-bearing unit and intermediate aquifer in AOC-2 and AOC-3. As noted in Section 8.1.1.4, treatment is targeted for areas where arsenic levels are elevated and there is evidence of anthropogenic releases of total organic carbon. Vinyl chloride has generally only been observed in groundwater beneath the southwest corner of the tank farm. Cyanide has been generally observed above CULs in the intermediate and deep aquifers (Figures 14 and 15, respectively), on the northwest side of AOC-2 (in monitoring wells MW-124-I1 and MW-24D), and on the southwest side of AOC-5 (in monitoring well MW-117D). Arsenic has also been observed above CULs along the southern side of the site in the vicinity of MW-117-I2 (Figure 14).

The PRB will consist of a strong chemical reducing agent such as ZVI, a carbon-based substrate, and a sulfide releasing compound to address all site COCs. The PRB will function as a chemical reducing barrier and support enhanced anaerobic bioremediation and bio-mediated sulfide precipitation of ferrous iron and co-precipitation of arsenic. The proprietary technology EHC®-M from PeroxyChem or equivalent technology may be used to effectively address all site COCs that come into direct contact with the PRB. A bench scale study will be performed in order to assess the exact mix or brand of PRB substrate prior to installation. The PRB will be installed using direct push methods to place the chosen substrate blend within the target area and required depth intervals (Figure 19). The PRB installation is not targeting source area soils or groundwater but is designed to place substrate in such a way that COC-affected groundwater will be treated as it flows through the barrier to achieve CULs for all COCs at the CPOC. Follow-up injections may be necessary every 10 years, depending on concentrations of COCs or other non-targeted compounds entering the PRB.

A groundwater monitoring program employing the existing monitoring well network would be conducted to verify that natural attenuation and degradation of COCs continue to occur at the site, and to assess the effectiveness of the PRB over time and to verify that CULs are being achieved at the CPOC. Groundwater monitoring both upgradient and downgradient of the PRB may be used to indicate exhaustion of the PRB reactive material. It is assumed for the purposes of consistent cost comparisons between alternatives that for this alternative, monitoring would take place for 30 years. There are currently 27 wells actively being monitored under the existing monitoring plan. Five new monitoring wells are proposed as part of Alternative 2 (Figure 19). The cost estimate was developed under the assumption that 32 wells will be monitored for five years, decreasing to 20 wells after five years, 15 wells after 10 years, and 10 wells after 20 years.

Under this alternative, soil CULs may not be met on site for some time, although the site is expected to ultimately achieve compliance with MTCA compliance monitoring criteria (WAC 173-340-410).

Concentrations of COCs would remain above CULs in affected soil, primarily beneath AOC-2 and AOC-3, with some very low level exceedances in AOC-4 and the 10-day hazardous waste transfer yard. Concentrations of COCs in soil that exceed CULs but that would not be planned for active remediation as part of Alternative 1 are generally less than two times the CUL and do not currently result in significant impacts to groundwater.. It is expected that this alternative would attain remediation objectives, including attainment of groundwater CULs at the CPOC. It is anticipated that the time frame to meet CULs would be faster than that of Alternative 1.

This alternative meets the threshold requirements established in WAC 173-340-360(2)(a). The alternative would provide short-term protection of human health and the environment through risk reduction (ICs and soil surface cover), and the use of a PRB to achieve CULs at the CPOC after installation. This alternative would also provide long-term protection through the long term monitoring and maintenance of the PRB and surface cover to allow for a longer period of time for source area natural attenuation to occur. This alternative is in compliance with state and federal laws, and provides for long-term compliance monitoring. The other MTCA requirements established in WAC 173-340-360(2)(b), including a reasonable restoration time frame, are evaluated as part of the alternatives evaluation presented in Section 8.2.

8.1.4 Alternative 3 In Situ Chemical Reduction and In Situ Bioremediation

Alternative 3 supplements the source material soil remediation, surface cover, and natural attenuation processes that would occur under Alternative 1 with in situ chemical reduction (ISCR) and in situ bioremediation (ISB), which consists of the injection of a in situ chemical reductant and substrate to promote anaerobic degradation and bio-mediated precipitation of ferrous iron and sulfide. Direct push injections allow for distribution of ISCR and ISB solutions across target depth intervals. Injections would be timed and strategically placed to make use of the seasonal changes in groundwater flow. In particular, the shallow water-bearing unit and intermediate aquifer have drastic seasonal changes in groundwater flow direction (Figures 3 through 6) that can be utilized to spread chemicals into target areas, including those that may be otherwise inaccessible, such as beneath the tank farm in AOC-2 and buildings in AOC-3. The approximate locations of injections are shown on Figure 20. The remedy includes injections into the shallow water-bearing unit and the intermediate and deep aquifers, primarily in the vicinity of AOC-2 and AOC-3, with a few injection locations in the intermediate and deep aquifer adjacent to MW-117D. The use of ISCR and ISB should result in meeting CULs for site COCs in groundwater and result in attainment of CULs the most rapidly of all the alternatives. It is expected that the implementation of Alternative 3 would result in attainment of CULs along the CPOC and protect downgradient receptors.

The following elements are included in Alternative 3 (Figure 20):

- Remediation of contaminated soils from AOC-2 and AOC-3 when the areas become accessible;
- Assessing and repairing the existing surface cover, as necessary, in remaining source soil areas in AOCs 2 and 3;
- Long-term monitoring and maintenance of the cover over remaining soil source areas in AOC 2 and 3;
- Seasonal injections of a chemical reductant and a substrate to facilitate in situ biological remediation;

- Monitored natural attenuation of groundwater from other known or suspected source areas;
- Long term groundwater monitoring; and
- ICs, including a deed restriction.

Ferrous iron, arsenic, and hexavalent chromium have generally been observed above CULs around in the shallow water-bearing unit and intermediate aquifer in AOC-2 and AOC-3. As noted in Section 8.1.1.4, treatment is targeted for areas where arsenic levels are elevated and there is evidence of anthropogenic releases of total organic carbon. Vinyl chloride has generally only been observed in groundwater beneath the southwest corner of the tank farm. Cyanide has been generally observed above CULs in the intermediate and deep aquifers (Figures 14 and 15, respectively) on the northwest side of AOC-2 (in monitoring wells MW-124-I1 and MW-24D) and on the southwest side of AOC-5 (in monitoring well MW-117D). Arsenic has also been observed above CULs along the southern side of the site in the vicinity of MW-117-I2 (Figure 14).

The proprietary blend of chemical reductant and substrate will consist of a strong chemical reducing agent, such as ZVI; a carbon-based substrate; and a sulfide releasing compound to address all site COCs. The targeted injections will result in strong geochemical reducing conditions and support enhanced anaerobic bioremediation and bio-mediated sulfide precipitation of ferrous iron and co-precipitation of arsenic within the zone of influence. The proprietary technology EHC®-M from PeroxyChem or equivalent technology may be used to effectively address all site COCs that come into direct contact with the injected solution. A bench scale study will be performed in order to assess the exact mix or brand of ISCR/ISB substrate prior to installation. Unlike Alternative 2, the substrate will be evaluated for mobility as well as effectiveness. The chosen substrate for Alternative 3 should flow with groundwater into source areas, rather than remain in place as a barrier, as in Alternative 2. The injections will be delivered to the targeted areas and zones using direct push methods to place the chosen substrate blend within the target area and required depth intervals (approximate locations shown on Figure 20). It is anticipated that the implementation of the ISCR/ISB alternative will treat the COC-affected groundwater beneath AOC-2 and other source groundwater areas. Injection spacing shown on Figure 20 is based on soil types and vendor reported zones of influence for similar aquifer materials.

Shallow water-bearing unit injections: During the wet season, shallow water-bearing unit injections will be placed:

- Along the south side of AOC-3 so that groundwater flow will spread the injected solution to the northwest beneath AOC-2 and AOC-3 (general groundwater flow directions shown on Figure 3).
- Along the northeast side of AOC-2, immediately south of the North Truck Load/Unload Area, so that groundwater will spread injected solution to the north and northwest to address affected groundwater in the vicinity of MW-126 (Figure 20).

During the dry season, shallow water-bearing unit injection locations will be placed such that prevailing groundwater flow directions (Figure 4) will distribute the solution across the tank farm area (Figure 20).

Intermediate aquifer injections: During the wet season, intermediate aquifer injections will be placed:

- Along the south side of AOC-3 so that groundwater flow will spread the injected solution to the northwest beneath AOC-2 and AOC-3 (general groundwater flow directions shown on Figure 5);

- Along the northeast side of AOC-2, immediately south of the North Truck Load/Unload Area, so that groundwater will spread injected solution along the northern side of AOC-2; and
- In the vicinity of MW-124-I1 to utilize the groundwater flow "hole" to spread solution throughout the area surrounding the hole (Figure 20).

During the dry season, injection locations will be placed:

- In the vicinity of MW-124-I1, this time to spread solution to the northeast and southeast to cover the area surrounding MW-102-I1 and AOC-2 (Figures 6 and 20);
- Along the northeast side of AOC-2 to spread solution to the northeast and address affected groundwater in the vicinity of MW-126-I; and
- In the vicinity of MW-117-I2 to address affected groundwater in the vicinity of the monitoring well.

It is anticipated that groundwater south of the site would attenuate as a result of addressing affected groundwater in the vicinity of MW-117-I2.

Deep aquifer injections: Cyanide is the primary COC in the deep aquifer (Figure 16), and groundwater flow directions during the wet and dry season are generally from east to west across the site. To address affected groundwater in the deep aquifer zone, during the dry season, injection locations would be placed upgradient (or east) of wells MW-117D, MW-112-D, and MW-24D to allow for groundwater to spread across areas where groundwater has been observed to be affected with cyanide (Figure 16). It is anticipated that these injections would take place in conjunction with the injections for the shallow water-bearing unit and intermediate aquifer, based on when the direct push rig will be in the area. The surface cover would be maintained and ICs would be implemented as described in Alternative 1.

A groundwater monitoring program employing the existing monitoring well network would be conducted to verify that the destruction/degradation of COCs from the injections was effective at reducing groundwater concentrations at the CPOC. Monitoring will also be conducted to verify that natural attenuation continues to occur at the site after the injected solution has been consumed and to verify that CULs are being obtained at the CPOC. There are currently 27 wells actively being monitored under the existing monitoring plan. Three new monitoring wells are proposed as part of Alternative 3 (Figure 20). It is assumed for the purposes of consistent cost comparisons between alternatives that for this alternative, monitoring would take place for 30 years. The cost estimate was developed under the assumption that 30 wells will be monitored for five years, decreasing to 15 wells after five years, 10 wells after 10 years, and five wells after 20 years.

Under this alternative, soil CULs may not be met on site for some time, although the site is expected to ultimately achieve compliance with MTCA compliance monitoring criteria (WAC 173-340-410).

Concentrations of COCs would remain above CULs in affected soil, primarily beneath AOC-2 and AOC-3, with some very low level exceedances in AOC-4 and the 10-day hazardous waste transfer yard. Concentrations of COCs in soil that exceed CULs but that would not be planned for active remediation as part of Alternative 1 are generally less than two times the CUL and do not currently result in significant impacts to groundwater. It is expected that this alternative would attain remediation objectives, including attainment of groundwater CULs at the CPOC, in a shorter time frame than the other alternatives described above.

This alternative meets the threshold requirements established in WAC 173-340-360(2)(a). The alternative would provide short-term protection of human health and the environment through risk reduction (ICs and soil surface cover), and the use of a targeted ISCR and ISB to aggressively reduce contaminant mass in groundwater and to obtain CULs at the CPOC after injections. This alternative would also provide long-term protection through the long term monitoring and maintenance of the surface cover to allow for a longer period of time for natural attenuation to occur after initial mass removal from groundwater as part of the ISCR/ISB remedial action. This alternative is in compliance with state and federal laws, and provides for long-term compliance monitoring. The other MTCA requirements established in WAC 173-340-360(2)(b), including a reasonable restoration time frame, will be evaluated as part of the alternatives evaluation presented in Section 8.2.

8.2 EVALUATION OF REMEDIAL ALTERNATIVES

The objectives for the three remedial alternatives considered for the site are to meet the remedial action objectives specified in Section 5.1 while supporting current and future operations at the facility. All three alternatives would attain these objectives.

This section compares and evaluates the remedial alternatives based on the MTCA criteria. For each criterion, the alternatives are evaluated on a scale of 1 to 5. A rating of 5 means the alternative is expected to most completely meet the criterion. For example, only alternatives that would result in meeting the cleanup criteria for all COCs would receive a rating of 5 for permanence and long term risk reduction. A rating of 1 indicates that the alternative is expected to perform poorly for that criterion, relative to the other criteria. A rating of 1 does not necessarily mean that the alternative would not adequately meet the criterion; it only means that other alternatives would be more effective in meeting that specific criterion.

All of the remedial alternatives under consideration attain the remediation objectives outlined in Section 5.1. ICs and long-term groundwater monitoring have been included in all of the alternatives.

Table 14 summarizes the results of the evaluation.

8.2.1 Protectiveness and Risk Reduction

The ratings of the alternatives for protectiveness and risk reduction are shown in Table 14. In general terms, the protectiveness and risk reduction criterion involves the degree to which remedial alternatives protect human health and the environment and provide a reduction in risks posed by the contamination. All of the alternatives under consideration are expected to significantly reduce risks and be protective of human health and the environment. However, the alternatives differ in the amount of contaminant mass reduction that could be achieved in soil and groundwater and the time to reach CULs, and therefore also differ in overall protectiveness and risk reduction.

Based on meeting CULs, Alternatives 3 and 2 would result in meeting CULs at the CPOC in a shorter time frame, but only Alternative 3 would potentially reduce concentrations of COCs to CULs under AOC-2 in the near future; therefore, Alternative 3 is the most protective. However, as noted in Section 8.1.1.4, arsenic levels may remain elevated due to natural total organic carbon. Alternative 1 relies solely on monitored natural attenuation, so is ranked the lowest. All of the alternatives would rely on essentially the same ICs to prevent direct exposure to affected groundwater and soil and would therefore be equally protective in this respect.

Alternative 1 includes surface cover, active remediation of source material in soil, monitored natural attenuation, and ICs to address contaminant concentrations in site soil and groundwater. Alternative 1 would address COCs in site groundwater through monitored natural attenuation, but would not use an active approach to reduce COC concentrations in groundwater. Alternative 1 relies on surface cover and ICs to prevent direct contact and protect groundwater from any remaining affected soil until closure of the facility. Although monitored natural attenuation appears to have reduced concentrations of VOCs at the site, additional time would be necessary for the aquifer geochemistry to return to normal and for inorganic COCs such as arsenic to return to concentrations typical of natural total organic carbon sources. Alternative 1 may not result in attainment of CULs in less than 30 years. As a result, Alternative 1 was given a rating of 2, the lowest rating of the three alternatives.

Alternatives 2 and 3 incorporate technologies that would reduce the mass of COCs at the site more immediately. These technologies should both reduce the cleanup time frame compared to monitored natural attenuation, but Alternative 3 should be the most effective under AOC-2. Alternative 2 was therefore rated as 3. Alternative 3 received a rating of 4 for it is most likely to treat a majority of the aquifers on site, including under AOC-2.

8.2.2 Permanence

The permanence criterion, as defined in MTCA, involves the degree to which the remedial alternative would reduce the toxicity and mobility of affected media through permanent destruction of hazardous substances. All of the alternatives incorporate monitored natural attenuation, resulting in the permanent removal of COCs. All of the alternatives would result in reduction in total mass of COCs. While two of the three technologies use more aggressive technologies to permanently remove mass, only Alternative 3 targets the source area in the tank farm under AOC-2 prior to facility closure.

Alternative 1 and 2 both received a rating of 3, because they both would use a passive approach to COC reduction in groundwater under AOC-2. This passive approach relies primarily on natural conditions to occur once carbon based COCs have attenuated. These alternatives include permanent destruction of volatile COCs due to ongoing natural attenuation, which is active at the site. Based on groundwater monitoring on site, CULs appear to have already been met by natural attenuation in many wells.

Both Alternatives 2 and 3 should result in a shortened time frame to meet preliminary groundwater CULs for COCs at the CPOC. However, Alternative 3 would attack source area contamination by flowing with groundwater under AOC-2 and around MW-117, which should result in better distribution throughout the remaining source areas. Thus, Alternative 3 received a rating of 4 for actively remediating a larger area of the site.

Because Alternative 3 has the highest permanence ranking, it is considered the “baseline alternative” under MTCA (WAC 173-360-340[2][e][ii][B]). Under MTCA’s preference for permanent remedies, the baseline alternative is typically considered for preference over less permanent alternatives, unless the cost for the baseline alternative is disproportionately high and/or other alternatives ultimately provide the same permanence (although perhaps a longer time frame). Cost information for each alternative is provided in a subsequent section. A disproportionate cost analysis has been conducted as part of the selection of the preferred alternative, and the results are presented in Section 8.3.

8.2.3 Cost

NPV cost estimates prepared for Alternatives 1 through 3 are summarized in Table 15. Assumptions used to develop the cost estimates and a more detailed breakdown of costs for each alternative are presented in Appendix G. The NPV cost estimates combine initial costs for implementation of an alternative with recurring costs for future O&M and monitoring. NPV cost estimates allow the alternatives to be compared on an equal basis. Some implementation costs would occur in the future, after initial remediation or planning tasks are completed. As outlined in Appendix G, an NPV discount rate of 2.5 percent was selected, based on current inflation and interest rates.

Implementation costs include estimated costs for obtaining access to conduct the remediation; for engineering and planning; for purchasing equipment, materials, and chemicals; for permitting; and for construction. Recurring costs include estimates for O&M labor, Ecology oversight, materials and chemicals used in remediation, periodic replacement of remediation equipment, long-term site access, power and waste disposal, water quality monitoring, and project management. As detailed in Appendix G, the NPV costs are based on the implementation and operation period for each of the four alternatives.

As noted in Section 8.1.1.2, remediation of the source material soils in AOC-2 and AOC-3 is not expected to be completed as part of the initial implementation as part of any of the alternatives. The costs for eventual soil remediation are not included in this FS. Each alternative would have the same soil remediation costs at facility closure (or whenever soils become accessible), so this cost should not differentiate them for comparison purposes. Costs for soil remediation at facility closure have not been included as part of the alternative comparison, but will be included in the Corrective Action Plan in order to meet requirements for financial assurance under MTCA.

The implementation cost and NPV cost for each alternative is shown in Table 15. The NPV costs were compared by alternative and the alternatives were simply ranked on their costs compared to the other alternatives. As a result, Alternative 1 would be the least expensive ($0.6 million) and was rated highest (5), as shown on Table 14. The NPV cost for Alternative 2 is next lowest ($0.9 million), followed by Alternative 3 ($1.2 million). Alternative 3 is rated 2, as its cost is more than 2 times higher than the cost of Alternative 1, Alternative 2 is also rated 2, as its cost is 1.6 times higher than the cost of Alternative 1.

8.2.4 Long-Term Effectiveness

Long-term effectiveness includes the degree of certainty and reliability of the alternative to maintain its effectiveness over the long term. This criterion also includes whether treatment residue would remain from the alternative that would require management. The benefits realized by an alternative are compared to the negative consequences associated with the alternative in assessing long-term effectiveness. All three alternatives remediate the same areas of soil contamination and leave soil in place on the site that potentially exceeds unrestricted-use CULs, at least at individual locations.

However, remaining soils significantly above the CULs will be remediated eventually, as noted in Section 8.1.1.2, and all other remaining soils above CULs are expected to meet statistical review under MTCA (Section 4.2.2.2). All three alternatives under consideration would need to incorporate the same ICs; therefore, the ICs for each alternative would have essentially the same effectiveness and reliability.

Alternative 1 would rely on monitored natural attenuation to achieve long-term effectiveness, whereas all other alternatives would use a more active approach to reduce COC mass, combined with monitored natural attenuation for polishing. Theoretically, the main difference in alternatives is speed of remediation, since all three alternatives rely on monitored natural attenuation. Each alternative receives a ranking of 3.

8.2.5 Management of Short-Term Risks

Short-term risk refers to the risk to human health and the environment during implementation of an alternative.

Although it is possible to design remedial actions to mitigate or minimize potential risks, it is not possible to eliminate risks through design or actions. In assessing this criterion, it has been assumed that alternatives have been designed to incorporate appropriate and proven methods to mitigate short-term risks. However, regardless of the approach taken, remedial actions that remove soil or require construction of any type have higher short-term risks than those that do not. Although measures to mitigate these risks are not discussed in this section, appropriate measures have been included in the cost analysis as part of this feasibility study to minimize short-term risks in all alternatives. None of the alternatives achieve cleanup objectives in the short term; therefore, the short term risks are all related to implementation of the remedy.

Alternative 1 is rated 4, which is the highest of the alternatives under consideration, because it would require the least amount of subsurface activities (e.g., installation of wells, etc.), be the fastest to implement, and have the lowest short-term exposure potential. It did not receive the maximum possible rating of 5 because it would leave contamination in place that would require proper management to prevent exposure. As shown on Table 14, Alternatives 2 and 3 were given a rating of 3, because both include substantial subsurface activities (drilling and injection of chemicals) in addition to the subsurface activities included in Alternative 1. There would be some increase in short- term risks due to the potential for exposure to affected soil and groundwater and to treatment chemicals during these activities.

8.2.6 Technical and Administrative Implementability

This criterion involves both technical and administrative issues related to construction and operation of the remedial alternatives. Factors considered in assessing the alternatives against this criterion include administrative/regulatory requirements, impact on existing land uses, the means for implementing and enforcing ICs, and requirements for extensive construction or ongoing operation and maintenance.

As shown in Table 14, Alternative 1 would rely on the most basic of remedial technologies among all of the alternatives and therefore receives a rating of 5.

Alternatives 2 and 3 are both rated 3, since they would be relatively easy to implement, although underground injection permitting would be required for injections of chemicals.

8.2.7 Public Concern

Potential community concerns with implementation of each remedial alternative are assessed for this criterion, including general concerns of the public and specific concerns of neighboring landowners. It is expected that the primary public concerns associated with the remedial alternatives would be from neighboring landowners, because the site and neighboring properties are used for industrial purposes. None of these three alternatives are likely to create noticeable and prolonged nuisances such as noise, traffic, and air emissions. However, there may be some public concern over potential discharges to Mill Creek and eventual discharge to the Duwamish River and the associated stormwater conveyances as described in Section 2.4.3.

Public concerns could also be related to restoration time frames. The period of implementation of the various alternatives could range from as little as a few months for MNA to as much as 10 years for the injection technologies (counting the repeat injections).

Alternative 1 received the lowest rating of 2 for this criterion, because it would likely have the longest restoration time frame of the alternatives and the least amount of active efforts to reduce COC concentrations that could potentially migrate to the Mill Creek. The lack of an active remedy could be perceived negatively by the public; however, Alternative 1 is the easiest to implement and could be completed and implemented with minor concerns from the local public.

Alternatives 2 and 3 both received a rating of 3, since the public would perceive these remedies as active remedies as opposed to the passive approach of Alternative 1. The shorter time frames for reaching CULs at the CPOC also should be perceived more favorably for Alternatives 2 and 3.

However, these alternatives do not receive the highest ranking since they also rely on eventual remediation of remaining site soils when areas become accessible.

8.2.8 Restoration Time Frame

Restoration time frame involves the urgency of achieving remediation objectives and the practicability of attaining a shorter restoration time frame, with consideration given to a number of factors, such as site risks, site use and potential use, availability of alternative water supply, effectiveness and reliability of ICs, and toxicity of hazardous substances at the site. The criteria for evaluating if a restoration time frame is reasonable are provided in WAC 173-340-360(4). The following criteria, as listed in WAC 173-340-360(4), were considered to determine if each of the alternatives provides a reasonable restoration time frame:

- **Potential risks posed by the site to human health and the environment.** Each alternative includes ICs to manage risk and prevent the site from posing an unacceptable risk; therefore, each of the alternatives meet this criterion.

- **Practicability of achieving a shorter restoration time frame.** The alternatives provide a range of remediation time frames to reach CULs at the CPOC, but since contaminated soils will remain in active areas of the facility for each alternative they all have the same overall remediation time frame. The practicability and cost-benefit (i.e. disproportionate cost analysis) of each alternative is discussed in the alternatives evaluation provided as part of this FS.

- **Current use of the site, surrounding areas, and associated resources that are, or may be, affected by releases from the site.** The site is currently an active industrial facility and is largely surrounded by industrial properties. Groundwater beneath the site is not a source of drinking water. Mill Creek and the Duwamish Waterway are the surface water bodies nearby, but the only potential pathway from groundwater to surface water is to several culverts running along roads or eventually to surface water bodies miles away (Section 2.4.3). There is a potentially complete pathway for COCs to travel from site groundwater or surface water to these water bodies, but the combination of low concentrations of COCs in groundwater and the distances to be travelled makes risk to human health or the environment very low.

- **Potential future use of the site, surrounding areas, and associated resources that are, or may be, affected by releases from the site.** The site is currently zoned for industrial use and heavy industrial use is planned at the site for the foreseeable future. Each alternative is designed to mitigate unacceptable site risks and no unacceptable risk has been identified in the nearby waterways.

- **Availability of alternative water supplies.** Groundwater at the site is not currently a drinking water source and alternative water supplies are available and in use.

- **Likely effectiveness and reliability of ICs.** Because the site is an active industrial facility, ICs are very likely to be effective. Regular use of the site is also likely to result in regular maintenance of controls, thereby increasing their reliability.

- **Ability to control and monitor migration of hazardous substances from the site.** Groundwater monitoring has been ongoing both on the site and on adjacent properties, and continued groundwater monitoring is included in each of the alternatives.
- **Toxicity of the hazardous substances at the site.** The toxicity of the hazardous substances has been evaluated in the Final RI Report (Geomatrix, 2007), and a cleanup standard for each COC has been established, including both a CUL and a POC. At the concentrations present in the soil and groundwater, risk from the COCs is low.
- **Natural processes that reduce concentrations of hazardous substances and have been documented to occur at the site or under similar site conditions.** Natural attenuation of many COCs has been observed and documented at the site.

The alternatives all include the same active remedial actions to reduce COC concentrations in site soils, but the remediation of contaminated soils in active areas of the facility will only be completed when the facility is closed or as redevelopment and maintenance activities allow. Hence the restoration time frame for all three alternatives has been estimated to last 30 years.

Based on the current trends in groundwater concentrations, Alternatives 2 and 3 would meet CULs at the CPOC or reach concentrations of inorganics consistent with natural total organic carbon geochemistry within approximately five years. Since Alternative 3 could potentially treat groundwater under AOC-2 in that time, it received a rating of 4, while Alternative 2 received a rating of 3.

Alternative 1 received a rating of 2, as it may require longer than five years to meet the cleanup standards or reach concentrations of inorganics consistent with natural total organic carbon geochemistry, but vinyl chloride is still expected to meet the CUL by 2021 (Figure 17).

8.3 DISPROPORTIONATE COST ANALYSIS

The MTCA disproportionate cost analysis is used to evaluate which of the alternatives that meet the threshold requirements are permanent to the maximum extent practicable. This analysis involves comparing the costs and benefits of alternatives and selecting the alternative whose incremental costs are not disproportionate to the incremental benefits. The evaluation criteria for the disproportionate cost analysis: protectiveness, permanence, cost, long-term effectiveness, management of short-term risks, implementability, and consideration of public concerns, are specified in WAC 173-340-360(2) and (3). For this analysis, restoration time frame will also be considered.

As outlined in WAC 173-340-360(3)(e), MTCA provides a methodology that uses these criteria to determine whether the costs associated with each cleanup alternative are disproportionate relative to the incremental benefit of the alternative above the next lowest cost alternative. The comparison of benefits relative to costs may be quantitative but will often be qualitative (for example, restoration time frames and costs associated with them are very not quantifiable). Costs are disproportionate to benefits if the incremental costs of the more permanent alternative exceed the incremental degree of benefits achieved by the other lower-cost alternative (WAC 173-340-360[e][i]). Where two or more alternatives are equal in benefits, Ecology selects the less costly alternative (WAC 173-340- 360[e][ii][c]). Each criterion is weighted equally in this DCA.

Each of the alternatives is expected to meet the threshold criteria and use permanent solutions. The end ranking of the alternatives is very close, with scores ranging from 23 to 26 (Table 14).

The baseline alternative (Alternative 3) is the most expensive alternative, with a cost of $1.21 million. The estimated cost for Alternative 1 is $550,000, almost $700,000 less than the baseline alternative. Alternative 2 provides roughly the same benefit as the baseline alternative at the CPOC, and at about the same cost, without the added benefit of active treatment under AOC-2.

The chief benefit of the baseline alternative is a shorter remedial time frame in the groundwater under AOC-2. All three alternatives reduce risk to human health and the environment—monitored natural attenuation reduces the risk to human health and the environment in Alternative 1, the PRB reduces risk in Alternative 2, and the ISCR/ISB injections reduce risk in Alternative 3. All three alternatives utilize the same ICs and source remediation for the small areas of remaining soil contamination on site. Since the chief benefit is a shorter remedial time frame with little change in overall risk, the cost of the baseline alternative is disproportionate.

8.4 SELECTION OF THE PREFERRED REMEDIAL ALTERNATIVE

Selection of a preferred alternative under MTCA requires that preference be given to alternatives that use permanent solutions to the maximum extent practicable, provide for a reasonable restoration time frame, and consider public concerns. According to MTCA (WAC 173-340-200), a permanent solution or permanent cleanup action means an action in which cleanup standards can be met without further action being required at the site involved, other than the approved disposal of any residue from the treatment of hazardous substances.

The MTCA rules also specify that a baseline alternative be defined as the remedial alternative that permanently destroys site COCs to the maximum extent practicable and achieves the shortest restoration time frame. The baseline alternative is to be used as a basis for comparing other remedial alternatives and selecting the preferred alternative. Three remedial alternatives have been established as potentially applicable to the site. Of those alternatives, Alternatives 2 and 3 are expected to be capable of restoring groundwater at the CPOC within the shortest time frame, as they all actively address vinyl chloride and inorganic COCs. Alternative 3 was selected as the baseline alternative for the site, because it would result in the greatest removal and/or destruction of site COCs and therefore has the greatest degree of permanence.

As shown in Table 14, Alternatives 1 and 3 received the highest total rating (26), followed closely by Alternative 2 (23). Although the overall ranking is not necessarily indicative of the alternative that provides the most permanent solution, it is indicative of the benefit that each alternative provides and can be used in a disproportionate cost analysis.

Each of the alternatives would likely result in the attainment of groundwater CULs within a reasonable restoration time frame (approximately five to ten years). Alternative 1 received a higher score than the others for technical and administrative implementability and cost, Alternative 3 received higher marks for protectiveness and risk reduction, permanence, and restoration time frame, while Alternative 2 was generally in the middle ranking for all criteria.

Although Alternative 3, the baseline Alternative, would theoretically remove more COC mass in groundwater than the other alternatives in a shorter time frame, all of the alternatives rely on monitored natural attenuation for polishing of groundwater and eventual soil remediation during facility closure or redevelopment. So while it is the most likely to significantly reduce the mass of COCs fastest, including from AOC-2, there is still a possibility it would not greatly decrease the restoration time frame compared to Alternative 1.

Based on the numerical comparison and DCA presented above, the preferred remedial alternative for the site is Alternative 1, which would fully attain remediation objectives. The preferred alternative also would:

- Prevent direct contact with soils and inhalation of dust at the site and be protective of industrial workers;
- Address groundwater COCs above CULs including chlorinated VOCs and inorganic COCs caused by anthropogenic releases of carbon sources;
- Reduce risks due to inhalation of vapors or dust by incorporating ICs;
- Protect human and ecological receptors in Mill Creek by natural degradation of groundwater COCs and limiting the further release of COCs by remediation of site soils; and
- Support current and future industrial use of the site.

In addition, the Preferred Alternative would provide:

- A monitoring well network that would allow ongoing monitoring and assessment of the effectiveness of the remedial measures;
- A reliable remediation approach using proven, robust technologies with low long-term maintenance requirements; and
- An approach that would create moderate short-term risks and have minimal potential for causing public concern about exposure to site constituents during construction.

The Preferred Alternative would fully comply with MTCA, the Dangerous Waste Regulations (WAC 173-303), and RCRA regulations. The Preferred Alternative would comply with the requirements of the facility's RCRA permit and achieve the environmental indicator standards for controlling potential exposure to both soil and groundwater for affected media located at and near the facility.

The Preferred Alternative would control potential exposures related to affected soil, groundwater, and soil gas, achieving the environmental indicator goals for the site.

9.0 REPORT LIMITATIONS

Within the limitations of the agreed-upon scope of work, this assessment has been undertaken and performed in a professional manner in accordance with generally accepted practices, using the degree of skill and care ordinarily exercised by reputable environmental consultants under similar circumstances. Due to physical limitations inherent to this or any environmental assessment, DOF expressly do not warrant that the site is free of pollutants or that all pollutants have been identified. No other warranties, express or implied, are made.

In preparing this report, DOF has relied upon documents provided by the others. Except as discussed within the report, DOF did not attempt to independently verify the accuracy or completeness of that information. To the extent that the conclusions in this report are based in whole or in part on such information, those conclusions are contingent on its accuracy and validity. DOF assumes no responsibility for any consequence arising from any information or condition that was concealed, withheld, misrepresented, or otherwise not fully disclosed or available to DOF.

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This report does not constitute legal advice. In addition, DOF makes no determination or recommendation regarding the decision to purchase, sell, or provide financing for this site.

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TABLES

TABLE 1

SUMMARY OF HYDRAULIC PROPERTIES

Stericycle Kent Facility
Kent, Washington

		Horizontal					Vertical				
Hydrogeological Units	**Effective Porosity[1]**	**Horizontal Hydraulic Conductivity Ranges[2] (feet/day)**	**Hydraulic Conductivity Used in Velocity Calculations (feet/day)**	**Gradient Ranges (feet/foot)**	**Velocity[3] (feet/day)**	**Velocity[3] (feet/year)**	**Vertical Hydraulic Conductivity Ranges[4] (feet/day)**	**Gradient Between Shallow and Intermediate[5] (feet/foot)**	**Gradient Between Shallow and Deep[5] (feet/foot)**	**Gradient Between Intermediate and Deep[5] (feet/foot)**	**Vertical Gradient Direction[5]**
Shallow Water-Bearing Unit	0.25	85.00 [2]	85.00	0.003 to 0.011	1.2 to 3.8	429 to 1,393	31.18 to 42.52	0.006 to 0.32	0.01 to 0.05	--	Down
Upper Aquitard	--	--	--	--	--	--	0.00006 to 0.02	--	--	--	--
Intermediate Aquifer[6]	0.30	8.50 to 31.18	15.31 [7]	0.00010 to 0.005	0.008 to 0.25	2.76 to 91.01	0.002 to 8.50			0.02 to 0.04	Down
Intermediate Aquitard	--	--	--	--	--	--	0.001 to 0.004	--	--	--	--
Lower Aquitard	--	--	--	--	--	--	0.002 to 0.008	--	--	--	--
Deep Aquifer	0.30	0.45 to 4.82	4.82 [8]	0.003 to 0.004	0.04 to 0.06	16.05 to 22.18	65.20	--	--	--	--

Notes:

1. Effective porosity values were estimated based on literature values for the type of lithological material present at the site (Driscoll, 1986).
2. Horizontal hydraulic conductivity for the shallow water-bearing unit is based on representative hydraulic conductivity for a poorly-graded gravelly sand (Fetter, 1994); horizontal hydraulic conductivity for the intermediate and deep aquifers were determined by slug tests performed in selected wells.
3. Horizontal velocity was calculated using the formula $V=Ki/n_e$.
4. Vertical hydraulic conductivity values are measured from laboratory testing.
5. Vertical gradient ranges were determined by calculating the vertical gradient from the mid-point of screen to mid-point of screen. Vertical gradients were calculated using the EPA on-line tools for site assessment calculation – vertical gradient calculator at: http://www3.epa.gov/ceampubl/learn2model/part-two/onsite/vgradient02.html
6. The Intermediate Zone A and Intermediate Zone B units were combined together for the summary of hydraulic properties because the silt clay layer separating the two units is not continuous across the site.
7. The horizontal hydraulic value of 15.31 foot/day for the intermediate aquifer was used in the velocity calculation because it was the average horizontal hydraulic conductivity based off of the three slug tests.
8. The horizontal hydraulic value of 4.82 foot/day for the deep aquifer was used in the velocity calculation because it was the average horizontal hydraulic conductivity for a silty sand given (Freeze and Cherry, 1979).

Abbreviations:

-- = no values calculated
EPA = U.S. Environmental Protection Agency
K = hydraulic conductivity
i = horizontal gradient
n_e = effective porosity
V = velocity

TABLE 2

SOIL COC CLEANUP LEVELS
Stericycle Kent Facility
Kent, Washington

all concentrations in milligrams per kilogram (mg/kg)

Compound	CAS Number	Soil Cleanup Level	Basis
Volatile Organic Compounds			
Benzene	71-43-2	**8.43E-03**	Protection of groundwater
Vinyl Chloride	75-01-4	**9.40E-04**	Practical quantitation limit
Semivolatile Organic Compounds			
Benzo(a)pyrene	50-32-8	**1.80E+01**	Protection of direct contact
Benzo(b)fluoranthene	205-99-2	**2.46E+00**	Protection of groundwater
Chrysene	218-01-9	**7.96E-01**	Protection of groundwater
Inorganics			
Arsenic	7440-38-2	**7.30E+00**	Natural background
Cyanide	57-12-5	**2.00E-01**	Practical quantitation limit
Total Petroleum Hydrocarbons			
TPH as gasoline	86290-81-5	**3.00E+01**	Protection of direct contact
TPH as diesel	68334-30-5	**2.00E+03**	Protection of direct contact
TPH as lube oil	---	**2.00E+03**	Protection of direct contact

Abbreviations:
CAS = Chemical Abstract Service
TPH = total petroleum hydrocarbons

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TABLE 3

GROUNDWATER COC CLEANUP LEVELS

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Compound	CAS Number	Groundwater Cleanup Level	Basis
Volatile Organic Compounds			
Vinyl chloride	75-01-4	**0.025**	Protection of surface water
Inorganics			
Arsenic	7440-38-2	**10.5**	MTCA C Value
Hexavalent Chromium	18540-29-9	**10**	Protection of surface water
Cyanide	57-12-5	**10**	Area background
Iron	7439-89-6	**24,500**	MTCA C Value
Manganese	7439-96-5	**4,900**	MTCA C Value

Abbreviations:
CAS = Chemical Abstract Service
MTCA = Model Toxics Control Act

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TABLE 4

CONSTITUENTS OF CONCERN IN SOIL[1]

Stericycle Kent Facility
Kent, Washington

AOC-1	AOC-2	AOC-3	AOC-4	AOC-5	10-Day Transfer Yard	Process and Storage Area
No COCs exceeding FS CUL	Arsenic	Arsenic	Arsenic	No COCs detected	Arsenic	No COCs exceeding FS CUL
	Benzene		Benzene			
	Benzo(b)fluoranthene	Benzene	Benzo(a)pyrene			
	Chrysene		Benzo(b)fluoranthene			
	Cyanide	Gasoline	Chrysene			
	Diesel		Diesel			
	Gasoline	Vinyl Chloride	Gasoline			
	Lube Oil					

Notes:
1. Constituents were evaluated as constituents of concern based on criteria described in text.

Abbreviations:
COCs = constituents of concern
CUL = clean up level
FS = feasibility study

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TABLE 5

CONSTITUENTS OF CONCERN IN GROUNDWATER[1]

Stericycle Kent Facility
Kent, Washington

AOC-1	AOC-2	AOC-3	AOC-5	10-Day Transfer Yard	Other	Off-Site
Arsenic						
Hexavalent Chromium						
Cyanide						
Iron						
Vinyl Chloride						

Notes:

1. Constituents were evaluated as constituents of concern based on criteria described in text.

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TABLE 6

AVERAGE AND MAXIMUM GROUNDWATER CONCENTRATIONS FOR CONSTITUENTS OF CONCERN, 2010-2015[1,2,3]

Stericycle Kent Facility
Kent, Washington

WELLS SCREENED IN THE SHALLOW WATER-BEARING UNIT

		Well ID	MW-102-S		MW-112-S		MW-122-S		MW-123-S		MW-126-S		MW-127-S		MW-132-S		MW-133-S	
Analyte	**Cleanup Level**	**Units**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**
Total Arsenic	10.5	µg/L	6.4	**11.6**	12.3	**19.2**	7.5	**19.1**	73.1	**84.3**	8.7	**17.3**	7.9	**28.8**	6.2	**13.5**	74.5	**100**
Chromium (Hexavalent)	10	µg/L	5 U	10 U	8	**17**	6	10 J	12	**19**	5 U	10 U	6	**14**	5 U	10 U	10	**16 J**
Cyanide	10	µg/L	5	**12**	5	**11**	22	**79**	6	**29**	9	**28**	1	3.0 U	4	7	7	9
Total Iron	24.5	mg/L	--	0.971	--	NA	--	NA	--	NA	--	NA	--	NA	--	NA	--	NA
Vinyl Chloride	0.025	µg/L	0.044	**0.10 J**	0.058	**0.16**	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U

WELLS SCREENED IN INTERMEDIATE A AND B AQUIFERS

		Well ID	MW-102-I1		MW-114-I1		MW-117-I2		MW-118-I1		MW-120-I1		MW-122-I2		MW-123-I		MW-124-I1	
COC	**FS Cleanup Level**	**Units**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**
Total Arsenic	10.5	µg/L	25.2	**29.6**	11.0	**14.4**	34.0	**41.9**	12.7	**15.1**	3.8	5.1	1.8	2.4	6.4	8.3	12.3	**21.2**
Chromium (Hexavalent)	10	µg/L	11	**18**	13	**34**	11	**22**	13	**32**	12	**35**	9	**30**	12	**25**	15	**37**
Cyanide	10	µg/L	4	9	1	4	5	**28**	2	**11**	2	3 J	4	**28**	2	5 J	4	**28**
Total Iron	24.5	mg/L	--	**94.5**	--	**71.3**	--	**36.8**	--	**74.9**	--	**50.1**	--	**46.1**	--	**109**	--	**75.1**
Vinyl Chloride	0.025	µg/L	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	0.40	**0.93**	0.0375 U	0.075 U	0.0375 U	0.075 U	0.047	**0.11 J**

WELLS SCREENED IN INTERMEDIATE A AND B AQUIFERS (CONTINUED)

		Well ID	MW-126-I		MW-128-I		MW-129-I		MW-130-I		MW-131-I		GP2010-1		GP2010-3		GP2010-4		GP2010-5	
COC	**FS Cleanup Level**	**Units**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**
Total Arsenic	10.5	µg/L	22.5	**24.8**	9.2	10.3	10.4	**12**	8.1	8.8	11.2	**15.8**	19.9	**44.9**	--	**15.5**	--	**30**	--	9.9
Chromium (Hexavalent)	10	µg/L	11	**22**	15	**35**	10	**23**	11	**30**	17	**35**	5 UJ	10 UJ	--	**45 J**	--	10 UJ	--	10 UJ
Cyanide	10	µg/L	21	**81**	1.24 U	3.0 U	1	3.0 J	1	3.0 U	5	**14**	182	**435**	--	10 U	--	10 U	--	**21**
Total Iron	24.5	mg/L	--	**60.7**	--	**80.3**	--	**66.4**	--	**57.5**	--	**66.0**	--	NA	--	NA	--	NA	--	NA
Vinyl Chloride	0.025	µg/L	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	--	0.50 U	--	**0.10 J**	--	0.50 U

WELLS SCREENED IN THE DEEP AQUIFER

		Well ID	MW-16		MW-24-D		MW-112-D		MW-117-D		MW-133-D	
COC	**FS Cleanup Level**	**Units**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**
Total Arsenic	10.5	µg/L	2.8	6.6	1.5	2.1	1.6	2.1	1.6	1.8	5.1	5.4
Chromium (Hexavalent)	10	µg/L	9	**23**	12	**27**	9	**32**	7	**21**	10	**21**
Cyanide	10	µg/L	6	**12**	43	**56**	22	**36**	22	**30**	1.28 U	3.0 U
Total Iron	24.5	mg/L	--	**39.9**	--	**50.9**	--	**52.7**	--	21.4	--	**30.3**
Vinyl Chloride	0.025	µg/L	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U	0.0375 U	0.075 U

Notes:

1. Data qualifiers are as follows:
   U = The analyte was not detected at the detection limit indicated.
   J = The value is an estimate.
   UJ = Analyte was not detected; indicated value is estimated reporting limit.
2. Average values were calculated using 1/2 of the detection limit for nondetect values.
3. Maximum values exceeding the cleanup level are **bold.**

Abbreviations:

-- = average was not calculated if only one result was available
NA = not analyzed
µg/L - micrograms per liter
mg/L = milligrams per liter

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TABLE 6A

RECENT CYANIDE RESULTS
Stericycle Kent Facility
Kent, Washington

units in mg/L		Cyanide, Free	Cyanide, Total	Cyanide, Weak Acid Dissociable
Sample ID	Date	SM 4500-CN	SW9012B	SM 4500-CN
MW-102-I-1-0416	4/13/2016	<0.01	<0.01	<0.02
MW-102-S-0416	4/12/2016	<0.01	0.006 J	0.0008 J
MW-112-D-0416	4/12/2016	<0.01	0.018	0.002 J
MW-112-S-0416	4/12/2016	<0.01	0.002 J	0.002 J
MW-114-I-1-0416	4/26/2016	<0.01	<0.01	<0.01
MW-117-D-0416	4/25/2016	<0.01	0.018	<0.01
MW-117-I-2-0416	4/25/2016	<0.01	<0.01	<0.01
MW-118-I-1-0416	4/25/2016	<0.01	<0.01	<0.01
MW-120-I-1-0416	4/26/2016	<0.01	<0.01	<0.01
MW-122-I-2-0416	4/20/2016	<0.01	<0.01	<0.01
MW-122-S-0416	4/20/2016	<0.01 J	0.014	0.003 J
MW-123-I-2-0416	4/13/2016	<0.01	<0.01	<0.02
MW-123-S-0416	4/13/2016	<0.01	0.001 J	0.002 J
MW-124-I-1-0416	4/25/2016	<0.01	<0.01	<0.01
MW-126-I-0416	4/13/2016	<0.01	0.009 J	<0.02
MW-126-S-0416	4/13/2016	<0.01	<0.01	<0.02
MW-127-S-0416	4/13/2016	<0.01	<0.01	<0.02
MW-128-I-0416	4/27/2016	<0.01	<0.01	<0.01
MW-129-I-0416	4/26/2016	<0.01	0.001 J	<0.01
MW-130-I-0416	4/26/2016	<0.01	<0.01	<0.01
MW-131-I-0416	4/27/2016	<0.01	0.003 J	<0.01
MW-132-S-0416	4/14/2016	<0.01	<0.01	<0.01
MW-133-D-0416	4/21/2016	<0.01	<0.01	<0.01
MW-16-0416	4/21/2016	<0.01	0.001 J	<0.01
MW-24D-0416	4/21/2016	<0.01	0.017	0.002 J
MW-102-I-1-1016	10/4/2016	<0.01	<0.01	<0.01
MW-112-D-1016	10/4/2016	<0.01	0.017	0.001 J
MW-114-I-1-1016	10/6/2016	<0.01	<0.01	<0.01
MW-117-D-1016	10/6/2016	<0.01	0.019	0.002 J
MW-117-I-2-1016	10/6/2016	<0.01	<0.01	<0.01
MW-118-I-1-1016	10/17/2016	<0.01	<0.01	<0.01
MW-120-I-1-1016	10/17/2016	<0.01	<0.01	<0.01
MW-122-I-2-1016	10/17/2016	<0.01	<0.01	<0.01
MW-123-I-2-1016	10/4/2016	<0.01	<0.01	<0.01
MW-124-I-1-1016	10/13/2016	<0.01	<0.01	<0.01
MW-126-I-1016	10/5/2016	<0.01	0.005 J	<0.01
MW-128-I-1016	10/17/2016	<0.01	<0.01	<0.01
MW-129-I-1016	10/6/2016	<0.01	<0.01	<0.01
MW-130-I-1016	10/18/2016	<0.01	<0.01	<0.01
MW-131-I-1016	10/18/2016	<0.01	0.003 J	<0.01
MW-133-D-1016	10/5/2016	<0.01	<0.01	<0.01
MW-16-1016	10/5/2016	<0.01	0.001 J	<0.01
MW-24D-1016	10/13/2016	<0.01	0.0261	0.002 J

Notes:
Red indicates concentration is over the draft cleanup level for cyanide (0.01 mg/L).
J indicates value is estimated.

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
T-3	2/27/1990	--	56.4	5.0 U
T-4	2/27/1990	--	12.2	5.0 U
W-4	11/29/1990	--	8.8	5.0 U
HA-9	7/5/2000	26.6	--	--
	7/14/2000	15.1	--	--
HA-11	7/17/2000	5 U	7.72	--
GP-125-I	11/22/2002	5 UJ	2.44	--
GP-118-D	2/8/2003	5 UJ	21	--
NW DITCH EAST	10/27/2015	10 U	6.09	5.58
NW DITCH CENTRAL	10/27/2015	10 U	2.49	2.51
NW DITCH WEST	10/27/2015	10 U	2.65	2.42
MW-1	2/28/1989	--	5.0 U	--
	3/13/1990	--	5.0 U	5.0 U
	11/28/1990	--	5.0 U	5.0 U
	4/8/1991	--	6.1	5.7
	7/17/2000	5 U	1 U	--
	10/5/2000	25 U	1 U	--
MW-2	2/23/1989	--	5.0 U	--
	3/14/1990	--	10	5.0 U
	3/14/1990	--	56.3	5.0 U
	11/28/1990	--	5.0 U	5.0 U
	4/8/1991	--	5.0 U	5.0 U
	7/19/2000	5 U	1 U	--
	10/4/2000	5.55	2.15	--
MW-3	2/23/1989	--	5 U	--
	3/13/1990	--	5.8 B	5 U
	11/29/1990	--	30.7	5 U
	4/8/1991	--	12.3	5 U
	7/17/2000	5 U	2.81	--
	10/4/2000	64.8 DB	6.27	--
MW-4	2/23/1989	--	5 U	--
	3/12/1990	--	6.2 B	5 U
	11/29/1990	--	132	5.6
	4/9/1991	--	5 U	7.3
MW-5	2/23/1989	--	5 U	--
	3/12/1990	--	5 U	5 U
	11/29/1990	--	87	10.7
	4/9/1991	--	5 U	5 U

TABLE 7

CHROMIUM SPECIATION COMPARISON[1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-6	3/13/1990	--	5 U	5 U
	11/28/1990	--	5 U	11.4
	4/8/1991	--	9.1	9.2
MW-7S	3/13/1990	--	64.3	5 U
	11/29/1990	--	53	5 U
	4/9/1991	--	5.2	5 U
MW-7D	3/12/1990	--	5.6 B	5 U
	11/29/1990	--	5 U	5 U
	4/9/1991	--	5 U	5 U
MW-8	3/14/1990	--	36.5	5 U
	11/28/1990	--	8.5	8.9
MW-9	3/13/1990	--	5 U	5 U
	11/28/1990	--	5 U	5 U
MW-11	4/8/1991	--	5 U	5 U
MW-12	3/13/1990	--	5 U	5 U
	3/13/1990	--	5.0 U	5.0 U
	11/28/1990	--	5.0 U	5.0 U
	4/8/1991	--	5.0 U	5.0 U
	7/20/2000	5 U	2.98	--
	10/9/2000	25 U	2.23	--
MW-13	3/13/1990	--	5.0 U	5.0 U
	11/28/1990	--	5.0 U	5.0 U
	4/8/1991	--	5.0 U	5.0 U
	7/19/2000	5 U	3.88	--
	10/3/2000	25 U	3.56	--
MW-14	3/13/1990	--	5	5 U
	3/13/1990	--	5.1 B	5.0 U
	11/28/1990	--	5.0 U	--
	11/28/1990	--	5.4	--
	4/8/1991	--	5.0 U	5.0 U
	7/20/2000	5 U	1.8	--
	10/3/2000	5 U	40.2	--
MW-15	3/12/1990	--	6.2 B	5.0 U
	11/29/1990	--	6.9	5.0 U
	4/9/1991	--	5.0 U	5.0 U

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]
Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-16	3/14/1990	--	5.0 U	5.0 U
	11/29/1990	--	5.0 U	5.0 U
	4/8/1991	--	5.0 U	5.0 U
	7/19/2000	5 U	1.29	--
	10/4/2000	5 U	4.26	--
	2/23/2001	5 UR	1.12	--
	4/26/2001	100 U	--	--
	7/13/2001	5 UR	1.16	--
	10/18/2001	6.41	2.64	--
	1/17/2002	5 UR	1 U	--
	4/16/2002	15 UR	1 U	--
	7/16/2002	25 UR	1 U	--
	10/15/2002	5 UJ	1.81	--
	1/8/2003	5 UJ	2.4	--
	4/15/2003	61.7 DJ	--	--
	4/4/2007	30 UJ	--	--
	7/10/2007	30UJ	--	--
	10/11/2007	30 UJ	--	--
	1/18/2008	20 UJ	--	--
	4/10/2008	20UJ	--	--
	7/17/2008	20 UJ	--	--
	10/7/2008	20 UJ	--	--
	1/14/2009	10 UJ	--	--
	4/15/2010	10 UJ	--	--
	10/5/2010	17 J	--	--
	4/14/2011	10 UJ	--	--
	10/12/2011	10 UJ	--	--
	4/16/2012	10 UJ	--	--
	10/24/2012	10 UJ	--	--
	4/25/2013	10 UJ	--	--
	10/17/2013	10 UJ	--	--
	4/14/2015	13 J	--	--
	10/15/2015	23 J	--	--
MW-17	7/18/2000	5 U	1 U	--
	10/5/2000	25.3 D	3.57	--
MW-18	7/18/2000	5 U	1 U	--
	10/2/2000	5 U	1 U	--
MW-19	7/20/2000	5 U	1.31	--
	10/5/2000	5 U	1 U	--
MW-20	7/20/2000	5 U	4.18	--
	10/9/2000	25 U	3.33	--
MW-21	7/21/2000	6.76	--	--
	10/3/2000	25 U	8.66	--

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-22	7/19/2000	5 U	2.39	--
	10/5/2000	5 U	1.16	--
MW-23	7/19/2000	5 U	6.76	--
	10/3/2000	25 U	10.3	--
MW-24	7/17/2000	5 U	3.25	--
	10/4/2000	5 U	3.33	--
MW-24D	7/17/2000	5 U	1.3	--
	10/4/2000	5 U	4.57	--
	2/23/2001	5 UR	1.79	--
	4/27/2001	5 UR	1 U	--
	7/11/2001	5 UR	1 U	--
	10/18/2001	5 U	1 U	--
	1/15/2002	5 UR	3.38 U	--
	4/17/2002	15 UR	1.35	--
	7/16/2002	25 UR	1.04	--
	10/15/2002	5 UJ	1 U	--
	1/10/2003	5 U	1 U	--
	4/15/2003	50 UJ	--	--
	4/4/2007	30 UJ	--	--
	7/10/2007	30 UJ	--	--
	10/11/2007	30 UJ	--	--
	1/16/2008	20 UJ	--	--
	4/9/2008	20 UJ	--	--
	7/16/2008	20 UJ	--	--
	10/7/2008	20 UJ	--	--
	1/14/2009	9 J	--	--
	4/16/2010	10 UJ	--	--
	10/5/2010	15 J	--	--
	4/18/2011	10 UJ	--	--
	10/12/2011	19 J	--	--
	4/17/2012	10 UJ	--	--
	10/24/2012	10 UJ	--	--
	4/24/2013	15 J	--	--
	10/22/2013	10 J	--	--
	4/21/2014	27 J	--	--
	4/16/2015	10 UJ	--	--
	10/21/2015	26	--	--
MW-25	7/18/2000	5 U	1.72	--
	10/5/2000	50.7 D	2.21	--

TABLE 7

CHROMIUM SPECIATION COMPARISON[1]
Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-102-I1	2/23/2001	5 UR	1.24	--
	4/27/2001	5 R	1 U	--
	7/13/2001	5 UR	1.57	--
	10/18/2001	5.52	1.35	--
	1/15/2002	5 UR	1.3 U	--
	4/16/2002	15 UR	1.1 J	--
	7/15/2002	25 UR	1.18	--
	10/15/2002	5 UJ	1 U	--
	1/7/2003	5 U	1 U	--
	4/15/2003	50 UJ	--	--
	4/2/2007	30 UJ	--	--
	7/9/2007	30 UJ	--	--
	10/8/2007	4 UJ	--	--
	1/14/2008	20 UJ	--	--
	4/7/2008	20 UJ	--	--
	7/14/2008	20 UJ	--	--
	10/6/2008	20 UJ	--	--
	1/14/2009	18 J	--	--
	4/14/2010	10 UJ	--	--
	10/4/2010	15 J	--	--
	4/13/2011	10 UJ	--	--
	10/11/2011	10 UJ	--	--
	4/10/2012	12 J	--	--
	10/23/2012	10 UJ	--	--
	4/16/2013	18 J	--	--
	10/15/2013	18	--	--
	4/7/2015	17 J	--	--
	10/13/2015	13 J	--	--
MW-102-S	1/7/2003	5 U	1 U	--
	4/15/2003	5 U	--	--
	4/2/2007	30 UJ	--	--
	7/9/2007	30 UJ	--	--
	10/8/2007	30 UJ	--	--
	1/14/2008	20 UJ	--	--
	4/7/2008	20 UJ	--	--
	7/14/2008	20 UJ	--	--
	10/6/2008	20 UJ	--	--
	1/7/2009	4 UJ	--	--
	4/13/2010	100 UJ	--	--
	10/4/2010	10 UJ	--	--
	4/13/2011	10 UJ	--	--
	4/10/2012	10 UJ	--	--
	10/23/2012	10 UJ	--	--
	4/16/2013	10 UJ	--	--
	10/15/2013	10 UJ	--	--
	4/7/2015	10 UJ	--	--
	10/13/2015	10 UJ	--	--

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TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-112-D	2/26/2001	500 U	1.96	--
	4/26/2001	100 UJ	--	--
	7/11/2001	5 UR	1 U	--
	10/17/2001	5 UR	1 U	--
	1/14/2002	8.18 J	1 U	--
	4/18/2002	10 U	1 U	--
	7/18/2002	12.2 J	1 U	--
	10/14/2002	5 UJ	1.09	--
	1/13/2003	6.25 UJ	1 U	--
	4/15/2003	25 UJ	--	--
	4/3/2007	30 U	--	--
	7/9/2007	30 UJ	--	--
	10/9/2007	30 UJ	--	--
	1/15/2008	20 UJ	--	--
	4/10/2008	20 UJ	--	--
	7/18/2008	20 UJ	--	--
	10/8/2008	20 UJ	--	--
	1/6/2009	10 J	--	--
	4/13/2010	11 J	--	--
	10/4/2010	10 UJ	--	--
	4/13/2011	10 UJ	--	--
	10/11/2011	10 UJ	--	--
	4/10/2012	10 UJ	--	--
	10/25/2012	10 UJ	--	--
	4/17/2013	15 J	--	--
	10/15/2013	10 U	--	--
	4/7/2015	10 U	--	--
	10/15/2015	32 J	--	--
MW-112-I2	2/26/2001	50 U	1	--
	4/26/2001	100 UJ	--	--
	7/11/2001	5.64 R	1 U	--
	10/17/2001	5 UR	1 U	--
	1/14/2002	6.15 J	1 U	--
	4/18/2002	10 UR	1 U	--
	7/18/2002	11.2 J	1 U	--
	10/14/2002	5 UJ	1 U	--

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TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-112-S	2/27/2001	--	17.1	--
	7/12/2001	5 U	6.47	--
	10/24/2001	6.66	3.67	--
	1/16/2002	5 UR	1.27 U	--
	4/17/2002	5 UR	1.39	--
	7/19/2002	14.1	1.65	--
	10/16/2002	5 UJ	2.53	--
	4/15/2003	5 U	--	--
	4/2/2007	30 UJ	--	--
	1/15/2008	20 UJ	--	--
	4/10/2008	20UJ	--	--
	1/6/2009	13 J	--	--
	4/13/2010	10 UJ	--	--
	4/13/2011	10 UJ	--	--
	4/10/2012	10 UJ	--	--
	4/17/2013	17 J	--	--
	4/7/2015	10 J	--	--
MW-113-I1	2/27/2001	250 U	12.1	--
	4/26/2001	100 UJ	1.97	--
	7/16/2001	5 UR	1.95	--
	10/18/2001	8.06	2.53	--
	1/16/2002	5 UR	1.84 U	--
	4/16/2002	15 UR	2.12 J	--
	7/19/2002	5 U	1.88	--
	10/17/2002	5 UJ	2.05	--

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-114-I1	2/27/2001	250 U	2.84	--
	4/25/2001	10 UR	1.77	--
	7/16/2001	5 UR	1.85	--
	10/23/2001	5 UR	1.87	--
	1/16/2002	5 UR	1.68 U	--
	4/17/2002	15 UR	1.85	--
	7/16/2002	25 UR	1.55	--
	10/16/2002	10 UJ	1 U	--
	1/9/2003	5 UJ	1.45	--
	4/18/2003	25 UJ	--	--
	4/5/2007	30 U	--	--
	7/13/2007	30 UJ	--	--
	10/15/2007	30 UJ	--	--
	1/18/2008	20 UJ	--	--
	4/15/2008	20 UJ	--	--
	7/22/2008	20 UJ	--	--
	10/13/2008	20 UJ	--	--
	1/23/2009	14 J	--	--
	4/20/2010	34 J	--	--
	10/7/2010	10 UJ	--	--
	4/19/2011	10 UJ	--	--
	10/13/2011	20 J	--	--
	4/19/2012	10 UJ	--	--
	10/30/2012	25 J	--	--
	4/22/2013	14 J	--	--
	10/22/2013	12 J	--	--
	4/17/2014	21 J	--	--
	4/16/2015	10 U	--	--
	10/14/2015	10 U	--	--
	10/14/2015	10 U	--	--

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-117-I2	2/22/2001	5 UJ	1 U	--
	5/2/2001	10 UR	1 U	--
	7/17/2001	5 UR	1 U	--
	10/16/2001	5 UR	1 U	--
	1/16/2002	5.14 J	1 U	--
	4/18/2002	10 UR	1 U	--
	7/17/2002	5 UR	1 U	--
	10/16/2002	5 UJ	1 U	--
	1/14/2003	15.2 DJ	1 U	--
	4/21/2003	5 UJ	--	--
	4/3/2007	30 U	--	--
	7/13/2007	30 UJ	--	--
	10/16/2007	30 UJ	--	--
	1/21/2008	20 UJ	--	--
	4/17/2008	20 UJ	--	--
	7/18/2008	20 UJ	--	--
	10/13/2008	20 UJ	--	--
	1/13/2009	8 J	--	--
	4/19/2010	15 J	--	--
	10/6/2010	10 UJ	--	--
	4/20/2011	10 UJ	--	--
	10/18/2011	10 UJ	--	--
	4/16/2012	17 J	--	--
	10/29/2012	10 UJ	--	--
	4/22/2013	14 J	--	--
	10/16/2013	22 J	--	--
	4/17/2014	14 J	--	--
	4/14/2015	14 J	--	--
	10/26/2015	10 UJ	--	--
MW-117-S	4/21/2003	5 UJ	--	--
	4/2/2007	30 UJ	--	--
MW-117-D	4/19/2010	10 UJ	--	--
	10/5/2010	10 UJ	--	--
	4/20/2011	10 UJ	--	--
	10/18/2011	10 UJ	--	--
	4/16/2012	10 UJ	--	--
	10/29/2012	10 UJ	--	--
	4/22/2013	10 UJ	--	--
	10/16/2013	15 J	--	--
	4/17/2014	21 J	--	--
	4/14/2015	10 UJ	--	--
	10/26/2015	10UJ	--	--

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TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-118-I1	2/22/2001	5 UJ	1.06	--
	5/2/2001	10 UR	1 U	--
	7/17/2001	5 UR	1 U	--
	10/19/2001	5 UR	1 U	--
	1/17/2002	5 UR	1 U	--
	4/19/2002	10 UR	1 U	--
	7/17/2002	5 UR	1 U	--
	10/16/2002	5 UJ	1 U	--
	1/9/2003	5 UJ	1 U	--
	4/18/2003	5 UJ	--	--
	4/3/2007	30 U	--	--
	7/13/2007	30 UJ	--	--
	10/16/2007	30 UJ	--	--
	1/21/2008	20 UJ	--	--
	4/17/2008	20 UJ	--	--
	7/18/2008	20 UJ	--	--
	10/10/2008	20 UJ	--	--
	1/13/2009	22 J	--	--
	4/19/2010	10 UJ	--	--
	10/6/2010	10 UJ	--	--
	4/20/2011	10 UJ	--	--
	10/18/2011	32 J	--	--
	4/17/2012	10 UJ	--	--
	10/29/2012	10 UJ	--	--
	4/25/2013	12 J	--	--
	10/17/2013	10 J	--	--
	4/17/2014	26 J	--	--
	10/14/2014	17 J	--	--
	4/14/2015	17 J	--	--
	10/26/2015	14 J	--	--
MW-118-S	2/22/2001	5 UJ	1 U	--
	5/2/2001	5 UR	1 U	--
	7/12/2001	5 UR	1.02	--
	10/19/2001	5 U	1.05	--
	1/17/2002	5 UR	1.11 U	--
	4/19/2002	5 UR	1 U	--
	7/17/2002	5 UR	1 U	--
	10/16/2002	5 UJ	19.8	--

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-120-I1	2/27/2001	250 U	2.04	--
	4/27/2001	5.85 R	1.31	--
	7/12/2001	5 UR	1.95	--
	10/23/2001	5 UR	1.51	--
	1/17/2002	5 UR	1.78 U	--
	4/18/2002	10 UR	1.52 J	--
	7/18/2002	19.4 J	1.46	--
	10/17/2002	5 UJ	1.6	--
	1/10/2003	5 U	1.19	--
	4/16/2003	30.8 DJ	--	--
	4/6/2007	30 U	--	--
	7/11/2007	30 UJ	--	--
	10/15/2007	30 UJ	--	--
	1/18/2008	20 UJ	--	--
	4/18/2008	20 UJ	--	--
	7/17/2008	20 UJ	--	--
	10/13/2008	20 UJ	--	--
	1/21/2009	7 J	--	--
	4/19/2010	10 UJ	--	--
	10/6/2010	10 UJ	--	--
	4/19/2011	10 UJ	--	--
	10/13/2011	23 J	--	--
	4/17/2012	10 UJ	--	--
	10/26/2012	19 J	--	--
	4/25/2013	10 UJ	--	--
	10/17/2013	12 J	--	--
	4/21/2014	35 J	--	--
	10/14/2014	15 J	--	--
	4/16/2015	10 UJ	--	--
	10/22/2015	10 UJ	--	--
MW-120-I2	2/27/2001	250 U	2.01	--
	5/2/2001	10 UR	1.66	--
	7/12/2001	5 UR	1.68	--
	10/23/2001	5 UR	1.38	--
	1/17/2002	5 UR	1.46 U	--
	4/18/2002	10 UR	1.46 J	--
	7/18/2002	15.2 J	1.27	--
	10/17/2002	5 UJ	1.09	--

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-122-I2	2/27/2001	250 U	1.8	--
	4/25/2001	5 UR	1 U	--
	7/17/2001	5 UR	1 U	--
	10/19/2001	5 UR	3.96	--
	1/16/2002	5 UR	1.26 U	--
	4/17/2002	10 UR	1.22	--
	7/19/2002	5 U	1 U	--
	10/16/2002	5 UJ	1 U	--
	1/10/2003	5 U	1 U	--
	4/18/2003	5 UJ	--	--
	4/4/2007	30 U	--	--
	7/11/2007	30 UJ	--	--
	10/9/2007	30 UJ	--	--
	1/17/2008	20 UJ	--	--
	4/11/2008	20 UJ	--	--
	7/17/2008	20 UJ	--	--
	10/8/2008	20 UJ	--	--
	1/19/2009	4 UJ	--	--
	4/15/2010	10 UJ	--	--
	10/7/2010	10 UJ	--	--
	4/18/2011	10 UJ	--	--
	10/19/2011	10 UJ	--	--
	4/12/2012	10 UJ	--	--
	10/29/2012	10 UJ	--	--
	4/24/2013	10 UJ	--	--
	10/21/2013	15 J	--	--
	4/15/2014	30 J	--	--
	10/15/2014	15 J	--	--
	4/15/2015	10 UJ	--	--
MW-122-S	1/10/2003	8.19	1 U	--
	4/18/2003	5 UJ	--	--
	4/4/2007	30 U	--	--
	10/9/2007	30 UJ	--	--
	1/17/2008	20 UJ	--	--
	4/11/2008	20 UJ	--	--
	1/20/2009	6 J	--	--
	4/18/2011	10 UJ	--	--
	4/11/2012	10 UJ	--	--
	4/23/2013	10 UJ	--	--
	10/21/2013	10 UJ	--	--
	4/15/2014	10 UJ	--	--
	4/15/2015	10 UJ	--	--

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TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-123-I	2/26/2001	50 U	1.78	--
	4/25/2001	10 UR	1.16	--
	7/13/2001	5 UR	1.49	--
	10/23/2001	5 UR	1.15	--
	1/15/2002	9.71 J	1.01 U	--
	4/16/2002	15 UR	1.34 J	--
	7/17/2002	25 UR	1.06	--
	10/17/2002	5 UJ	1.11	--
	1/8/2003	5 UJ	1 U	--
	4/16/2003	50 UJ	--	--
	4/3/2007	30 UJ	--	--
	7/9/2007	30 UJ	--	--
	10/8/2007	30 UJ	--	--
	1/15/2008	20 UJ	--	--
	4/7/2008	20 UJ	--	--
	7/14/2008	20 UJ	--	--
	10/6/2008	20 UJ	--	--
	1/7/2009	6 J	--	--
	4/14/2010	10 UJ	--	--
	10/4/2010	17 J	--	--
	4/13/2011	10 UJ	--	--
	10/11/2011	10 UJ	--	--
	4/11/2012	15 J	--	--
	10/24/2012	10 UJ	--	--
	4/16/2013	12 J	--	--
	10/15/2013	16 J	--	--
	10/13/2015	25 J	--	--
MW-123-S	2/26/2001	500 U	15.1 D	--
	4/25/2001	50 UR	20.9	--
	7/16/2001	22.9 R	14.5	--
	1/17/2002	5 UR	8.72	--
	4/16/2002	150 UR	11.8 J	--
	7/17/2002	50 UR	14.5	--
	7/19/2002	--	12.5	--
	1/10/2003	26.2	11.8	--
	4/16/2003	5 UJ	--	--
	4/2/2007	30 U	--	--
	1/14/2008	20 UJ	--	--
	4/8/2008	30 J	--	--
	1/7/2009	7 J	--	--
	4/14/2010	10 UJ	--	--
	4/14/2011	10 UJ	--	--
	4/11/2012	13 J	--	--
	4/16/2013	19 J	--	--
	10/15/2013	18 J	--	--

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-124-I1	2/23/2001	5 UR	7.75	--
	4/27/2001	7.44 R	2.55	--
	7/16/2001	5 UR	3.89	--
	10/24/2001	5 U	1.78	--
	1/15/2002	5 UR	10.3	--
	4/17/2002	15 UR	2.57	--
	7/16/2002	25 UR	1.35	--
	10/15/2002	5 UJ	2.33	--
	1/8/2003	5 UJ	1.25	--
	4/16/2003	10 U	--	--
	4/4/2007	30 UJ	--	--
	7/10/2007	30 UJ	--	--
	10/12/2007	30 UJ	--	--
	1/17/2008	20 J	--	--
	4/9/2008	20 UJ	--	--
	7/16/2008	20 UJ	--	--
	10/8/2008	20 UJ	--	--
	1/21/2009	4 UJ	--	--
	4/16/2010	10 UJ	--	--
	10/5/2010	15 J	--	--
	4/19/2011	10 UJ	--	--
	10/12/2011	16 J	--	--
	4/17/2012	10 UJ	--	--
	10/25/2012	10 UJ	--	--
	4/24/2013	26 J	--	--
	10/21/2013	28 J	--	--
	4/15/2015	10 UJ	--	--
	10/21/2015	37 J	--	--
MW-125-I1	2/27/2001	250 U	1.56	--
	4/25/2001	10 UR	2.15	--
	7/10/2001	5 UR	1.56	--
	10/15/2001	6.41 R	1.56	--
	1/16/2002	5 UR	1.41 U	--
	4/19/2002	30 UR	1.54 J	--
	7/15/2002	25 UR	1.14	--
	10/14/2002	10 UJ	2.32	--

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-126-I1	1/9/2003	5 UJ	1.1	--
	4/16/2003	50 UJ	--	--
	4/5/2007	30 UJ	--	--
	7/11/2007	30 UJ	--	--
	10/11/2007	30 UJ	--	--
	1/16/2008	20 UJ	--	--
	4/8/2008	20 UJ	--	--
	7/15/2008	20 UJ	--	--
	10/7/2008	20 UJ	--	--
	1/14/2009	8 J	--	--
	4/15/2010	10 UJ	--	--
	10/4/2010	12 J	--	--
	4/14/2011	10 UJ	--	--
	10/12/2011	18 J	--	--
	4/18/2012	10 UJ	--	--
	10/30/2012	22 J	--	--
	4/23/2013	10 UJ	--	--
	10/16/2013	22 J	--	--
	10/22/2015	10 UJ	--	--
MW-126-S	4/5/2007	300 UJ	--	--
	1/16/2008	20 UJ	--	--
	4/8/2008	20 UJ	--	--
	1/19/2009	5 J	--	--
	4/14/2010	10 UJ	--	--
	4/14/2011	10 UJ	--	--
	4/18/2012	10 UJ	--	--
	4/22/2013	10 UJ	--	--
	10/16/2013	10 UJ	--	--
MW-127-S	1/9/2003	5 UJ	1.73	--
	4/17/2003	5 UJ	--	--
	4/5/2007	30 UJ	--	--
	7/11/2007	30 UJ	--	--
	1/16/2008	20 UJ	--	--
	4/9/2008	20 UJ	--	--
	7/15/2008	20 UJ	--	--
	1/19/2009	4 UJ	--	--
	4/14/2010	10 UJ	--	--
	10/5/2010	14 J	--	--
	4/14/2011	10 UJ	--	--
	4/11/2012	10 UJ	--	--
	4/23/2013	10 UJ	--	--
	10/16/2013	10 UJ	--	--
	4/9/2015	10 UJ	--	--

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-128-I	1/9/2003	5 UJ	1 U	--
	4/18/2003	5 UJ	--	--
	4/5/2007	30 U	--	--
	7/12/2007	30 UJ	--	--
	10/12/2007	30 UJ	--	--
	1/22/2008	20 UJ	--	--
	4/15/2008	20 UJ	--	--
	7/23/2008	20 UJ	--	--
	10/9/2008	20 UJ	--	--
	1/23/2009	4 UJ	--	--
	4/20/2010	29 J	--	--
	10/7/2010	12 J	--	--
	4/21/2011	10 UJ	--	--
	10/13/2011	21 J	--	--
	4/19/2012	10 UJ	--	--
	10/31/2012	10 UJ	--	--
	4/25/2013	10 UJ	--	--
	10/23/2013	25 J	--	--
	4/21/2014	32 J	--	--
	10/14/2014	10 UJ	--	--
	4/20/2015	35 J	--	--
	10/22/2015	10 UJ	--	--
MW-129-I	7/13/2007	30 UJ	--	--
	10/17/2007	30 UJ	--	--
	1/22/2008	20 UJ	--	--
	4/16/2008	20 UJ	--	--
	7/21/2008	20 UJ	--	--
	10/10/2008	20 UJ	--	--
	1/22/2009	4 UJ	--	--
	4/20/2010	23 J	--	--
	10/7/2010	10 UJ	--	--
	4/19/2011	10 UJ	--	--
	10/13/2011	23 J	--	--
	4/19/2012	10 UJ	--	--
	10/30/2012	11 J	--	--
	4/22/2013	10 UJ	--	--
	10/22/2013	10 UJ	--	--
	4/17/2014	13 J	--	--
	4/16/2015	10 UJ	--	--
	10/14/2015	10 UJ	--	--

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-130-I	1/13/2003	6.25 UJ	1.67	--
	4/18/2003	5 UJ	--	--
	4/6/2007	20 J	--	--
	7/12/2007	30 UJ	--	--
	10/15/2007	30 UJ	--	--
	1/22/2008	20 UJ	--	--
	4/16/2008	20 UJ	--	--
	7/22/2008	20 UJ	--	--
	10/9/2008	20 UJ	--	--
	1/19/2009	4 UJ	--	--
	4/20/2010	22 J	--	--
	10/7/2010	10 UJ	--	--
	4/21/2011	10 UJ	--	--
	10/19/2011	10 UJ	--	--
	4/19/2012	10 UJ	--	--
	10/30/2012	13 J	--	--
	4/25/2013	10 UJ	--	--
	10/22/2013	12 J	--	--
	4/15/2014	30 J	--	--
	10/15/2014	16 J	--	--
	4/16/2015	10 UJ	--	--
	10/26/2015	10 UJ	--	--
MW-131-I	1/13/2003	6.25 UJ	1 U	--
	4/17/2003	5 UJ	--	--
	4/6/2007	30 UJ	--	--
	7/12/2007	30 UJ	--	--
	10/17/2007	30 UJ	--	--
	1/21/2008	20 UJ	--	--
	4/18/2008	20 UJ	--	--
	7/21/2008	20 UJ	--	--
	10/9/2008	20 UJ	--	--
	1/22/2009	8 J	--	--
	4/21/2010	31 J	--	--
	10/6/2010	10 UJ	--	--
	4/21/2011	10 UJ	--	--
	10/19/2011	10 UJ	--	--
	4/18/2012	10 UJ	--	--
	10/31/2012	10 UJ	--	--
	4/25/2013	10 UJ	--	--
	10/23/2013	23 J	--	--
	4/21/2014	30 J	--	--
	10/15/2014	23 J	--	--
	4/20/2015	35 J	--	--
	10/28/2015	33 J	--	--

TABLE 7

CHROMIUM SPECIATION COMPARISON [1]

Stericycle Kent Facility
Kent, Washington

all concentrations in micrograms per liter (µg/L)

Well/Sample Location ID	Date	Hexavalent Chromium	Total Chromium	Dissolved Chromium
MW-132-S	1/14/2003	12.5 UJ	5.23	--
	4/21/2003	5 UJ	--	--
	4/4/2007	30 U	--	--
	1/17/2008	20 UJ	--	--
	4/11/2008	20 UJ	--	--
	1/20/2009	16 J	--	--
	4/16/2010	10 UJ	--	--
	4/18/2011	10 UJ	--	--
	4/12/2012	10 UJ	--	--
	4/23/2013	10 UJ	--	--
	4/16/2014	10 UJ	--	--
	4/9/2015	10 UJ	--	--
MW-133-D	4/19/2010	10 UJ	--	--
	10/6/2010	10 UJ	--	--
	4/20/2011	10 UJ	--	--
	10/19/2011	10 UJ	--	--
	4/12/2012	10 UJ	--	--
	10/26/2012	21 J	--	--
	4/18/2013	10 UJ	--	--
	10/17/2013	10 UJ	--	--
	4/17/2014	19 J	--	--
	10/14/2014	11 J	--	--
	4/14/2015	11 J	--	--
	10/15/2015	19 J	--	--
MW-133-S	4/20/2010	16 J	--	--
	4/20/2011	10 UJ	--	--
	4/16/2012	10 UJ	--	--
	4/18/2013	14 J	--	--

Notes:

1. Data qualifiers are as follows:
   - B = Analyte detected in associated blank
   - D = Sample was diluted
   - DB = Sample was diluted/analyte detected in associated blank
   - DJ = Sample was diluted/result is an estimate
   - J = The value is an estimate
   - R = The result is rejected due to quality control issues
   - U = The analyte was not detected at the reporting limit indicated
   - UJ = The analyte was not detected at the estimated reporting limit indicated
   - UR = The non-detected result is rejected due to quality control issues.
2. Yellow highlighting indicates that both hexavalent chromium and total chromium were tested, and that hexavalent chromium was higher.

Abbreviations:

-- indicates a sample was not tested for that analysis

TABLE 7A

RECENT CHROMIUM RESULTS
Stericycle Kent Facility
Kent, Washington

units mg/L		Chromium, Dissolved	Total Chromium	Chromium, Hexavalent
Sample ID	Date	SW6020A	SW6020A	SM3500Cr-B
MW-102-I-1-0416	4/13/2016	--	0.00127	0.012 J
MW-102-S-0416	4/12/2016	--	0.00276	<0.01 J
MW-112-D-0416	4/12/2016	--	0.0008	0.011 J
MW-112-S-0416	4/12/2016	--	0.0009	<0.01 J
MW-114-I-1-0416	4/26/2016	--	0.00115	0.033 J
MW-117-D-0416	4/25/2016	--	0.00054	<0.01 J
MW-117-I-2-0416	4/25/2016	--	0.00107	0.016 J
MW-118-I-1-0416	4/25/2016	--	0.00084	<0.01 J
MW-120-I-1-0416	4/26/2016	--	0.00153	0.027 J
MW-122-I-2-0416	4/20/2016	--	--	<0.01 J
MW-122-S-0416	4/20/2016	--	--	<0.01 J
MW-123-I-2-0416	4/13/2016	--	0.00157	<0.01 J
MW-123-S-0416	4/13/2016	0.00594	0.00611	0.058 J
MW-124-I-1-0416	4/25/2016	0.00225	0.00219	0.013 J
MW-126-I-0416	4/13/2016	--	0.00107	<0.01 J
MW-126-S-0416	4/13/2016	--	0.00203	<0.01 J
MW-127-S-0416	4/13/2016	0.0007	0.0007	<0.01 J
MW-128-I-0416	4/27/2016	--	0.00084	0.038 J
MW-129-I-0416	4/26/2016	--	0.00066	0.017 J
MW-130-I-0416	4/26/2016	0.00088	0.0008	0.02 J
MW-131-I-0416	4/27/2016	--	0.00056	0.043 J
MW-132-S-0416	4/14/2016	0.00161	0.0016	<0.01 J
MW-133-D-0416	4/21/2016	--	--	<0.01 J
MW-16-0416	4/21/2016	--	--	<0.01 J
MW-24D-0416	4/21/2016	--	--	<0.01 J
MW-102-I-1-1016	10/4/2016	--	0.001	0.049 J
MW-112-D-1016	10/4/2016	--	0.00069	0.031 J
MW-114-I-1-1016	10/6/2016	--	0.00106	0.013 J
MW-117-D-1016	10/6/2016	--	0.00047	<0.013 J
MW-117-I-2-1016	10/6/2016	--	0.00102	0.014 J
MW-118-I-1-1016	10/17/2016	--	0.0006	<0.013 J
MW-120-I-1-1016	10/17/2016	--	0.00148	0.025 J
MW-122-I-2-1016	10/17/2016	--	0.0005	0.014 J
MW-123-I-2-1016	10/4/2016	--	0.00108	0.046 J
MW-124-I-1-1016	10/13/2016	0.00203	0.00221	<0.013 J
MW-126-I-1016	10/5/2016	--	0.001	
MW-128-I-1016	10/17/2016	--	0.00073	<0.013 J
MW-129-I-1016	10/6/2016	--	0.00068	<0.013 J
MW-130-I-1016	10/18/2016	--	0.0008	<0.013 J
MW-131-I-1016	10/18/2016	--	0.0005	<0.013 J
MW-133-D-1016	10/5/2016	--	0.00086	
MW-16-1016	10/5/2016	--	0.00092	
MW-24D-1016	10/13/2016	--	0.00089	0.032 J

Notes:
Red indicates concentration is over the draft cleanup level for hexavalant chromiur
J indicates value is estimated.

TABLE 8

SURFACE WATER SAMPLE RESULTS^{1,2}
Stericycle Kent Facility
Kent, Washington

Analyte	Feasibility Study Cleanup Level^{3}	NW Ditch East	NW Ditch Central	Field Duplicate	NW Ditch West	Minimum Historically Detected Concentration^{4}	Maximum Historically Detected Concentration^{4}
		10/27/2015	**10/27/2015**	**10/27/2015**	**10/27/2015**		
Total Metals (µg/L)							
Arsenic	10.5	7.80	4.30	4.20	3.10	4.6 J	**22**
Barium	*320/--*	35.4	11.2	11.1	14.6	27	160
Cadmium	5.0	4.22	0.347	0.362	0.217	0.278 J	0.278 J
Chromium	*50/--*	6.09	2.49	2.51	2.65	3.8	38
Copper	3.5	**29.4**	**7.27**	**7.20**	**6.18**	**9.48**	**28**
Iron	*84,430*	3,920	1,120	1,150	880	3,400	10,700
Lead	*15/--*	8.45	0.734	0.687	0.460	1.81	8.3
Nickel	*32/1,100*	10.3	5.67	5.51	10.5	5.1	35
Mercury	0.20	0.06 J	0.20 U	0.20 U	0.20 U	0.2	0.2
Silver	0.32	**0.36**	0.090	0.084	0.044	0.095	0.095
Zinc	32	**48.6**	11.2	10.9	12.5	**103**	**540**
Dissolved Metals (µg/L)							
Arsenic	10.5	6.6	4.0	4.1	2.9	2.2 J	**23**
Barium	*320/--*	27.0	8.6	8.8	13.7	18	260
Cadmium	5.0	3.0	0.26	0.26	0.15	--	--
Chromium	*50/--*	5.6	2.5	2.5	2.4	34	**52.5**
Copper	3.5	**22.37**	**6.28**	**6.19**	**5.25**	**7.5**	**7.5**
Iron	84,430	3,060	736	725	672	2,070	7,000
Lead	*15/--*	6.84	0.546	0.557	0.363	--	--
Nickel	*32/1,100*	9.59	5.60	5.52	10.0	24	33
Mercury	0.20	0.02 J	0.20 U	0.20 U	0.20 U	--	--
Silver	0.32	0.287	0.072	0.087	0.035	--	--
Zinc	32	30.7	8.59	8.92	9.58	20	**480**
Conventionals (mg/L)							
Iron, Ferrous	11.2	1.55	0.04	0.04	0.02	--	--
Iron, Ferric	11.2	2.4	1.1	1.1	0.86	--	--
Polychlorinated Biphenyls (µg/L)							
Aroclor 1260	*0.0438/--*	0.0090 J	0.020 U	0.020 U	0.020 U	0.4 J	**1.8**
Total PCBs	*0.0438/0.000105*	0.009	--	--	--	0.4 J	**1.8**
Herbicides (µg/L)							
Malathion	*320/--*	0.018 J	0.20 U	--	0.20 U	0.4	0.4
Volatile Organic Compounds (µg/L)							
Acetone	*7200/--*	11 J	4.7 J	--	20 U	9.4 J	900
Ethylbenzene	*800/6,820*	0.12 J	0.50 U	--	0.50 U	--	--
Toluene	*640/18,900*	14	0.50 U	--	0.73 U	1.63	30
Semivolatile Organic Compounds (µg/L)							
2-Methylphenol	*400/--*	0.18 J	0.48 U	--	0.49 U	--	--
Pentachlorophenol	*0.219/1.47*	0.56 J	0.95 U	--	0.97 U	20 U	20 U
Phenol	*2,400/556,000*	17	0.48 U	--	0.49 U	1 J	230

Notes:
1. Data qualifiers are as follows:
   J = Analyte was positively identified; indicated concentration is estimated
   U = Analyte was not detected at the reporting limit indicated.
2. **Bold** text indicate detections exceeding the FS cleanup level.
3. For analytes that are not COCs and therefore do not have established site-specific cleanup levels, MTCA Method B groundwater and surface water screening levels were used. These are shown in italics, with the groundwater level first, then surface water, separated by a slash.
4. Historically detected concentrations are referenced from Table 6-10 in the Final RI Report (Geomatrix, 2007).

Abbreviations
µg/l= micrograms per liter
mg/L = milligrams per liter
PCBs = polychlorinated biphenyls
SVOCs = semi volatile organic compounds
VOCs = volatile organic compounds

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TABLE 9

SOIL REMEDIATION TECHNOLOGIES CONSIDERED FOR INCORPORATION INTO REMEDIAL ALTERNATIVES

Stericycle Kent Facility
Kent, Washington

General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Areas Addressed	Site Contaminants Addressed
In Situ Physical/Chemical Treatment	Chemical Oxidation	6.1.1.1	Oxidation chemically converts hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, persulfate or permanganate. Reaction occurs only in aqueous solution.	Full-Scale	Technology demonstrated to be moderately effective under certain site conditions. Ineffective for most inorganics.	AOC-2, AOC-3, and AOC-4	VOCs, SVOCs, TPH
	Chemical Reduction	6.1.1.2	Reduction chemically converts hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. The reducing agents most commonly used are ZVI, ferrous sulfide, and hydrogen sulfide. Reaction occurs only in aqueous solution.	Full-Scale	Technology demonstrated to be moderately effective under certain site conditions.	AOC-2, AOC-3, and AOC-4	VOCs, SVOCs, TPH, some inorganics
Containment	Cap/Surface Cover	6.1.1.3	Surface caps constructed of asphalt concrete, Portland cement concrete, or flexible membrane liners prevent direct exposure to soil contaminants, control erosion, and reduce infiltration of stormwater into the subsurface, reducing the leaching of COCs to groundwater.	Full-Scale	Proven effective for preventing surface exposure to buried waste and for reducing infiltration of surface water through waste, limiting leaching of COCs to groundwater.	AOC-2, AOC-3, and AOC-4	VOCs, SVOCs, TPH, inorganics
Excavation/ Disposal	Excavation and Off-Site Disposal	6.1.2.1	Wastes exceeding site remediation goals are excavated and transported off site to an appropriate hazardous waste land disposal facility.	Full-Scale	Proven effective for all COCs.	Accessible soils in AOC-2, AOC-3, and AOC-4	VOCs, SVOCs, TPH, inorganics

Abbreviations:
AOC = Area of Concern
COCs = constituents of concern
SVOCs = semivolatile organic compounds
TPH = total petroleum hydrocarbons
VOCs = volatile organic compounds
ZVI = zero-valent iron

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TABLE 10

RATIONAL FOR RETENTION OF SOIL REMEDIATION TECHNOLOGIES FOR REMEMDIAL ALTERNATIVES

Stericycle Kent Facility
Kent, Washington

General Response Actions	Remediation Technologies	Section	Site-Specific Issues Affecting Technology or Implementation	Rationale for Retention or Rejection	Screening Result
In Situ Physical/Chemical Treatment	Chemical Oxidation	6.1.1.1	Handling of oxidant chemicals during remediation presents a safety concern. Chemical oxidant demand of soil can consume large quantities of oxidant (pilot test recommended). Establishing effective oxidant delivery system for even vadose zone distribution is difficult. Oxidants can mobilize some metals and may affect ongoing anaerobic biodegradation in the groundwater.	Not effective for some COCs, and high risk of mobilization of metals and cyanide. Very high cost of implementation compared to other technologies.	Reject
	Chemical Reduction	6.1.1.2	Handling of reducing chemicals during remediation presents a safety concern. Site groundwater chemistry is conducive to reductive processes, and the abundance of ferrous iron in site groundwater may prevent additional dissolution of inorganics to groundwater.	Not effective for all COCs in soil. Will immobilize some metals, and will enhance bioremediation conditions for organic COCs.	Retain
Containment	Cap/Surface Cover	6.1.1.3	The site is already largely covered in impervious surfaces in AOC-2, AOC-3, and AOC-4.	Would be effective in preventing exposure of workers at the facility to contaminated soils, and could potentially reduce migration of COCs into groundwater at the shallow water-bearing unit.	Retain
Excavation/Disposal	Excavation and Off-Site Disposal	6.1.2.1	Extensive shoring and support systems would be required for excavations near existing structures. Some impacted soils would likely remain in place due to the presence of existing structures/buildings.	Capable of addressing all contaminants in vadose zone soil at the site. Least administratively, logistically, and technically complex ex situ remediation technology. Potentially applicable to hot spots if site structures/buildings are removed.	Retain

Abbreviations:
AOC = Area of Concern
COC = constituents of concern

TABLE 11

GROUNDWWATER REMEDIATION TECHNOLOGIES CONSIDERED FOR INCORPORATION IN REMEDIAL ALTERNATIVES

Stericycle Kent Facility
Kent, Washington

General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Areas Addressed	Site Contaminants Addressed
In Situ Biological Treatment	Enhanced Anaerobic Biodegradation	6.2.1	A carbohydrate (e.g., molasses, sodium lactate, or proprietary blend) is injected into the affected groundwater to serve as an electron donor for indigenous organisms to enhance reductive biodegradation or precipitation/stabilization of metals. The carbohydrate may be combined with ZVI for very low redox conditions.	Full-Scale	Proven effective under proper conditions for degradation of chlorinated organics and precipitation of metals.	AOC-2, AOC-3, AOC-5, and 10-Day Hazardous Waste Transfer Yard	Vinyl chloride, arsenic, iron, and hexavalent chromium.
	Bioaugmentation	6.2.2	Injection of specialty, nonindigenous microbes to enhance biodegradation. Microorganisms are commercially available for both aerobic and anaerobic degradation of chlorinated organics. Commercially available microorganisms may be use to assist in stabilization of inorganics.	Full-Scale	Has been effective for biodegradation of chlorinated solvents, sulfate reduction, and metals stabilization. Requires application of specific microbial seed. May require repeated application.	AOC-2, AOC-3, AOC-5, and 10-Day Hazardous Waste Transfer Yard	Vinyl chloride, arsenic, iron.
	Monitored Natural Attenuation	6.2.3	Intrinsic attenuation of groundwater constituents via the natural processes of biodegradation (aerobic and/or anaerobic), adsorption, and dilution. This passive technology relies on natural conditions within impacted groundwater.	Full-Scale	Has been proven effective at sites with appropriate conditions.	AOC-2, AOC-3, AOC-5, and 10-Day Hazardous Waste Transfer Yard	Vinyl chloride, arsenic, iron, cyanide, and hexavalent chromium.
In Situ Physical/Chemical Treatment	Chemical Reduction	6.2.4	A reducing chemical such as hydrogen sulfide, hydrogen-releasing compound, ferrous sulfide or ZVI is added to the groundwater to chemically precipitate contaminants. Usually applied through injection wells or via direct-push technology. Some chemicals formulated for chemical reduction also promote biological degradation, such as emulsified ZVI.	Full-Scale	Can be effective depending on aquifer chemistry, tightness of formation, and number of injections.	AOC-2, AOC-3, AOC-5, and 10-Day Hazardous Waste Transfer Yard	Arsenic, iron, cyanide, and hexavalent chromium. May augment biodegradation of vinyl chloride.
	Chemical Oxidation	6.2.5	An oxidizing chemical (permanganate, hydrogen peroxide, Fentons Reagent, Regenox) is added to the groundwater to chemically oxidize contaminants. Usually applied through injection wells or via direct-push technology.	Full-Scale	Can be effective depending on oxidant demand of native material, tightness of formation, and number of injections. Not effective for most metals. May result in metals mobilization.	AOC-2, AOC-3, and AOC-5	Vinyl chloride, may reduce soluble iron and free cyanide.
	Passive/Reactive Treatment Barriers	6.2.6	Contaminant concentrations in groundwater are reduced as the groundwater flows through the permeable reactive barrier containing ZVI.	Full-Scale	Has been effectively used to reduce all groundwater COCs.	AOC-2, AOC-3, AOC-5, and 10-Day Hazardous Waste Transfer Yard	Vinyl chloride, arsenic, iron, cyanide, and hexavalent chromium.

Abbreviations
AOC = Area of Concern
COCs = constituents of concern
ZVI = zero-valent iron

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TABLE 12

RATIONALE FOR RETENTION OF GROUNDWATER REMEDIATION TECHNOLOGIES FOR REMEDIAL ALTERNATIVES

Stericycle Kent Facility
Kent, Washington

General Response Actions	Remediation Technologies	Section	Site-Specific Issues Affecting Technology or Implementation	Rationale for Retention or Rejection	Screening Result
In Situ Biological Treatment	Enhanced Anaerobic Biodegradation	6.2.1	Multiple injections of electron donor are typically required. Monitoring is required to confirm effectiveness.	May be useful to target small source areas for vinyl chloride and inorganics.	Retain
	Bioaugmentation	6.2.2	Nonindigenous organisms may not compete successfully with indigenous organisms. Vinyl chloride degradation is already occurring in groundwater. May be used in conjunction with enhanced biodegradation and in situ chemical reduction to address inorganics.	Bioaugmentation may be used if enhanced bioremediation is not meeting cleanup objectives for vinyl chloride and inorganics.	Retain
	Monitored Natural Attenuation	6.2.3	Natural biodegradation of vinyl chloride is active at the site. Potentially longer remediation times when compared to more active technologies.	Natural attenuation is a viable process and has been documented to be actively occurring at the site.	Retain
In Situ Physical/Chemical Treatment	Chemical Reduction	6.2.4	This technology would enhance naturally occurring anaerobic biodegradation occurring at the site. May be difficult to achieve effective reducing agent distribution in tight formations. Will immobilize all site COCs.	This technology has potential to immobilize all inorganic materials at the site under the appropriate geochemical conditions, and to accelerate the naturally occurring biodegradation of vinyl chloride.	Retain
	Chemical Oxidation	6.2.5	Active natural biological degradation of vinyl chloride would be inhibited by the addition of chemical oxidants. High reduced iron concentrations at the site would exert a large oxygen demand, affecting efficiency of treatment. May be difficult to obtain effective oxidant distribution in tight formations. May mobilize some metals.	Effective treatment may be limited due to the variable permeability in different groundwater zones and the high oxidant demand. May result in mobilization of reduced metals.	Reject
	Passive/Reactive Treatment Barriers	6.2.6	Would be difficult to build a passive/reactive barrier due to complex hydrogeology and seasonal groundwater flow fluctuations. Construction could interfere with activities at the facility.	May be useful in targeted locations or for contingency treatment if anaerobically biodegradable compounds or metals are recalcitrant.	Retain

Abbreviations
COCs = constituents of concern

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TABLE 13

SUMMARY OF RETAINED TECHNOLOGIES AND REMEDIAL ALTERNATIVES

Stericycle Kent Facility
Kent, Washington

General Response Actions	Remediation Technologies
Alternative 1: Monitored Natural Attenuation	
Containment, soil	Cap/Surface Cover
Excavation and Disposal, soil	Excavation and Off-Site Disposal
In Situ Biological Treatment, groundwater	Monitored Natural Attenuation
Alternative 2: Permeable Reactive Barriers	
Containment, soil	Cap/Surface Cover
Excavation and Disposal, soil	Excavation and Off-Site Disposal
In Situ Physical/Chemical Treatment, soil and groundwater	Passive/Reactive Treatment Barriers
	Enhanced Anaerobic Biodegradation
Alternative 3: In Situ Chemical Reduction	
Containment, soil	Cap/Surface Cover
Excavation and Disposal, soil	Excavation and Off-Site Disposal
In Situ Physical/Chemical Treatment, soil and groundwater	Chemical Reduction
	Enhanced Anaerobic Biodegradation

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TABLE 14

EVALUATION OF REMEDIAL ALTERNATIVES

Stericycle Kent Facility
Kent, Washington

	Alternative Rating[1]		
	1	**2**	**3**
Standards/Criteria[2]	**Monitored Natural Attenuation**	**Permeable Reactive Barriers**	**In Situ Chemical Reduction**
Protectiveness and Risk Reduction	2	3	4
Permanence	3	3	4
Cost	5	2	2
Long-term Effectiveness	3	3	3
Management of Short-Term Risks	4	3	3
Technical and Administrative Implementability	5	3	3
Public Concern	2	3	3
Restoration Time frame	2	3	4
TOTAL[2]	**26**	**23**	**26**

Notes:

1. Alternatives are rated from 5 to 1, with a rating of 5 indicating the highest or most favorable performance for that criterion.
2. In accordance with EPA guidance for each criterion and the MTCA regulations, all standards and/or criteria are considered equal; no weighting is given any individual criterion.

Abbreviations:

EPA = Environmental Protection Agency
MTCA = Model Toxics Control Act

TABLE 15

SUMMARY OF ESTIMATED COSTS FOR REMEDIAL ALTERNATIVES

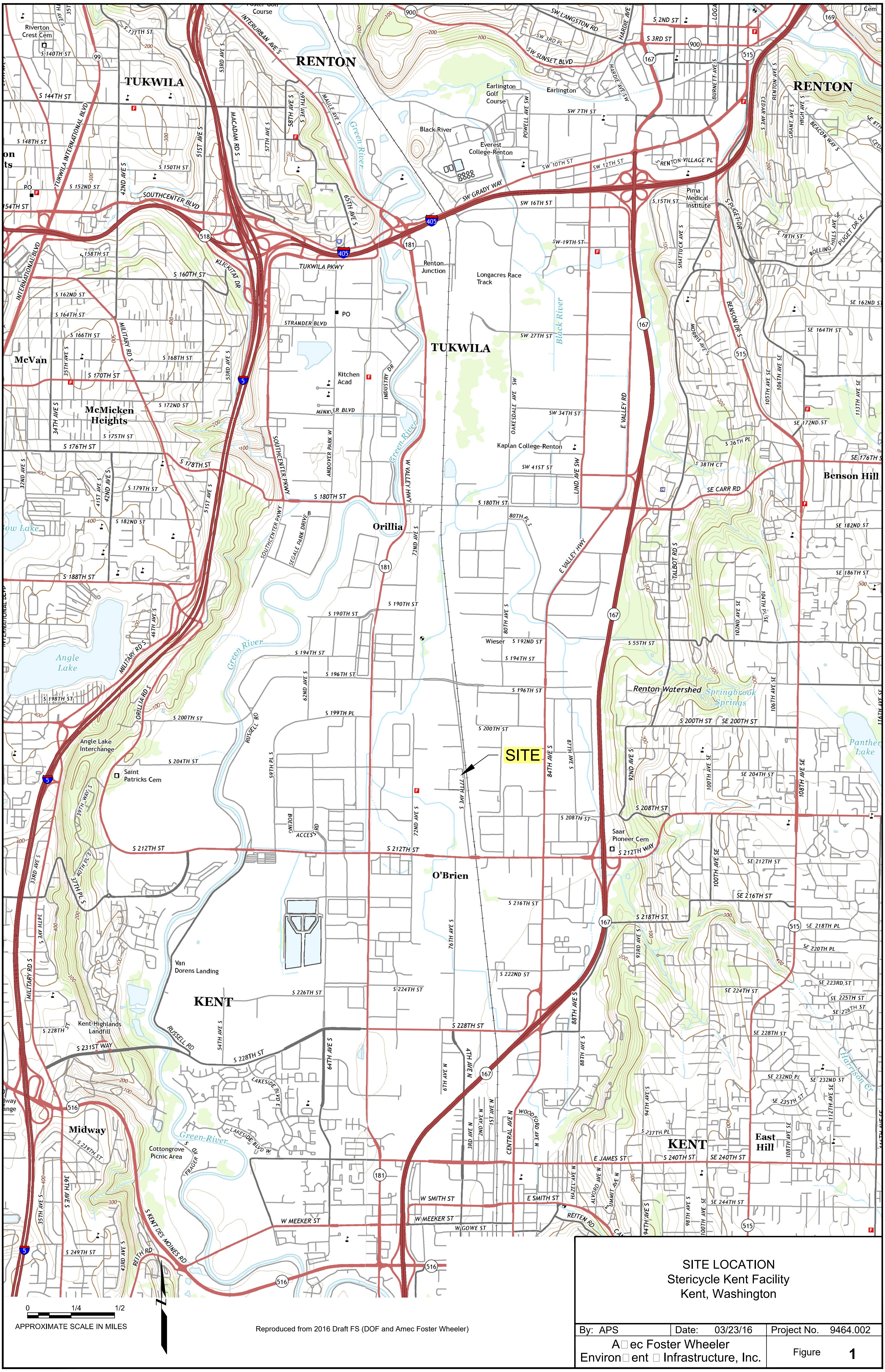
Stericycle Kent Facility
Kent, Washington

Alternative	Implementation Cost	Net Present Value Cost
A-1: Monitored Natural Attenuation	$70,000	$550,000
A-2: Permeable Reactive Barriers	$430,000	$910,000
A-3: In Situ Chemical Reduction	$780,000	$1,210,000

<u>Abbreviations</u>
ISCR = in situ chemical reduction
MNA = monitored natural attenuation
PRB = permeable reactive barrier

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

FIGURES



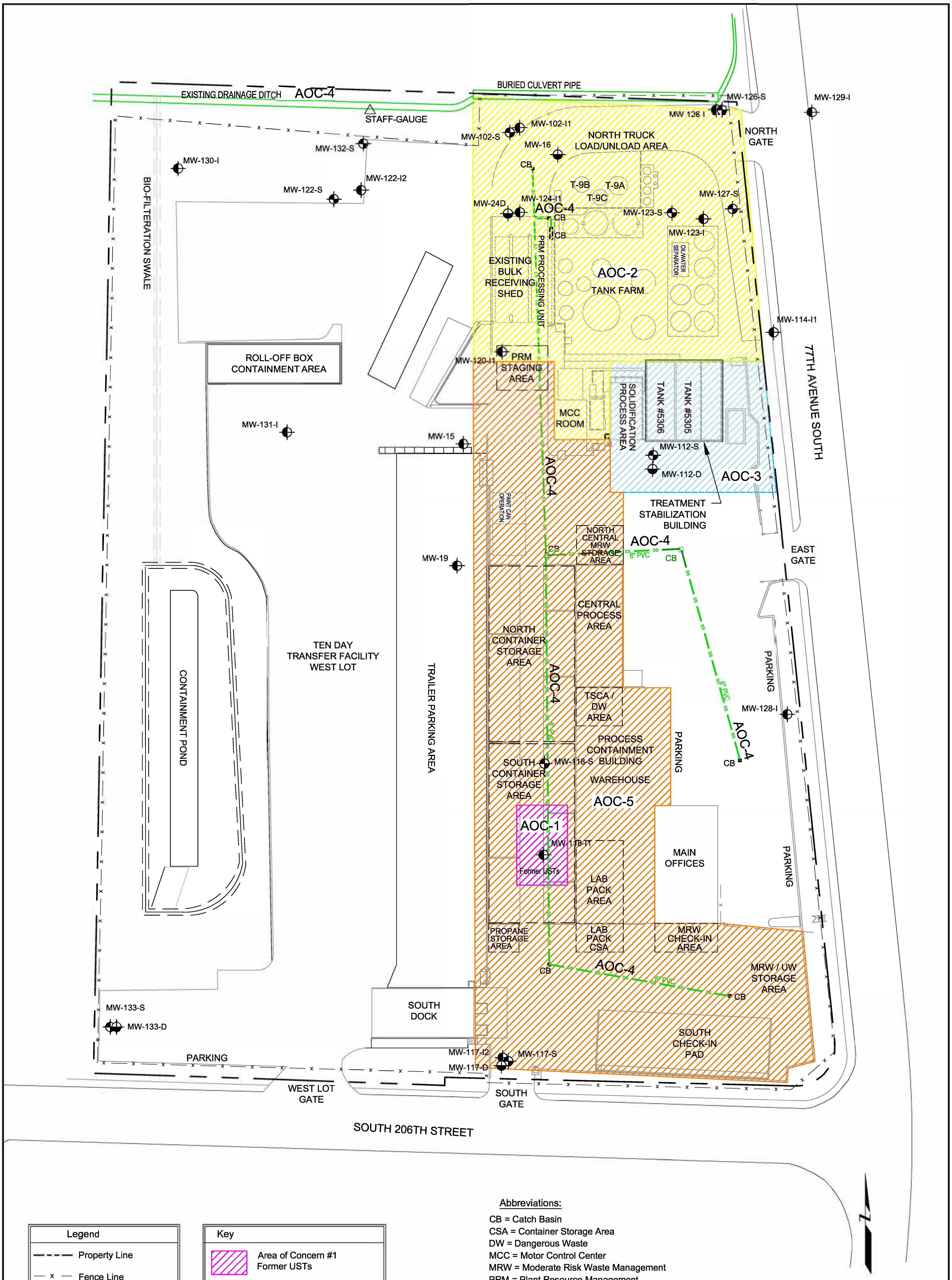
Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

SITE LOCATION
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002

Amec Foster Wheeler
Environment & Infrastructure, Inc.

Figure 1



Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

0 30 60
APPROXIMATE SCALE IN FEET

Legend

- — - — Property Line
- — x — Fence Line
- ⊕ Shallow Monitoring Well
- ⊕ Intermediate Aquifer Monitoring Well
- ⊕ Deep Aquifer Monitoring Well
- ▪ CB Catch Basin

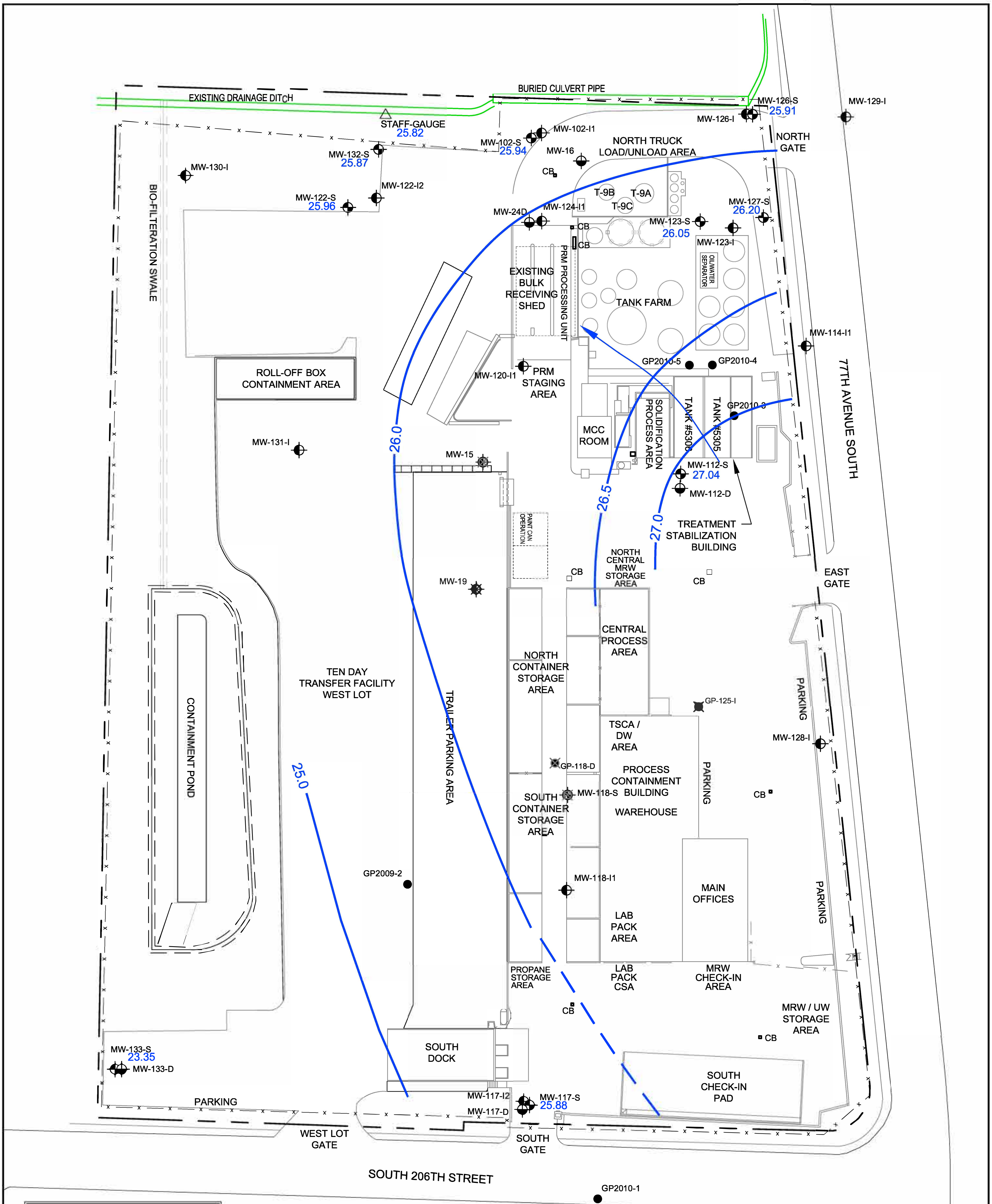
Key

- ▨ Area of Concern #1 Former USTs
- ▨ Area of Concern #2 Tank Farm Area
- ▨ Area of Concern #3 Stabilization Area
- — ss — Area of Concern #4 Stormwater Drainage System
- ▨ Area of Concern #5 Process and Storage Area

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

SITE LAYOUT
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 2



Legend

Property Line

Fence Line

Shallow Monitoring Well

Intermediate Aquifer Monitoring Well

Deep Aquifer Monitoring Well

● Direct Push Boring

Abandoned Monitoring Well / Boring

▪CB Catch Basin

23.35 Groundwater Elevation (NAVD-88-Feet)

Groundwater Elevation Contour (Dashed where inferred)

General Direction of Groundwater Flow

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

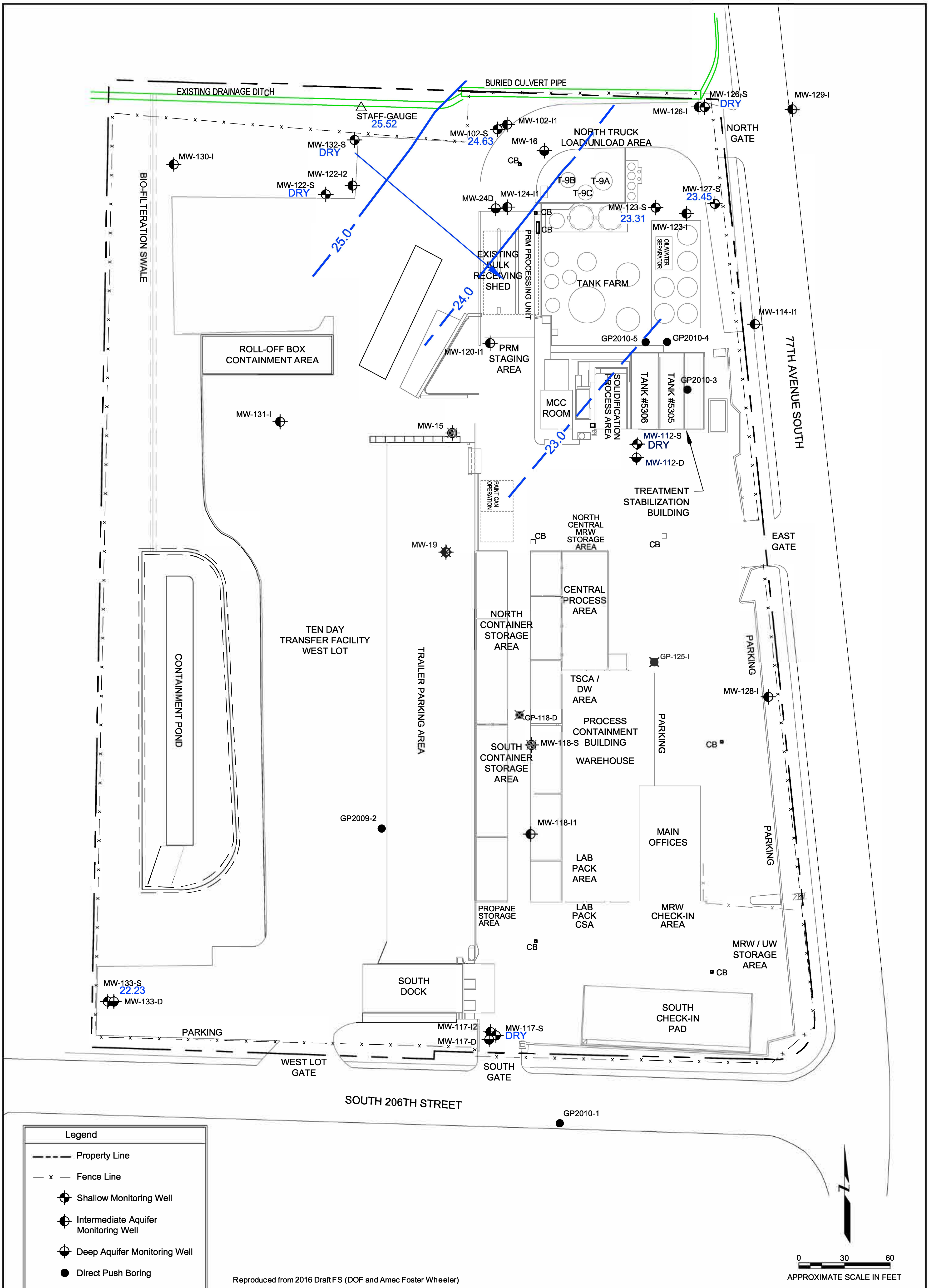
Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

0 30 60
APPROXIMATE SCALE IN FEET

SHALLOW WATER-BEARING UNIT
GROUNDWATER ELEVATIONS
APRIL 7, 2014
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 3



Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

Legend

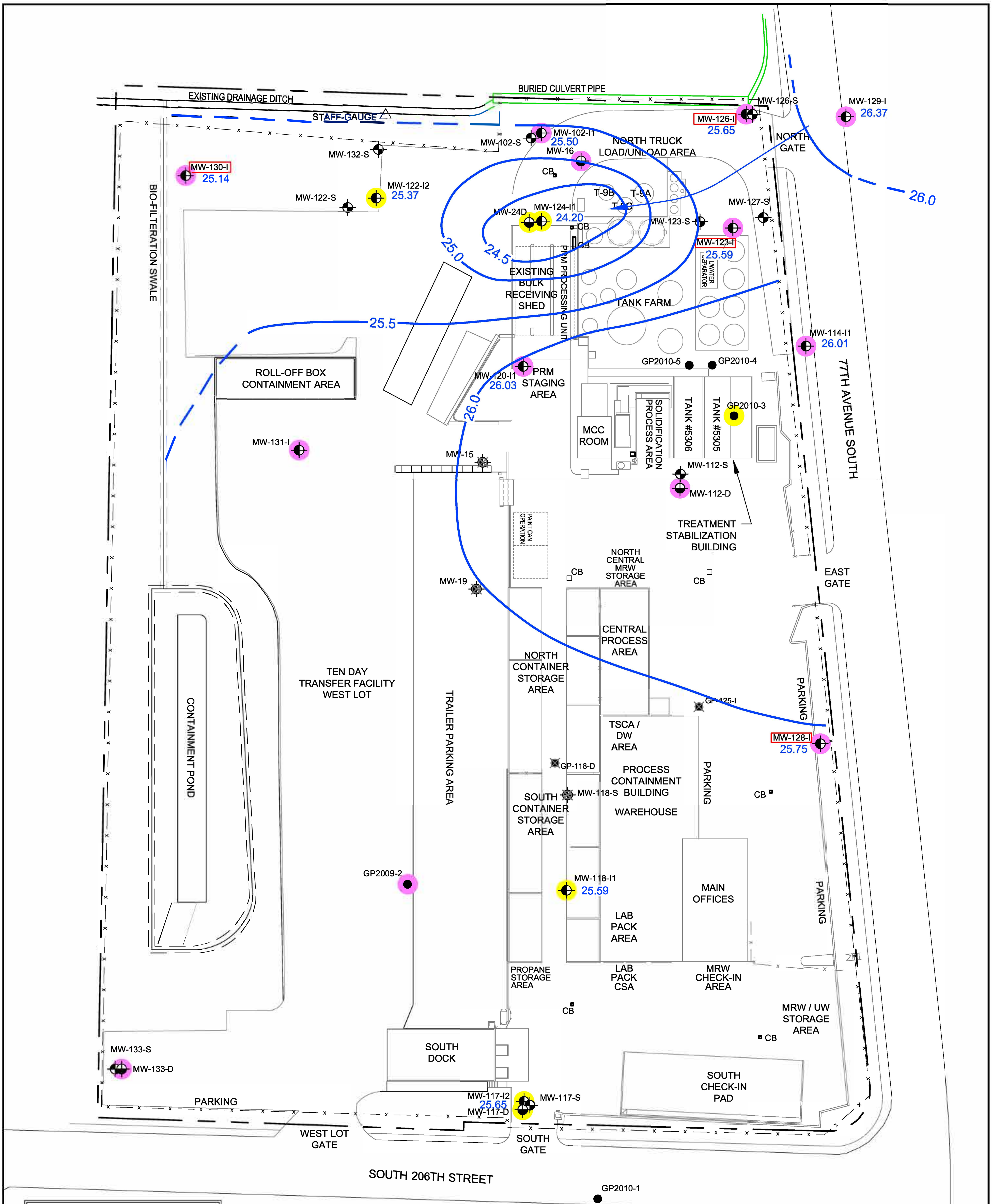
— — —	Property Line
— x —	Fence Line
⊕	Shallow Monitoring Well
⊕	Intermediate Aquifer Monitoring Well
⊕	Deep Aquifer Monitoring Well
●	Direct Push Boring
⊠	Abandoned Monitoring Well / Boring
▪ CB	Catch Basin
22.23	Groundwater Elevation (NAVD-88-Feet)
~	Groundwater Elevation Contour (Dashed where inferred)
←	General Direction of Groundwater Flow

Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

SHALLOW WATER-BEARING UNIT
GROUNDWATER ELEVATIONS
OCTOBER 6, 2014
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 4



Legend

- — — Property Line
- — x — Fence Line
- ⊕ Shallow Monitoring Well
- ⊕ Intermediate Aquifer Monitoring Well
- ⊕ Deep Aquifer Monitoring Well
- ● Direct Push Boring
- ⊠ Abandoned Monitoring Well / Boring
- ▪ CB Catch Basin
- 25.59 Groundwater Elevation (NAVD-88-Feet)
- ∼ Groundwater Elevation Contour (Dashed where inferred)
- ← General Direction of Groundwater Flow

Key

- 🟡 Missing Silt/Clay layer between Intermediate Aquifer A and Intermediate Aquifer B.
- 🟣 Contains Silt Layer between two Intermediate Aquifers.
- ☐ Screened in Intermediate "B" Aquifer
- * Shallow Wells were not used to determine if Silt Layer was present.

Abbreviations:

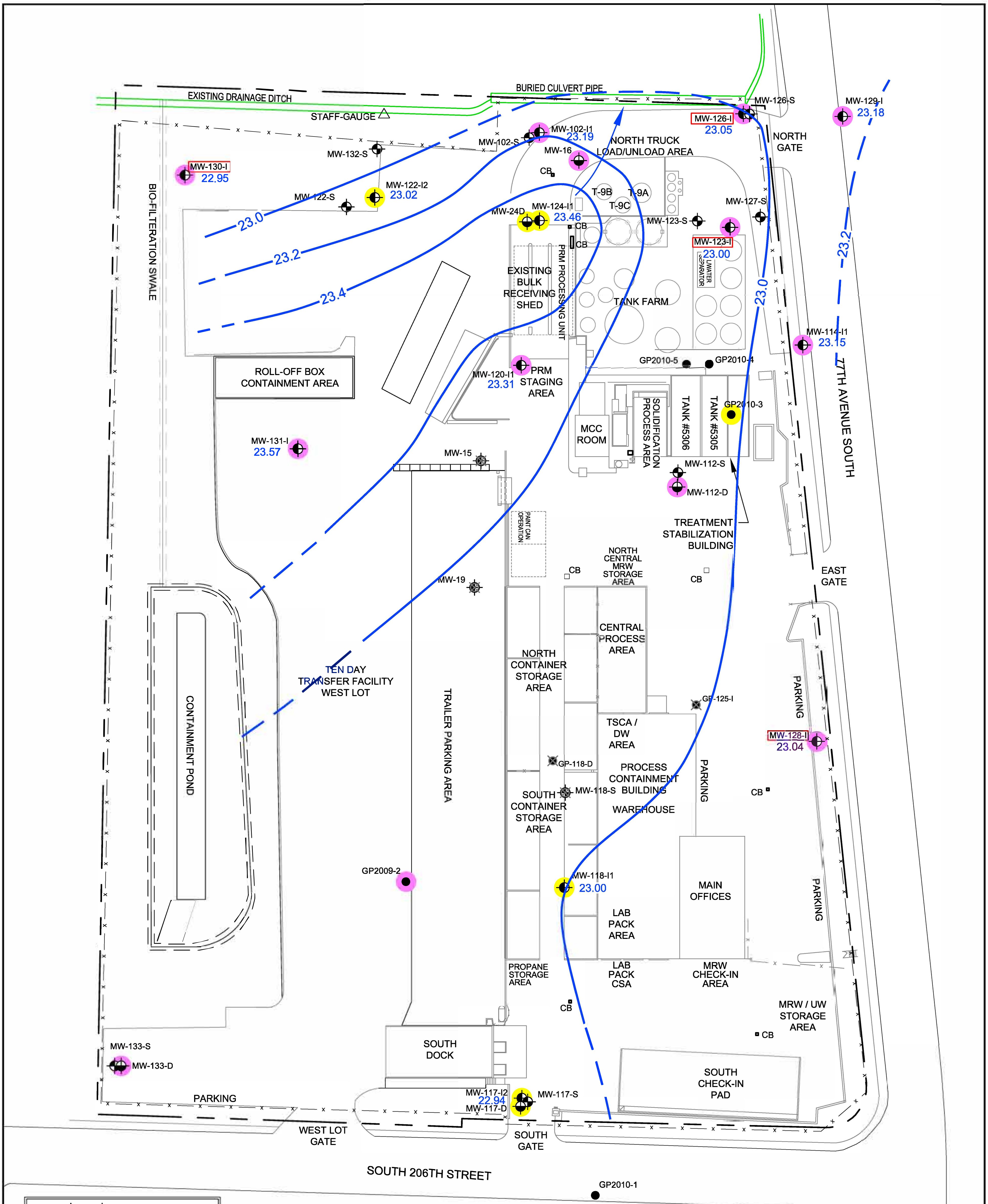
CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

0 30 60
APPROXIMATE SCALE IN FEET

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

INTERMEDIATE AQUIFER
GROUNDWATER ELEVATIONS
APRIL 7, 2014
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 5



N

0 30 60
APPROXIMATE SCALE IN FEET

Legend

— — —	Property Line
—x—	Fence Line
⊕	Shallow Monitoring Well
⊕	Intermediate Aquifer Monitoring Well
⊕	Deep Aquifer Monitoring Well
●	Direct Push Boring
⊠	Abandoned Monitoring Well / Boring
▪ CB	Catch Basin
22.94	Groundwater Elevation (NAVD-88-Feet)
∼	Groundwater Elevation Contour (Dashed where inferred)
←	General Direction of Groundwater Flow

Key

●	Missing Silt/Clay layer between Intermediate Aquifer A and Intermediate Aquifer B.
●	Contains Silt Layer between two Intermediate Aquifers.
▭	Screened in Intermediate "B" Aquifer

* Shallow Wells were not used to determine if Silt Layer was present.

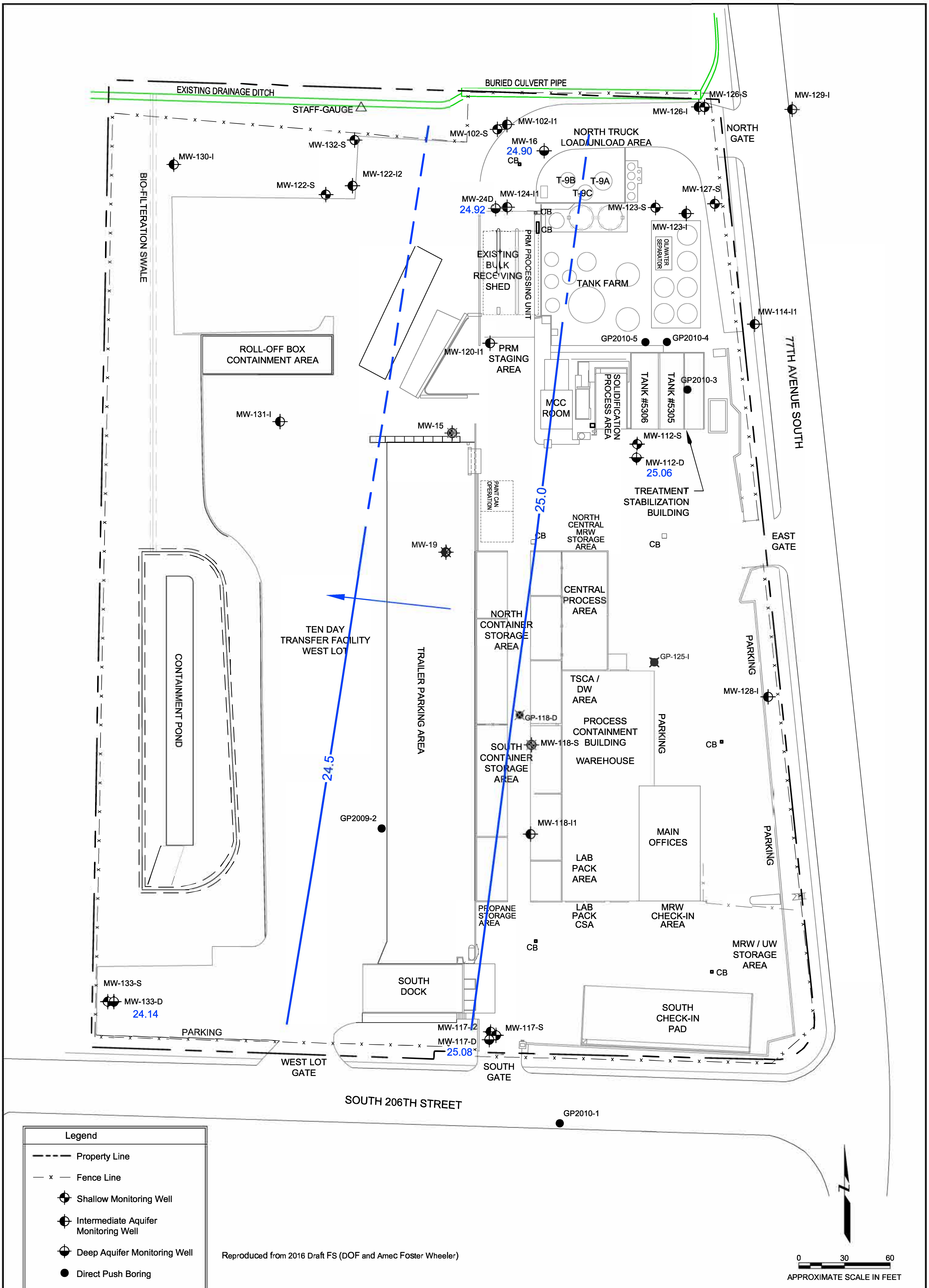
Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

INTERMEDIATE AQUIFER
GROUNDWATER ELEVATIONS
OCTOBER 6, 2014
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 6



Legend

- Property Line
- Fence Line
- Shallow Monitoring Well
- Intermediate Aquifer Monitoring Well
- Deep Aquifer Monitoring Well
- ● Direct Push Boring
- Abandoned Monitoring Well / Boring
- CB Catch Basin
- 24.14 Groundwater Elevation (NAVD-88-Feet)
- Groundwater Elevation Contour (Dashed where inferred)
- General Direction of Groundwater Flow

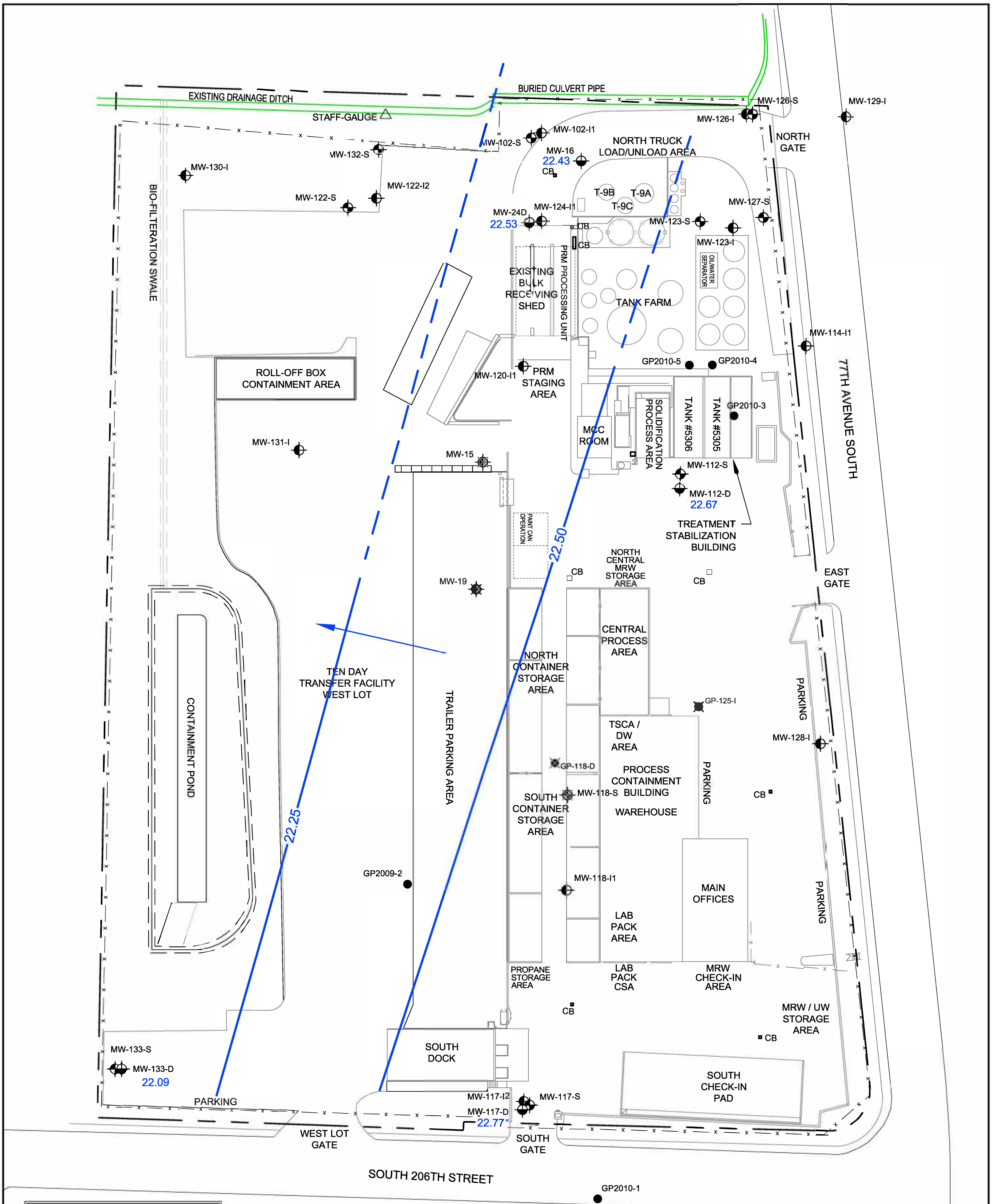
Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

DEEP AQUIFER
GROUNDWATER ELEVATIONS
APRIL 7, 2014
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 7



Legend

- Property Line
- Fence Line
- Shallow Monitoring Well
- Intermediate Aquifer Monitoring Well
- Deep Aquifer Monitoring Well
- ● Direct Push Boring
- Abandoned Monitoring Well / Boring
- CB Catch Basin
- 22.09 Groundwater Elevation (NAVD-88-Feet)
- Groundwater Elevation Contour (Dashed where inferred)
- General Direction of Groundwater Flow

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

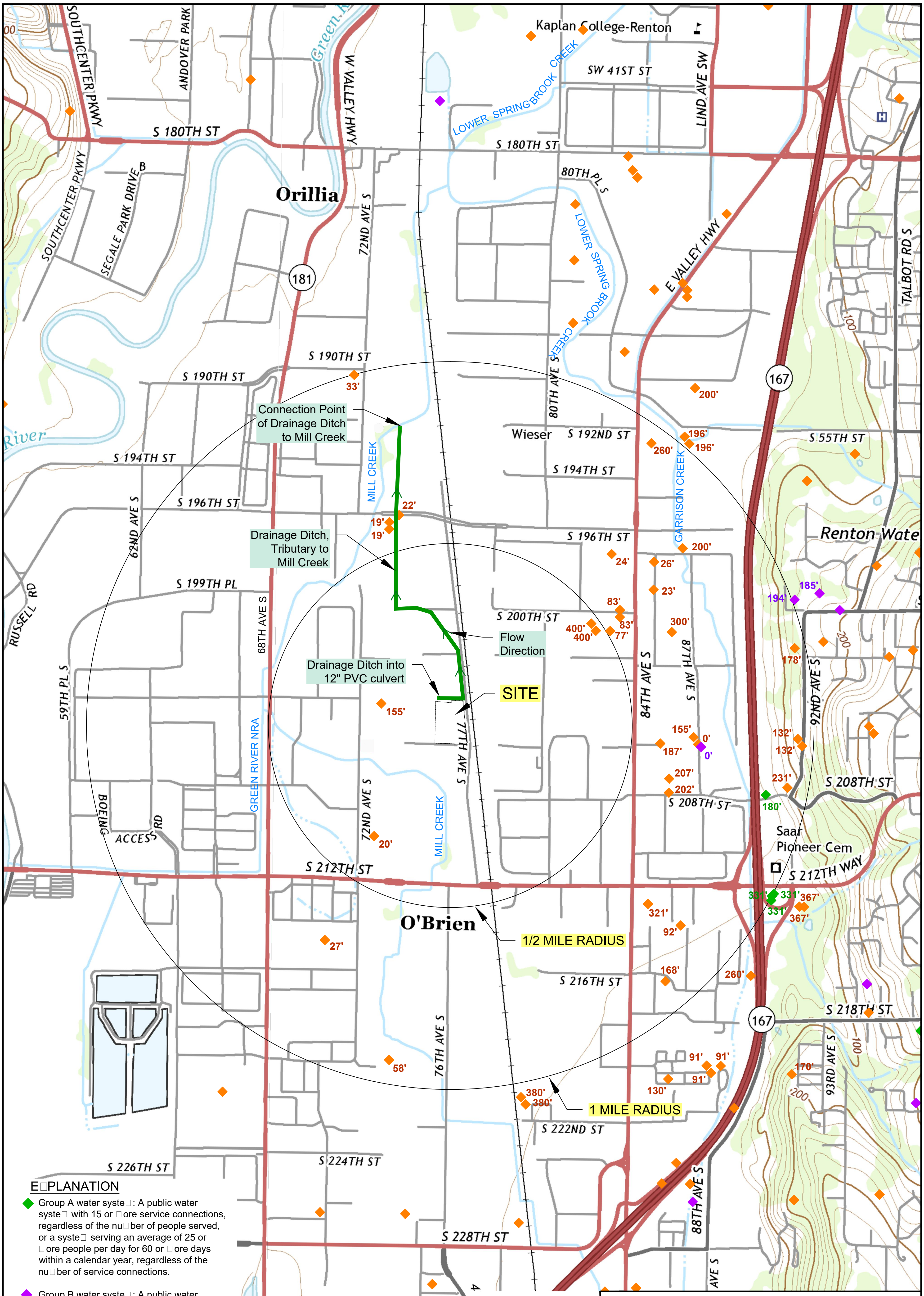
0 30 60
APPROXIMATE SCALE IN FEET

Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

DEEP AQUIFER
GROUNDWATER ELEVATIONS
OCTOBER 6, 2014
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 8



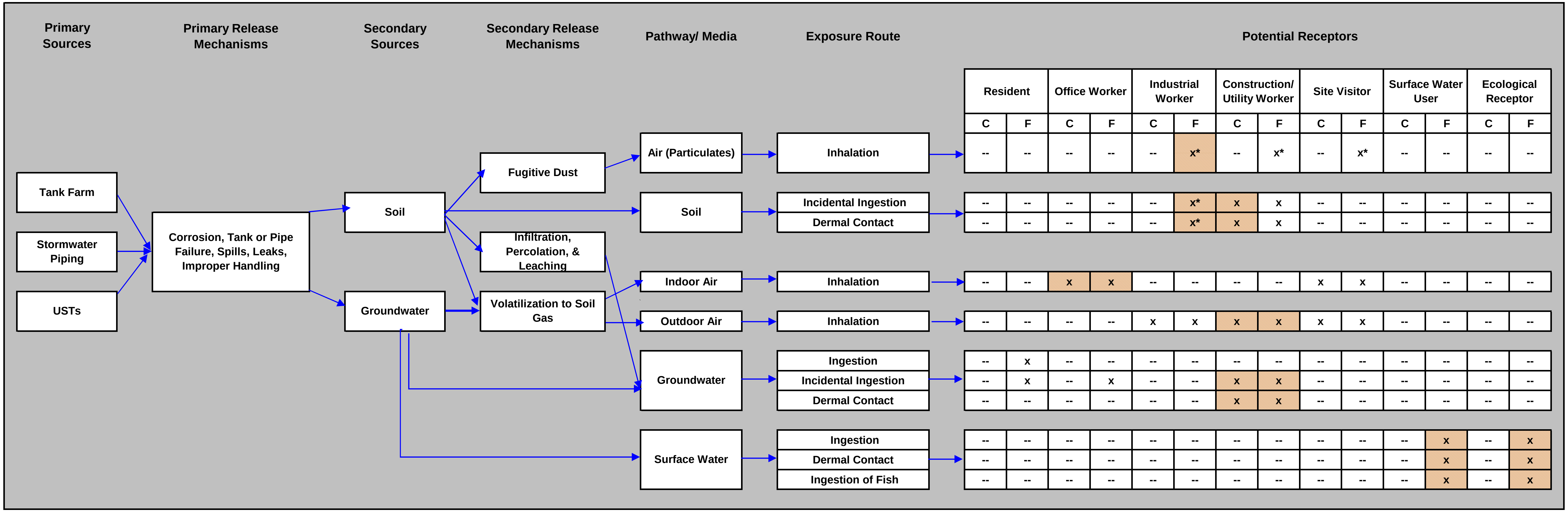
Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

EXPLANATION

- Group A water system: A public water system with 15 or more service connections, regardless of the number of people served, or a system serving an average of 25 or more people per day for 60 or more days within a calendar year, regardless of the number of service connections.
- Group B water system: A public water system which is not a Group A system, with less than 15 service connections and serving an average of less than 25 people for 60 or more days within a calendar year, or any number of people for less than sixty days within a calendar year.
- Group D water system: Includes service to single household.
- 27' Total depth of well in feet

KING COUNTY
GROUNDWATER SUPPLY WELL LOCATIONS
AND DRAINAGE DITCH CONNECTION POINT
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 9



Pathway/ Media	Exposure Route	Resident		Office Worker		Industrial Worker		Construction/ Utility Worker		Site Visitor		Surface Water User		Ecological Receptor	
		C	F	C	F	C	F	C	F	C	F	C	F	C	F
Air (Particulates)	Inhalation	--	--	--	--	--	▨x*	--	x*	--	x*	--	--	--	--
Soil	Incidental Ingestion	--	--	--	--	--	▨x*	▨x	x	--	--	--	--	--	--
	Dermal Contact	--	--	--	--	--	▨x*	▨x	x	--	--	--	--	--	--
Indoor Air	Inhalation	--	--	▨x	▨x	--	--	--	--	x	x	--	--	--	--
Outdoor Air	Inhalation	--	--	--	--	x	x	▨x	▨x	x	x	--	--	--	--
Groundwater	Ingestion	--	x	--	--	--	--	--	--	--	--	--	--	--	--
	Incidental Ingestion	--	x	--	x	--	--	▨x	▨x	--	--	--	--	--	--
	Dermal Contact	--	--	--	--	--	--	▨x	▨x	--	--	--	--	--	--
Surface Water	Ingestion	--	--	--	--	--	--	--	--	--	--	--	▨x	--	▨x
	Dermal Contact	--	--	--	--	--	--	--	--	--	--	--	▨x	--	▨x
	Ingestion of Fish	--	--	--	--	--	--	--	--	--	--	--	▨x	--	▨x

KEY

→	Potential Transport or Exposure Pathway
--	Incomplete Exposure Pathway
x	Potentially Complete Exposure Pathway
▨x	Most highly exposed receptor
*	Assumes cap removed in the future
C	Current land use
F	Future land use

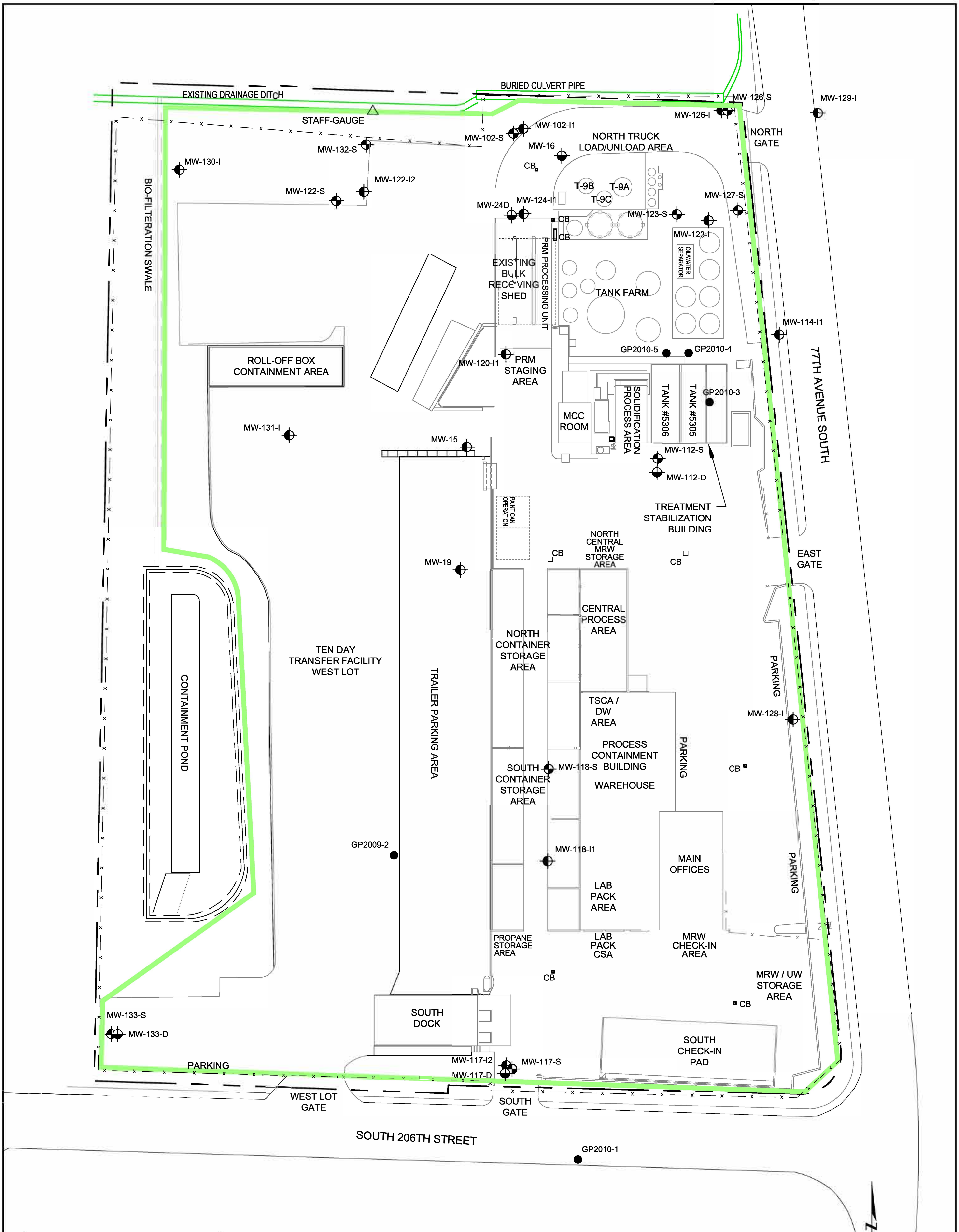
USTs =Underground Storage Tanks

Note: Indoor air was considered a potentially complete pathway from contaminated soil or groundwater and therefore csreening levels protective of this pathway were used in developing the FS.

Revised 06/06/17 by DOF to add footnote per Ecology comment.

CONCEPTUAL SITE MODEL
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/14/16	Project No.: 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure **10**



Legend

— — Property Line

— x — Fence Line

⊕ Shallow Monitoring Well

⊕ Intermediate Aquifer Monitoring Well

⊕ Deep Aquifer Monitoring Well

● 2009-10 Date Gaps Investigation Direct Push Location

🟩 Potential Conditional Point of Compliance

▪ CB Catch Basin

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

Abbreviations:

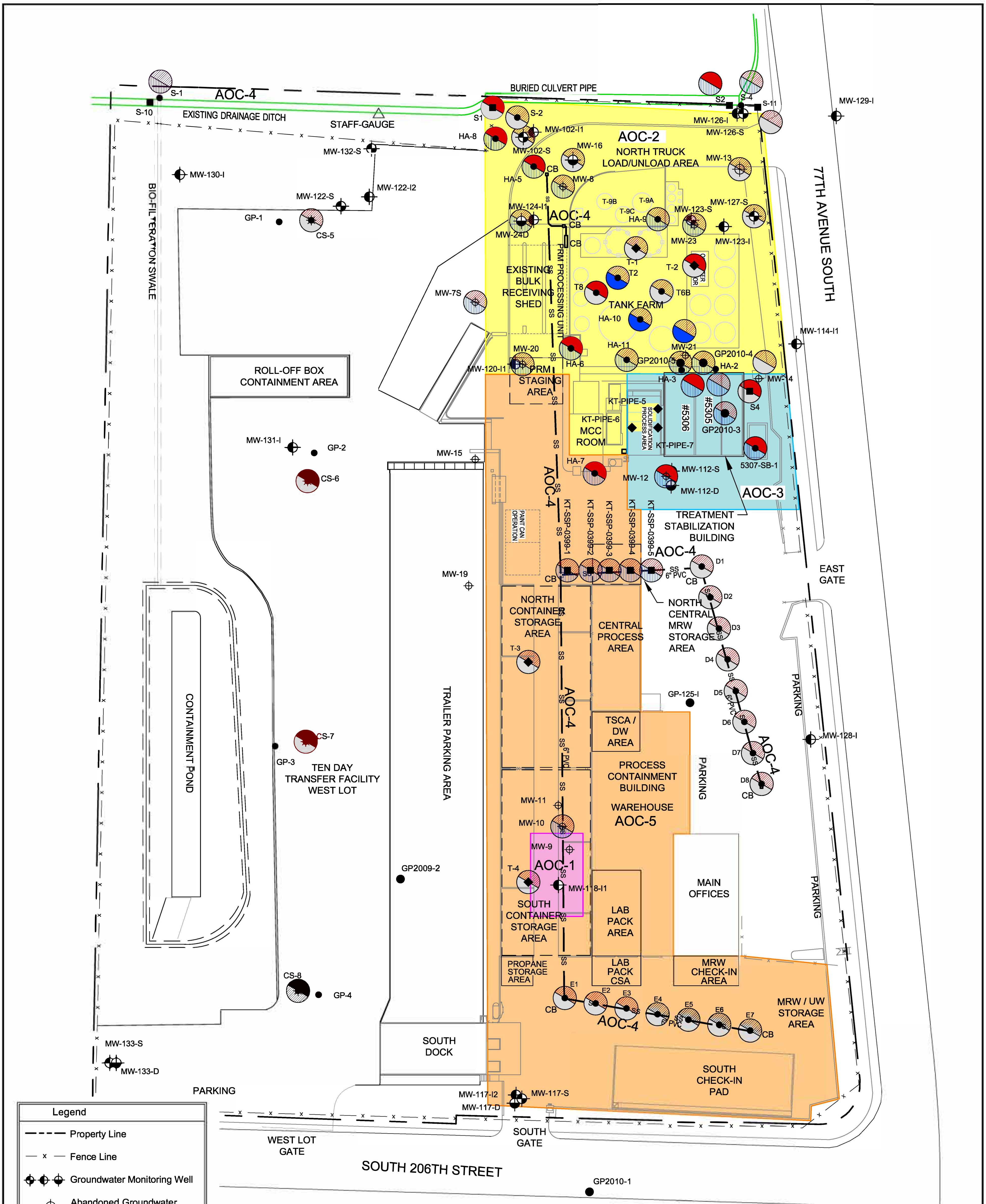
CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

PROPOSED GROUNDWATER
CONDITIONAL POINT OF COMPLIANCE LOCATION
Stericycle Kent Facility
Kent, Washington

By: APS
Date: 03/23/16
Project No. 9464.002

Amec Foster Wheeler
Environment & Infrastructure, Inc.

Figure 11



Legend

- ---- Property Line
- —x— Fence Line
- ⯐ ⯐ ⯐ Groundwater Monitoring Well
- ⊕ Abandoned Groundwater Monitoring Well
- ✸ Composite Soil Sample
- ● ■ ◆ Soil Sample
- ▪ CB Catch Basin
- — ss — Stormwater Drainage System

Key

- Area of Concern #1 Former USTs
- Area of Concern #2 Tank Farm Area
- Area of Concern #3 Stabilization Area
- — ss — Area of Concern #4 Stormwater Drainage System
- Area of Concern #5 Process and Storage Area

EXPLANATION

- ARSENIC SOIL CONCENTRATION ABOVE FS CLEANUP LEVEL
- ARSENIC SOIL CONCENTRATION BELOW FS CLEANUP LEVEL
- CYANIDE SOIL CONCENTRATION ABOVE FS CLEANUP LEVEL
- CYANIDE SOIL CONCENTRATION BELOW FS CLEANUP LEVEL
- NO SOIL SAMPLE COLLECTED

CYANIDE
FS CLEANUP LEVEL
0.2 mg/kg

ARSENIC
FS CLEANUP LEVEL
7.3 mg/kg

NOTES:

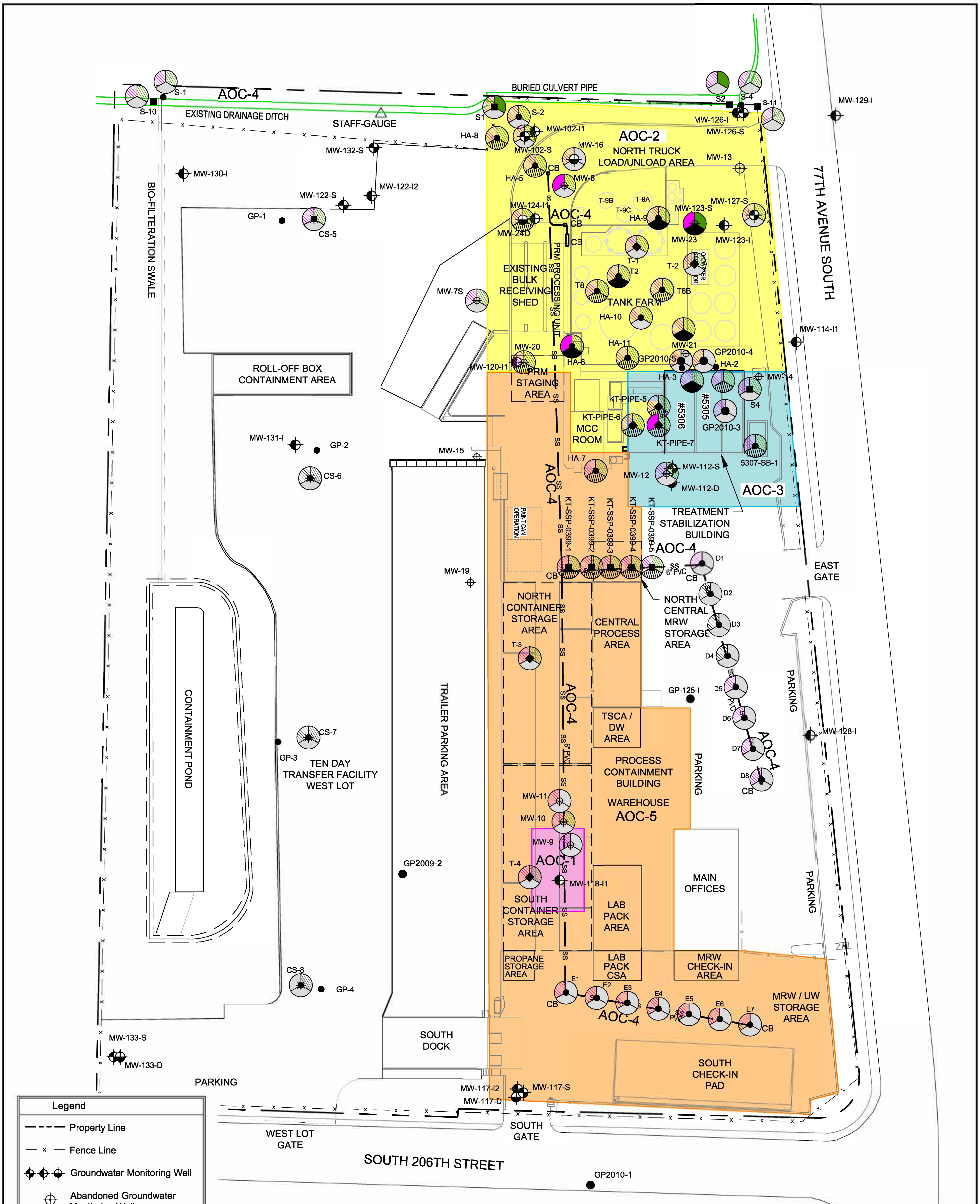
AT LOCATIONS OF OVERLAPPING SOIL SAMPLES, THE PIE HIGHLIGHT WAS MOVED OFF LOCATION FOR CLARITY.

SEE FIGURE 11 FOR ABBREVIATION DEFINITIONS.

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

INORGANIC ANALYTES IN SOIL
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 04/01/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 12



Legend

- Property Line
- Fence Line
- Groundwater Monitoring Well
- Abandoned Groundwater Monitoring Well
- Composite Soil Sample
- Soil Sample
- CB Catch Basin
- SS Stormwater Drainage System

Key

🟪	Area of Concern #1 Former USTs
🟨	Area of Concern #2 Tank Farm Area
🟦	Area of Concern #3 Stabilization Area
SS	Area of Concern #4 Stormwater Drainage System
🟧	Area of Concern #5 Process and Storage Area

EXPLANATION

◗	BENZENE SOIL CONCENTRATION ABOVE FS CLEANUP LEVEL
▨	BENZENE SOIL CONCENTRATION BELOW FS CLEANUP LEVEL
◗	CHRYSENE SOIL CONCENTRATION ABOVE FS CLEANUP LEVEL
▨	CHRYSENE SOIL CONCENTRATION BELOW FS CLEANUP LEVEL
◗	GASOLINE SOIL CONCENTRATION ABOVE FS CLEANUP LEVEL
▨	GASOLINE SOIL CONCENTRATION BELOW FS CLEANUP LEVEL
○	NO SOIL SAMPLE COLLECTED

BENZENE
FS CLEANUP LEVEL
0.00843 mg/kg

CHRYSENE
FS CLEANUP LEVEL
0.796 mg/kg

GASOLINE
FS CLEANUP LEVEL
30 mg/kg

NOTES:

AT LOCATIONS OF OVERLAPPING SOIL SAMPLES, THE PIE HIGHLIGHT WAS MOVED OFF LOCATION FOR CLARITY.

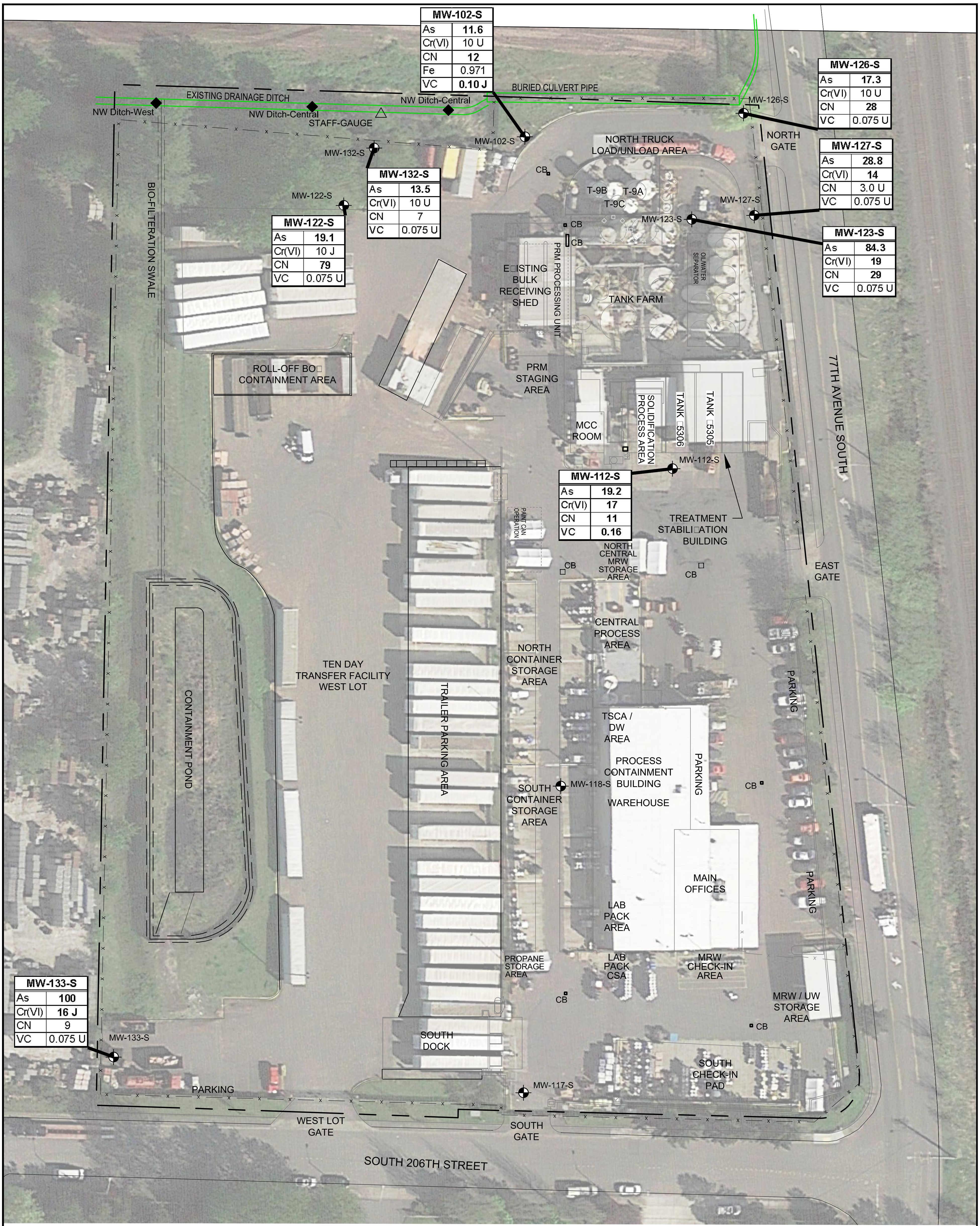
SEE FIGURE 11 FOR ABBREVIATION DEFINITIONS.

0 30 60
APPROXIMATE SCALE IN FEET

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

SELECT ORGANIC ANALYTES IN SOIL
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 04/01/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 13



Key		FS Cleanup Level
As	Arsenic	10.5 (µg/L)
Cr(VI)	Chromium (Hexavalent)	10 (µg/L)
CN	Cyanide	10 (µg/L)
Fe	Total Iron	24.5 (mg/L)
VC	Vinyl Chloride	0.025 (µg/L)

Notes:

1. Non-detect values are reported at method detection limit.
2. **BOLD** indicates FS cleanup level exceedance.

Legend	
— — —	Property Line
—— ▫ ——	Fence line
⊕	Shallow Monitoring Well
◆	Surface Water Sample
▪ CB	Catch Basin

Abbreviations:

CB □ Catch Basin
CSA □ Container Storage Area
DW □ Dangerous Waste
MCC □ Motor Control Center
MRW □ Moderate Risk Waste Management
PRM □ Plant Resource Management
TSCA □ Toxic Substances Control Act
UST □ Underground Storage Tank
UW □ Unidentified Waste

N

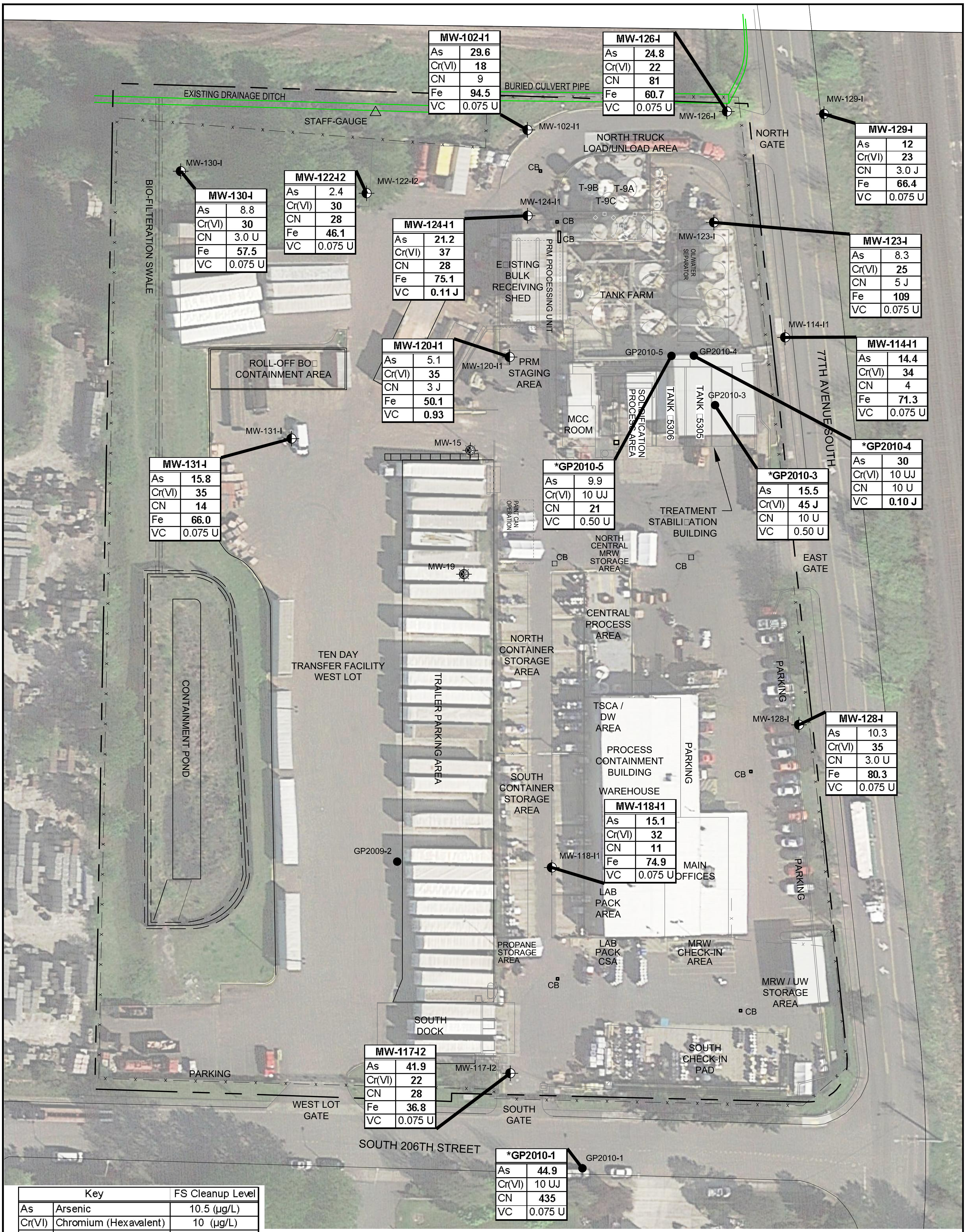
Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

0 30 60

APPROXIMATE SCALE IN FEET

HIGHEST ANALYTE CONCENTRATIONS IN
SHALLOW WATER-BEARING UNIT
2010 to 2015
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 04/01/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 14



MW-102-I1	
As	**29.6**
Cr(VI)	**18**
CN	9
Fe	**94.5**
VC	0.075 U

MW-126-I	
As	**24.8**
Cr(VI)	**22**
CN	**81**
Fe	**60.7**
VC	0.075 U

MW-129-I	
As	**12**
Cr(VI)	**23**
CN	3.0 J
Fe	**66.4**
VC	0.075 U

MW-130-I	
As	8.8
Cr(VI)	**30**
CN	3.0 U
Fe	**57.5**
VC	0.075 U

MW-122-I2	
As	2.4
Cr(VI)	**30**
CN	**28**
Fe	**46.1**
VC	0.075 U

MW-124-I1	
As	**21.2**
Cr(VI)	**37**
CN	**28**
Fe	**75.1**
VC	**0.11 J**

MW-123-I	
As	8.3
Cr(VI)	**25**
CN	5 J
Fe	**109**
VC	0.075 U

MW-114-I1	
As	**14.4**
Cr(VI)	**34**
CN	4
Fe	**71.3**
VC	0.075 U

MW-120-I1	
As	5.1
Cr(VI)	**35**
CN	3 J
Fe	**50.1**
VC	**0.93**

*GP2010-4	
As	**30**
Cr(VI)	10 UJ
CN	10 U
VC	**0.10 J**

*GP2010-5	
As	9.9
Cr(VI)	10 UJ
CN	**21**
VC	0.50 U

*GP2010-3	
As	**15.5**
Cr(VI)	**45 J**
CN	10 U
VC	0.50 U

MW-131-I	
As	**15.8**
Cr(VI)	**35**
CN	**14**
Fe	**66.0**
VC	0.075 U

MW-128-I	
As	10.3
Cr(VI)	**35**
CN	3.0 U
Fe	**80.3**
VC	0.075 U

MW-118-I1	
As	**15.1**
Cr(VI)	**32**
CN	**11**
Fe	**74.9**
VC	0.075 U

MW-117-I2	
As	**41.9**
Cr(VI)	**22**
CN	**28**
Fe	**36.8**
VC	0.075 U

*GP2010-1	
As	**44.9**
Cr(VI)	10 UJ
CN	**435**
VC	0.075 U

	Key	FS Cleanup Level
As	Arsenic	10.5 (µg/L)
Cr(VI)	Chromium (Hexavalent)	10 (µg/L)
CN	Cyanide	10 (µg/L)
Fe	Total Iron	24.5 (mg/L)
VC	Vinyl Chloride	0.025 (µg/L)

Notes:

1. Non-detect values are reported at method detection limit.
2. **BOLD** indicates FS cleanup level exceedance.
3. *GP2010-# are grab groundwater samples collected by a direct push rig and were only sampled in 2010.

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

Legend	
— — —	Property Line
—x—	Fence line
⊕	Intermediate Aquifer Monitoring Well
●	Direct Push Boring
▫ CB	Catch Basin

Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

N

0 30 60
APPROXIMATE SCALE IN FEET

HIGHEST ANALYTE CONCENTRATIONS IN
INTERMEDIATE AQUIFER
2010 to 2015
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 04/01/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 15

MW-16	
As	6.6
Cr(VI)	**23**
CN	**12**
Fe	**39.9**
VC	0.075 U

MW-24D	
As	2.1
Cr(VI)	**27**
CN	**56**
Fe	**50.9**
VC	0.075 U

MW-112-D	
As	2.1
Cr(VI)	**32**
CN	**36**
Fe	**52.7**
VC	0.075 U

MW-133-D	
As	5.4
Cr(VI)	**21**
CN	3.0 U
Fe	**30.3**
VC	0.075 U

MW-117-D	
As	1.8
Cr(VI)	**21**
CN	**30**
Fe	21.4
VC	0.075 U

Key		FS Cleanup Level
As	Arsenic	10.5 (µg/L)
Cr(VI)	Chromium (Hexavalent)	10 (µg/L)
CN	Cyanide	10 (µg/L)
Fe	Total Iron	24.5 (mg/L)
VC	Vinyl Chloride	0.025 (µg/L)

Notes:

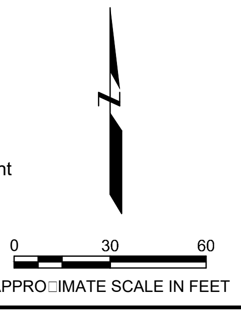
1. Non-detect values are reported at method detection limit.
2. **BOLD** indicates FS cleanup level exceedance.

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

Legend	
— — —	Property Line
— x —	Fence line
⊕	Deep Aquifer Monitoring Well
▪ CB	Catch Basin

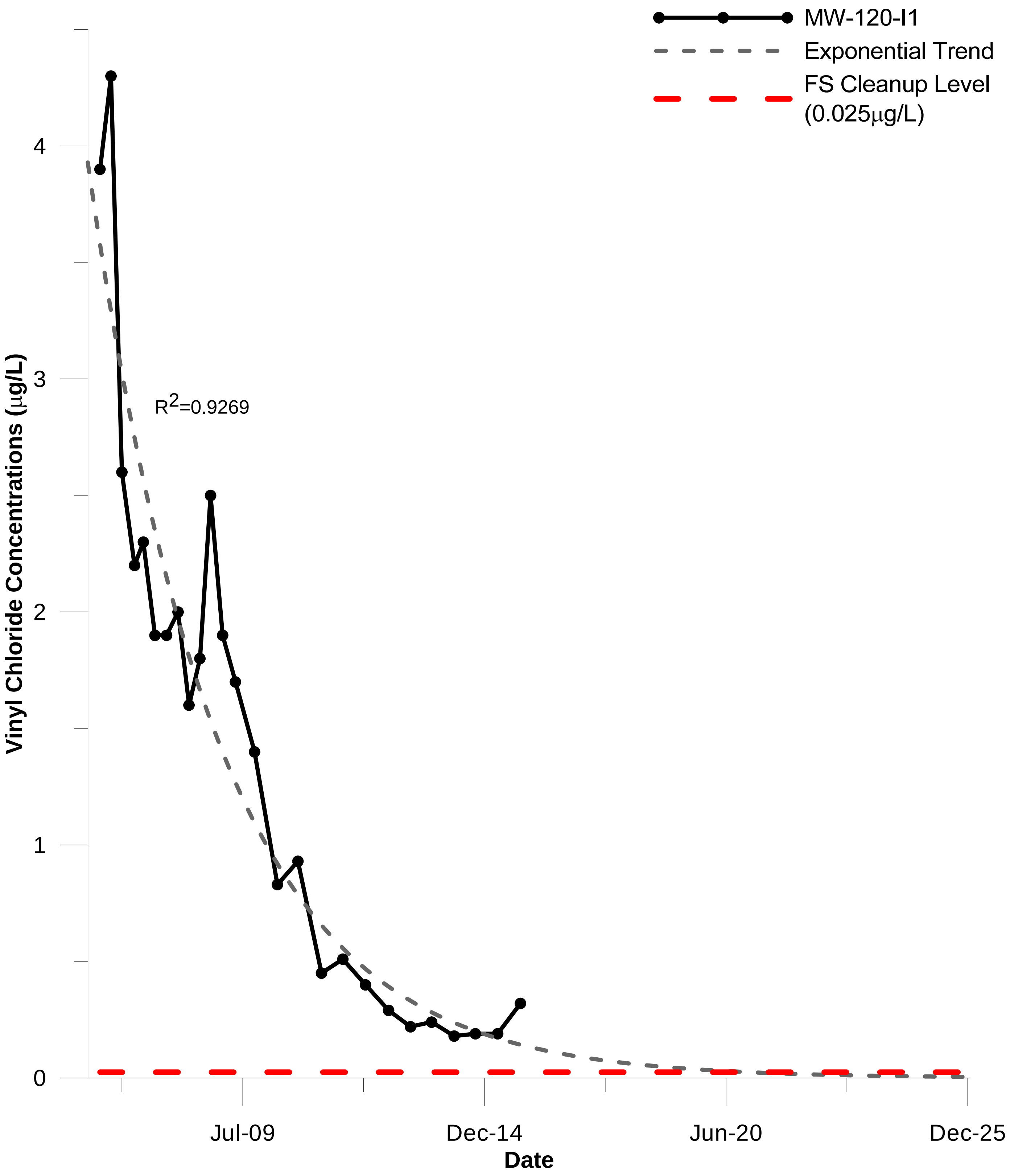
Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste



HIGHEST ANALYTE CONCENTRATIONS IN
DEEP AQUIFER
2010 to 2015
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 04/01/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure **16**

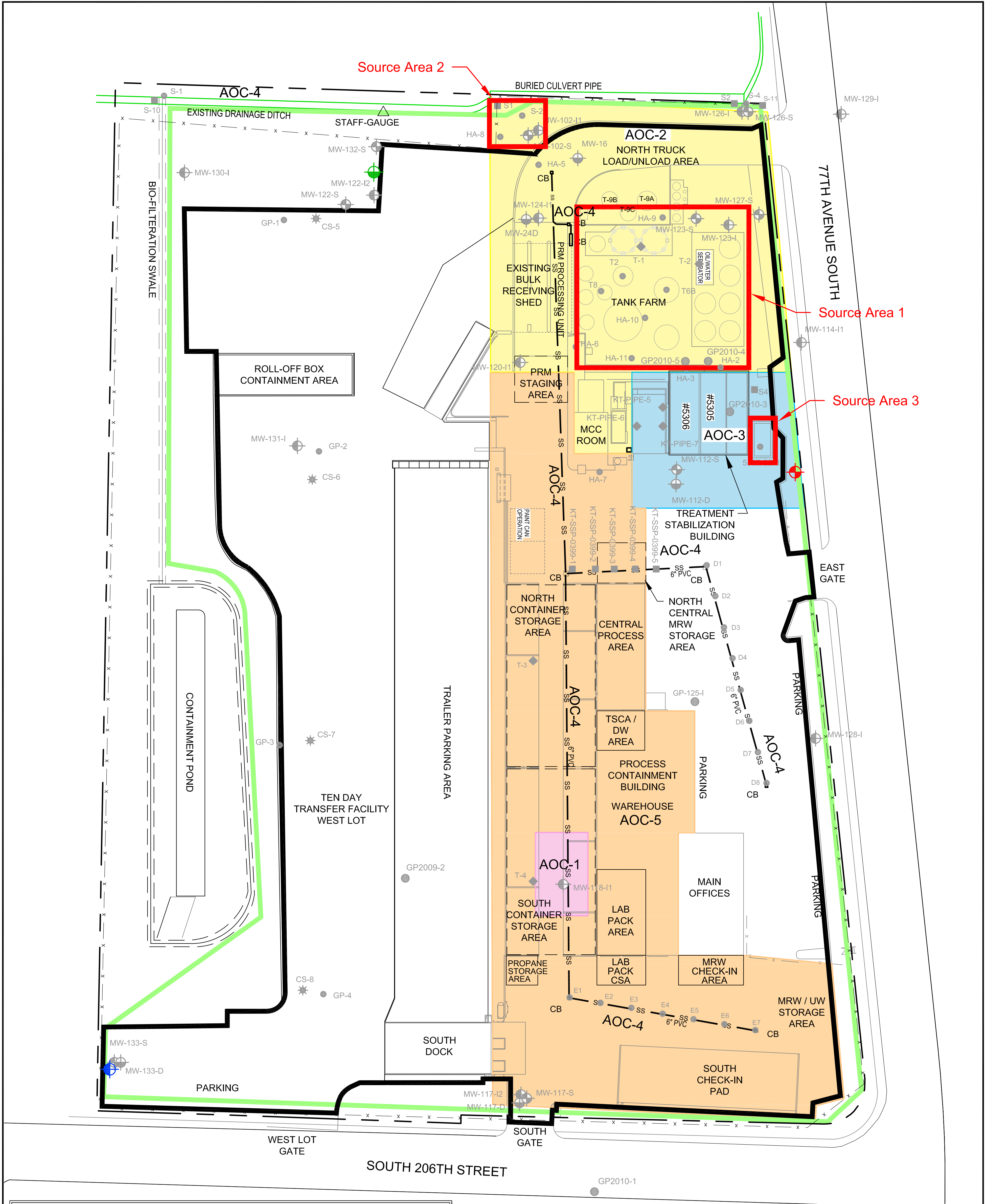


Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

PROJECTED VINYL CHLORIDE CONCENTRATIONS AT MW-120-I1
2007 TO 2025
Stericycle Kent Facility
Kent, Washington

Project No.
9464

Figure No.
17



Explanation

▭ Extent of existing surface cap	⊕ Proposed New Shallow Monitoring Well
🟥 Approximate areas for soil remediation at facility closure	⊕ Proposed New Intermediate Monitoring Well
	⊕ Proposed New Deep Monitoring Well

Legend

- — — — Property Line
- — x — Fence Line
- ⊕ ⊕ ⊕ Groundwater Monitoring Well
- ✹ Composite Soil Sample
- ● ■ ◆ Soil Sample
- ▫ CB Catch Basin
- — ss — Stormwater Drainage System
- ▬ Potential Conditional Point of Compliance

Key

🟪	Area of Concern #1 Former USTs
🟨	Area of Concern #2 Tank Farm Area
🟦	Area of Concern #3 Stabilization Area
— ss —	Area of Concern #4 Stormwater Drainage System
🟧	Area of Concern #5 Process and Storage Area

Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

N

0 30 60
APPROXIMATE SCALE IN FEET

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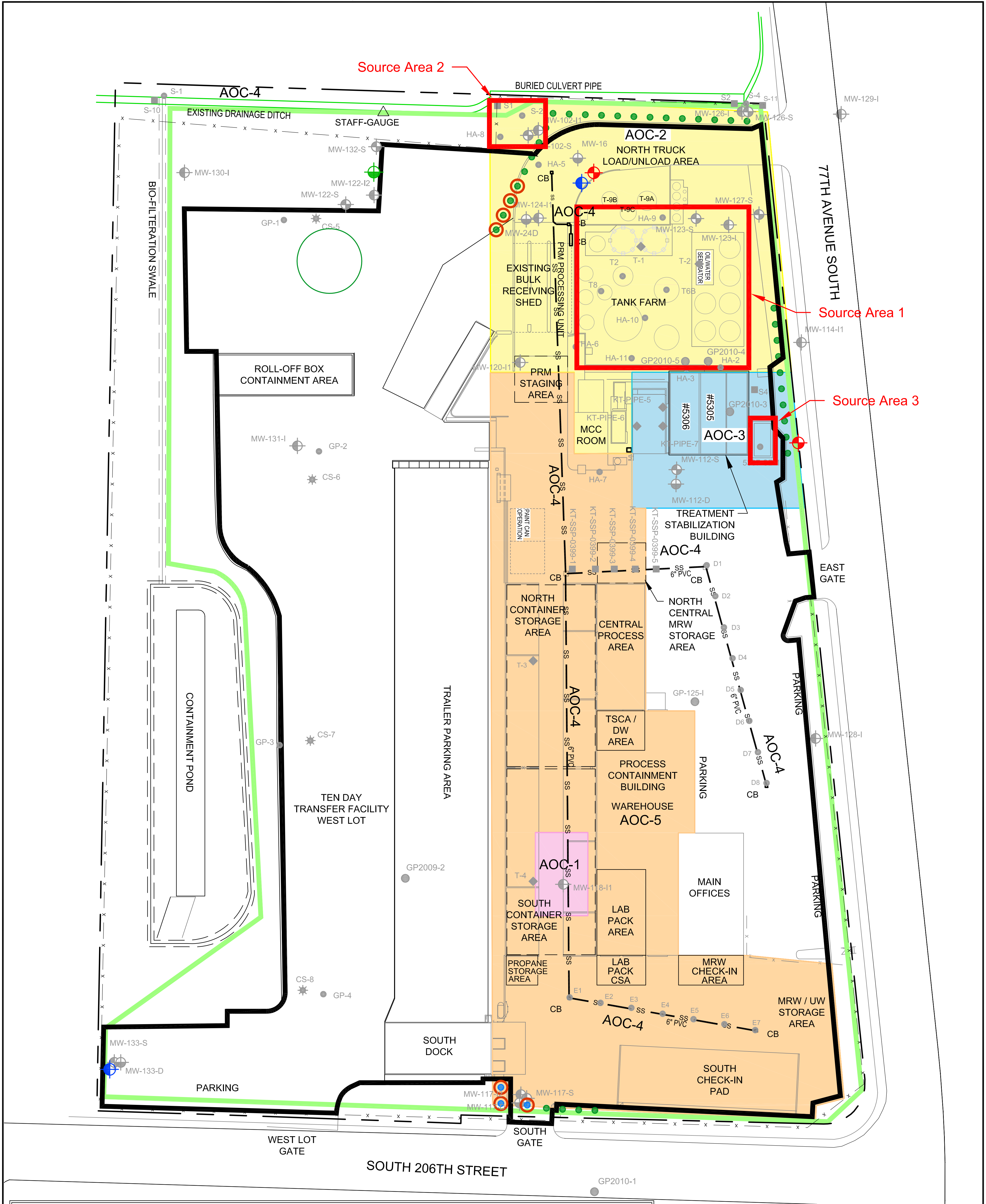
ALTERNATIVE 1
MONITORED NATURAL ATTENUATION
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 04/01/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 18



Explanation

▭	Extent of existing surface cap
🟥	Approximate areas for soil remediation at facility closure
⊕	Proposed New Shallow Monitoring Well
⊕	Proposed New Intermediate Monitoring Well
⊕	Proposed New Deep Monitoring Well
●	Possible extent of permeable reactive barrier (shallow water-bearing unit and intermediate aquifer)
◉	Possible extent of permeable reactive barrier (shallow water-bearing unit and intermediate and deep aquifers)
◉	Possible extent of permeable reactive barrier (intermediate and deep aquifers)

Legend

— — —	Property Line
— x —	Fence Line
⊕ ⊕ ⊕	Groundwater Monitoring Well
✹	Composite Soil Sample
● ■ ◆	Soil Sample
▫ CB	Catch Basin
— ss —	Stormwater Drainage System
▬	Potential Conditional Point of Compliance

Key

🟪	Area of Concern #1 Former USTs
🟨	Area of Concern #2 Tank Farm Area
🟦	Area of Concern #3 Stabilization Area
— ss —	Area of Concern #4 Stormwater Drainage System
🟧	Area of Concern #5 Process and Storage Area

Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

N

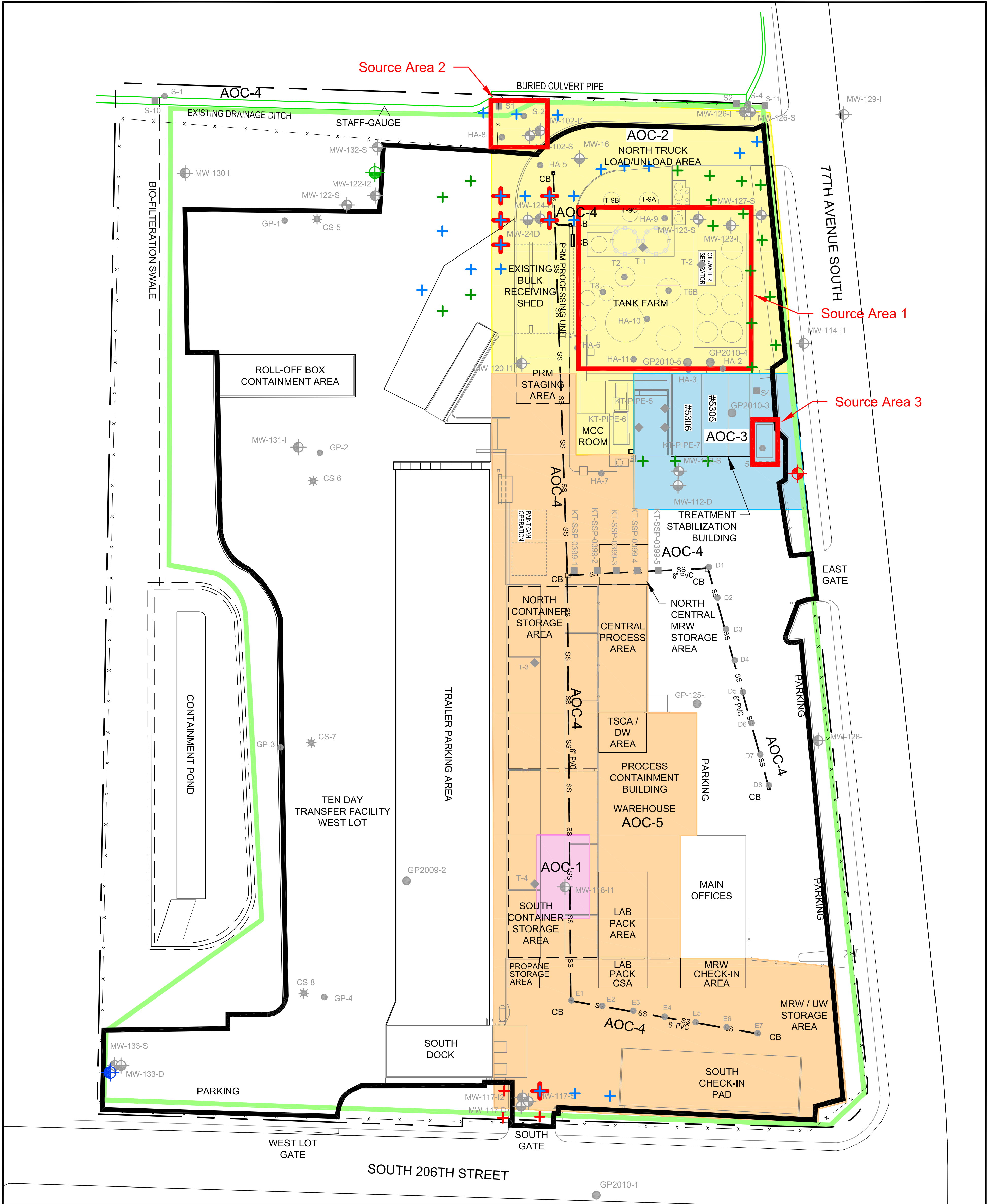
0 30 60
APPROXIMATE SCALE IN FEET

amec foster wheeler

ALTERNATIVE 2
PERMEABLE REACTIVE BARRIERS
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 04/01/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Figure 19

Plot Date: 04/01/16 - 2:14pm, Plotted by: adam.stenberg
Drawing Path: S:\9464\009_2015\CAD\, Drawing Name: StericycleKent_Alternatves_033116.dwg



Explanation

- ⬛ Extent of existing surface cap
- 🟥 Approximate area for soil remediation at facility closure
- ⊕ Proposed New Shallow Monitoring Well
- ⊕ Proposed New Intermediate Monitoring Well
- ⊕ Proposed New Deep Monitoring Well

Wet Season Injections
+ ISCR, shallow water-bearing unit and intermediate aquifer

Dry Season Injections
+ ISCR, shallow water-bearing unit and intermediate aquifer

+ ISCR, shallow water-bearing unit and intermediate and deep aquifers

+ ISCR, intermediate and deep aquifers

Abbreviations:

CB = Catch Basin
CSA = Container Storage Area
DW = Dangerous Waste
MCC = Motor Control Center
MRW = Moderate Risk Waste Management
PRM = Plant Resource Management
TSCA = Toxic Substances Control Act
UST = Underground Storage Tank
UW = Unidentified Waste

Legend

- — — Property Line
- — x — Fence Line
- ⊕ Groundwater Monitoring Well
- ✹ Composite Soil Sample
- ● ■ ◆ Soil Sample
- ▫ CB Catch Basin
- — ss — Stormwater Drainage System
- ▬ Potential Conditional Point of Compliance

Key

- 🟪 Area of Concern #1 Former USTs
- 🟨 Area of Concern #2 Tank Farm Area
- 🟦 Area of Concern #3 Stabilization Area
- — ss — Area of Concern #4 Stormwater Drainage System
- 🟧 Area of Concern #5 Process and Storage Area

amec foster wheeler

ALTERNATIVE 3
IN SITU CHEMICAL REDUCTION AND
IN SITU BIOREMEDIATION
Stericycle Kent Facility
Kent, Washington

By: APS | Date: 04/01/16 | Project No. 9464.002
Amec Foster Wheeler
Environment & Infrastructure, Inc.
Figure 20

APPENDIX A

Cleanup Levels Data Screening

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

TABLE A-1

SELECTION OF APPLICABLE SOIL CLEANUP LEVELS
Stericycle Kent Facility
Kent, Washington

concentrations in milligrams per kilogram (mg/kg)

Compound	CAS Number	MTCA Cleanup Levels Protective of Human Health			Natural Background[1]	Initial Soil Screening Level[2]	Final Applicable Practical Quantitation Limit	Final Soil Screening Level[3]	Basis
		Method C - Direct Contact		Protection of Groundwater					
		Noncarcinogen	Carcinogen						
Volatile Organic Compounds									
Benzene	71-43-2	1.40E+04	2.39E+03	8.43E-03	---	8.43E-03	5.40E-04	**8.43E-03**	Protection of groundwater
Methylene chloride	75-09-2	2.10E+04	6.56E+04	2.37E-02	---	2.10E+04	1.60E-03	**2.10E+04**	Protection of direct contact
p-Isopropyltoluene (p-cymene)	99-87-6	3.50E+05	--	--	---	3.50E+05	6.40E-04	**3.50E+05**	Protection of direct contact
sec-Butylbenzene	135-98-8	3.50E+05	--	3.94E+00	---	3.50E+05	7.40E-04	**3.50E+05**	Protection of direct contact
Tetrachloroethene	127-18-4	3.50E+04	2.4E+02	2.20E-02	---	2.40E+02	7.60E-04	**2.40E+02**	Protection of direct contact
Vinyl Chloride	75-01-4	1.05E+04	8.8E+01	1.95E-04	---	1.95E-04	9.40E-04	**9.40E-04**	Practical quantitation limit
Semivolatile Organic Compounds									
1,4-Dichlorobenzene	106-46-7	2.45E+05	2.43E+04	3.19E-01	---	2.43E+04	1.80E-01	**2.43E+04**	Protection of direct contact
2-Methylnaphthalene	91-57-6	1.40E+04	--	2.73E+01	---	1.40E+04	1.10E-01	**1.40E+04**	Protection of direct contact
Benzo(a)anthracene	56-55-3	--	1.80E+02	7.15E-01	---	1.80E+02	5.00E-03	**1.80E+02**	Protection of direct contact
Benzo(a)pyrene	50-32-8	--	1.80E+01	1.94E+00	---	1.80E+01	5.00E-03	**1.80E+01**	Protection of direct contact
Benzo(b)fluoranthene	205-99-2	--	1.80E+02	2.46E+00	---	1.80E+02	5.00E-03	**2.46E+00**	Protection of groundwater
Benzo(k)fluoranthene	207-08-9	--	1.80E+03	2.46E+00	---	1.80E+03	5.00E-03	**1.80E+03**	Protection of direct contact
Carbazole	86-74-8	--	--	--	---	--	1.10E-01	**--**	No risk-based cleanup level available
Chrysene	218-01-9	--	1.80E+04	7.96E-01	---	7.96E-01	5.00E-03	**7.96E-01**	Protection of groundwater
Naphthalene	91-20-3	7.00E+04	--	1.10E+00	---	7.00E+04	5.00E-03	**7.00E+04**	Protection of direct contact
Pesticides, Polychlorinated Biphenyls, and Herbicides									
4,4'-DDD	72-54-8	--	5.47E+02	6.88E-02	---	5.47E+02	5.00E-03	**5.47E+02**	Protection of direct contact
4,4'-DDE	7786-34-7	--	3.86E+02	3.10E-02	---	3.86E+02	5.00E-03	**3.86E+02**	Protection of direct contact
4,4'-DDT	50-29-3	1.75E+03	3.86E+02	3.93E-01	---	3.86E+02	5.00E-03	**3.86E+02**	Protection of direct contact
alpha-Chlordane[4]	5103-71-9	1.75E+03	3.75E+02	2.04E-01	---	3.75E+02	5.00E-03	**3.75E+02**	Protection of direct contact
Coumaphos	56-72-4	--	--	--	---	--	3.00E-02	**--**	No risk-based cleanup level available
Delta-BHC[5]	319-86-8	1.05E+03	1.19E+02	8.17E-03	---	1.19E+02	3.70E-03	**1.19E+02**	Protection of direct contact
Dieldrin	60-57-1	1.75E+02	8.20E+00	8.96E-03	---	8.20E+00	4.80E-03	**8.20E+00**	Protection of direct contact
Endosulfan Sulfate[6]	1031-07-8	2.10E+04	--	5.53E-03	---	2.10E+04	5.00E-03	**2.10E+04**	Protection of direct contact
gamma-BHC (Lindane)	58-89-9	1.05E+03	1.19E+02	2.64E-03	---	1.19E+02	4.50E-03	**1.19E+02**	Protection of direct contact
gamma-Chlordane[4]	5103-74-2	1.75E+03	3.75E+02	1.63E-02	---	3.75E+02	5.00E-03	**3.75E+02**	Protection of direct contact
Heptachlor epoxide	1024-57-3	4.55E+01	1.44E+01	2.66E-02	---	1.44E+01	3.90E-03	**1.44E+01**	Protection of direct contact
Mevinphos (Phosdrin)	7786-34-7	--	--	--	---	--	5.20E-02	**--**	No risk-based cleanup level available

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

TABLE A-1

SELECTION OF APPLICABLE SOIL CLEANUP LEVELS

Stericycle Kent Facility
Kent, Washington

concentrations in milligrams per kilogram (mg/kg)

Compound	CAS Number	MTCA Cleanup Levels Protective of Human Health			Natural Background[1]	Initial Soil Screening Level[2]	Final Applicable Practical Quantitation Limit	Final Soil Screening Level[3]	Basis
		Method C - Direct Contact		Protection of Groundwater					
		Noncarcinogen	Carcinogen						
Metals									
Antimony[7]	7440-36-0	1.40E+03	--	5.06E+00	5.00E+00	1.40E+03	5.00E-02	**1.40E+03**	Protection of direct contact
Arsenic	7440-38-2	1.05E+03	8.75E+01	6.13E+00	7.30E+00	7.30E+00	5.00E-01	**7.30E+00**	Natural background
Cadmium	7440-43-9	3.50E+03	--	1.54E+00	8.00E-01	3.50E+03	2.00E-02	**3.50E+03**	Protection of direct contact
Copper	7440-50-8	1.40E+05	--	1.54E+00	3.64E+01	1.40E+05	1.00E-01	**1.40E+05**	Protection of direct contact
Cyanide	57-12-5	2.10E+03	--	5.75E-02	---	5.75E-02	2.00E-01	**2.00E-01**	Practical quantitation limit
Mercury[8]	7439-97-6	2.00E+00	--	2.09E-01	7.00E-02	2.00E+00	2.00E-02	**2.00E+00**	Protection of direct contact
Selenium	7782-49-2	1.75E+04	--	5.20E-01	7.80E-01	1.75E+04	4.00E-01	**1.75E+04**	Protection of direct contact
Silver[7]	7440-22-4	1.75E+04	--	5.44E-02	6.10E-01	1.75E+04	2.00E-02	**1.75E+04**	Protection of direct contact
Thallium	7440-28-0	3.50E+01	--	2.28E-01	---	3.50E+01	2.00E-02	**3.50E+01**	Protection of direct contact
Zinc	7440-66-6	1.05E+06	--	4.02E+01	8.51E+01	1.05E+06	5.00E-01	**1.05E+06**	Protection of direct contact
Total Petroleum Hydrocarbons[9]									
TPH as gasoline	86290-81-5	3.00E+01	--	---	---	3.00E+01	5.00E+00	**3.00E+01**	Protection of direct contact
TPH as diesel	68334-30-5	2.00E+03	--	---	---	2.00E+03	7.90E+00	**2.00E+03**	Protection of direct contact
TPH as lube oil	---	2.00E+03	--	---	---	2.00E+03	2.90E+01	**2.00E+03**	Protection of direct contact

Notes:

1. Puget Sound natural background levels as calculated by Ecology (1994) except for antimony, selenium, and silver which are state wide background levels since no regional data calculated.
2. Initial soil screening level is the lesser of the MTCA cleanup levels. If natural background levels exceed the lower MTCA cleanup level, the initial soil screening level is the natural background concentration.
3. Final soil screening level is set as the initial soil screening, except if initial soil screening level is less than final applicable PQL, in which case the PQL is the final soil screening level.
4. Cleanup levels for chlordane were used for alpha- and gamma-chlordane.
5. Cleanup level for gamma-BHC was used for delta-BHC.
6. Cleanup level for Endosulfan was used for and Endosulfan sulfate.
7. Values for antimony and silver are state wide background levels; no regional data calculated.
8. Mercury cleanup levels are MTCA Method A cleanup levels; no Method C cleanup levels are available.
9. TPH cleanup levels are MTCA Method A cleanup levels; no Method C cleanup levels are available.

Abbreviations:

-- = not established, not applicable, or otherwise not available
CAS = Chemical Abstract Service
MTCA = Model Toxics Control Act
PQL = practical quantitation limit
TPH = total petroleum hydrocarbons

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TABLE A-2

CALCULATION OF VADOSE ZONE SOIL CLEANUP LEVELS BASED ON PROTECTION OF GROUNDWATER

Stericycle Kent Facility
Kent, Washington

Vadose Zone Soil Screening Level = C_w * CF * DF * [K_d + (O_w + O_a * H)/P_b]

Parameter	Description	Units	Values	Reference/Source
SSL	Soil Screening Level based on groundwater protection	mg/kg	chemical-specific	Calculated
C_w	Groundwater screening level	µg/L	chemical-specific	See Table 5-5 in the Final RI Report (Geomatrix, 2007)
CF	Conversion factor, µg to mg	mg/µg	1.00E-03	Conversion
DF_{vad}	Dilution factor, vadose zone	unitless	20	WAC 173-340
DF_{sat}	Dilution factor, saturated zone	unitless	1	WAC 173-340
K_d	Distribution coefficient	cm^3/g	chemical-specific	Calculated
O_w	Water-filled soil porosity	unitless	0.3	WAC 173-340
O_a	Air-filled soil porosity	unitless	0.13	WAC 173-340
n	Total saturated porosity	unitless	0.43	Site-specific data
H	Henry's Law constant	unitless	chemical-specific	EPA, 1996; EPA, 2000; Montgomery, 1996
P_b	Dry soil bulk density	g/cm^3	1.5	WAC 173-340
K_{oc}	Soil organic carbon partition coefficient	cm^3/g	chemical-specific	WAC 173-340-900 Table 747-1 and Table 747-2; EPA, 1996; EPA, 2000; Montgomery, 1996
f_{oc}	Fraction organic carbon	unitless	0.005	Site-specific data - Table 4-2 in Final RI Report (Geomatrix, 2007)

Compound	CAS Number	C_w	K_{oc}	K_d	H	SSL (DF = 20)	Source (if other than CLARC [Ecology, 2007])[1]
Volatile Organic Compounds							
Benzene	71-43-2	7.95E-01	6.20E+01	3.10E-01	2.28E-01	8.43E-03	
Methylene chloride	75-09-2	4.60E+00	1.00E+01	5.00E-02	8.98E-02	2.37E-02	
p-Isopropyltoluene (p-Cymene)	99-87-6	--	1.45E+00	7.25E-03	4.50E-01	--	Chemfinder, Henry's Law Constant converted used EPA converter (EPA, 2007)
sec-Butylbenzene	135-98-8	8.00E+02	1.41E+00	7.05E-03	4.50E-01	3.94E+00	Chemfinder, Henry's Law Constant converted used EPA converter (EPA, 2007)
Tetrachloroethene	127-18-4	6.90E-01	2.65E+02	1.33E+00	7.54E-01	2.20E-02	
Vinyl Chloride		2.50E-02	1.86E+01	9.30E-02	1.11E+00	1.95E-04	
Semivolatile Organic Compounds							
1,4-Dichlorobenzene	106-46-7	4.85E+00	6.16E+02	3.08E+00	9.96E-02	3.19E-01	
2-Methylnaphthalene	91-57-6	3.20E+01	8.50E+03	4.25E+01	2.12E-02	2.73E+01	Chemfate Syracuse Research Corp. Recommended Value, Henry's Law Constant converted used EPA converter (EPA, 2007)
Benzo(a)anthracene	56-55-3	2.00E-02	3.58E+05	1.79E+03	1.37E-04	7.15E-01	
Benzo(a)pyrene	50-32-8	2.00E-02	9.69E+05	4.84E+03	4.63E-05	1.94E+00	
Benzo(b)fluoranthene	205-99-2	2.00E-02	1.23E+06	6.15E+03	4.55E-03	2.46E+00	
Benzo(k)fluoranthene	207-08-9	2.00E-02	1.23E+06	6.15E+03	3.40E-05	2.46E+00	
Carbazole	86-74-8	--	3.39E+03	1.70E+01	6.26E-07	--	
Chrysene	218-01-9	2.00E-02	3.98E+05	1.99E+03	3.88E-03	7.96E-01	
Naphthalene	91-20-3	8.93E+00	1.19E+03	5.96E+00	1.98E-02	1.10E+00	

TABLE A-2

CALCULATION OF VADOSE ZONE SOIL CLEANUP LEVELS BASED ON PROTECTION OF GROUNDWATER

Stericycle Kent Facility
Kent, Washington

Compound	CAS Number	C_w	K_{oc}	K_d	H	SSL (DF = 20)	Source (if other than CLARC [Ecology, 2007])[1]
Pesticides, Polychlorinated Biphenyls and Herbicides							
4,4'-DDD	72-54-8	1.50E-02	4.58E+04	2.29E+02	1.64E-04	6.88E-02	
4,4'-DDE	7786-34-7	3.60E-03	8.60E+04	4.30E+02	8.60E-04	3.10E-02	
4,4'-DDT	50-29-3	5.80E-03	6.78E+05	3.39E+03	3.32E-04	3.93E-01	
alpha-Chlordane[2]	5103-71-9	4.00E-02	5.10E+04	2.55E+02	1.99E-03	2.04E-01	
Coumaphos	56-72-4	--	2.23E+03	1.12E+01	1.26E-06	--	Chemfinder, Henry's Law Constant converted used EPA converter (EPA, 2007), http://www.epa.gov/superfund/health/conmedia/soil/pdfs/part_5.pdf
Delta-BHC	319-86-8	1.90E-02	4.26E+03	2.13E+01	1.75E-05	8.17E-03	Chemfate,Chemfinder, Henry's Law Constant converted used EPA converter (EPA, 2007)
Dieldrin	60-57-1	3.50E-03	2.55E+04	1.28E+02	6.19E-04	8.96E-03	
Endosulfan sulfate	1031-07-8	5.60E-02	9.48E+02	4.74E+00	1.33E-05	5.53E-03	Chemfate, Henry's Law Constant converted used EPA converter (EPA, 2007), http://www.epa.gov/superfund/health/conmedia/soil/pdfs/part_5.pdf
gamma-BHC (Lindane)	58-89-9	1.90E-02	1.35E+03	6.76E+00	5.74E-04	2.64E-03	
gamma-Chlordane[2]	5103-74-2	3.20E-03	5.10E+04	2.55E+02	1.99E-03	1.63E-02	
Heptachlor epoxide	1024-57-3	3.20E-03	8.30E+04	4.15E+02	3.90E-04	2.66E-02	
Mevinphos (Phosdrin)	7786-34-7	--	2.00E+02	1.00E+00	2.61E-09	--	Chemfate, Chemfinder, Henry's Law Constant converted used EPA converter (EPA, 2007)

TABLE A-2

CALCULATION OF VADOSE ZONE SOIL CLEANUP LEVELS BASED ON PROTECTION OF GROUNDWATER

Stericycle Kent Facility
Kent, Washington

Compound	CAS Number	C_w	K_{oc}	K_d	H	SSL (DF = 20)	Source (if other than CLARC [Ecology, 2007])[1]
Metals							
Antimony	7440-36-0	5.60E+00	---	4.50E+01	0.00E+00	5.06E+00	
Arsenic	7440-38-2	1.05E+01	---	2.90E+01	0.00E+00	6.13E+00	
Cadmium	7440-43-9	5.00E+00	---	6.70E+00	0.00E+00	6.90E-01	
Copper	7440-50-8	3.47E+00	---	2.20E+01	0.00E+00	1.54E+00	
Cyanide	57-12-5	1.00E+01	1.74E+01	8.70E-02	5.44E-03	5.75E-02	Chemfate, SRC PhysProp Database, Henry's Law Constant converted used EPA converter (EPA, 2007)
Mercury	7439-97-6	2.00E-01	---	5.20E+01	4.70E-01	2.09E-01	
Selenium	7782-49-2	5.00E+00	---	5.00E+00	0.00E+00	5.20E-01	
Silver	7440-22-4	3.20E-01	---	8.30E+00	0.00E+00	5.44E-02	
Thallium	7440-28-0	1.60E-01	---	7.10E+01	0.00E+00	2.28E-01	
Zinc	7440-66-6	3.23E+01	---	6.20E+01	0.00E+00	4.02E+01	

Notes:

1. Sources:
   Chemfate: Syracuse Research Corporation, 2007, http://www.syrres.com/esc/efdb.htm.
   Chemfinder: ChemFinder, 2007, On-line chemical database, http://chemfinder.cambridgesoft.com/, CambridgeSoft Corporation.
2. Values for chlordane were used for alpha- and gamma-chlordane.

Abbreviations:

-- = not established, not applicable, or otherwise not available
µg/L = micrograms per liter
CAS = Chemical Abstract Service
CLARC = Cleanup Levels and Risk Calculation
cm^3/g = cubic centimeters per gram
Ecology = Washington State Department of Ecology
EPA = Environmental Protection Agency
g/cm^3 = grams per cubic centimeter
mg/kg = milligrams per kilogram
RI = remedial investigation
WAC = Washington Administrative Code

References:

Geomatrix Consultants, Inc. (Geomatrix), 2007, Final Remedial Investigation Report, PSC Kent Facility, Kent, Washington: Prepared for Philip Services Corporation, December.
Montgomery, J.H., 1996, *Groundwater Chemicals Desk Reference* , Second Edition, Lewis Publishers, Inc., Chelsea, MI.
U.S. Environmental Protection Agency (EPA), 1996, Soil Screening Guidance: User’s Guide, Office of Solid Waste and Emergency Reponse, July.
U.S. Environmental Protection Agency (EPA), 2007, http://www.epa.gov/ATHENS/learn2model/part-two/onsite/henryslaw.htm.
Washington State Department of Ecology (Ecology), 2007, CLARC database, located at: https://fortress.wa.gov/ecy/clarc/CLARCHome.aspx.

TABLE A-3

SELECTION OF APPLICABLE GROUNDWATER CLEANUP LEVELS

Stericycle Kent Facility
Kent, Washington

concentrations in micrograms per liter (µg/L)

			Groundwater Method B		Surface Water Method B		Groundwater ARAR		Surface Water Aquatic Life Fresh/Acute			Surface Water Aquatic Life Fresh/Chronic			Surface Water Human Health Fresh Water		2015 Groundwater Screening Level Protective of Indoor Air Method B				
Compound	CAS Number	Groundwater Method A[1]	Non-cancer	Cancer	Non-cancer	Cancer	Federal Primary MCL	State Primary MCL	173-201A WAC	CWA §304	NTR 40 CFR 131	173-201A WAC	CWA §304	NTR 40 CFR 131	CWA §304	NTR 40 CFR 131	Non-cancer	Cancer	Final Applicable Practical Quantitation Limit[2]	Groundwater Screening Level[3]	Basis
Volatile Organic Compounds																					
Benzene	71-43-2	5.0	32	0.80	1,994	23	5	5	--	--	--	--	--	--	2.20	1.20	103	2.4	0.5	**0.80**	Protection of drinking water use
Methylene chloride	75-09-2	5.0	48	22	17,284	3,601	5.0	5.0	--	--	--	--	--	--	4.60	4.70	4,865	4,434	1.0	**4.6**	Protection of surface water
p-Isopropyltoluene (p-cymene)	99-87-6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.60	**--**	No risk-based cleanup level available
sec-Butylbenzene	135-98-8	--	800	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.62	**800**	Protection of drinking water use
Tetrachloroethene	127-18-4	5.00	48	20.83	501.79	99.56	5.00	5.00	--	--	--	--	--	--	0.69	0.80	44	23	0.5	**0.69**	Protection of surface water
Vinyl chloride	75-01-4	0.20	24	0.03	6,481	3.70	2.0	2.0	--	--	--	--	--	--	0.03	2.00	57	0.35	0.02	**0.025**	Protection of surface water
Semivolatile Organic Compounds																					
1,4-Dichlorobenzene	106-46-7	--	560	8.1	3,241	21	75	75	--	--	--	--	--	--	63.00	400.00	7,808	4.9	3.2	**4.9**	Protection of indoor air
2-Methylnaphthalene	91-57-6	--	32	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.02	**32**	Protection of drinking water use
Benzo(a)anthracene	56-55-3	--	--	0.12	--	0.30	--	--	--	--	--	--	--	--	0.004	0.003	--	--	0.02	**0.020**	Practical quantitation limit
Benzo(a)pyrene	50-32-8	0.10	--	0.01	--	0.03	0.20	0.20	--	--	--	--	--	--	0.004	0.003	--	--	0.02	**0.020**	Practical quantitation limit
Benzo(b)fluoranthene	205-99-2	--	--	0.12	--	0.30	--	--	--	--	--	--	--	--	0.004	0.003	--	--	0.02	**0.020**	Practical quantitation limit
Benzo(k)fluoranthene	207-08-9	--	--	1.20	--	2.96	--	--	--	--	--	--	--	--	0.004	0.003	--	--	0.02	**0.020**	Practical quantitation limit
Carbazole	86-74-8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.6	**--**	No risk-based cleanup level available
Chrysene	218-01-9	--	--	11.99	--	30	--	--	--	--	--	--	--	--	0.004	0.003	--	--	0.02	**0.020**	Practical quantitation limit
Naphthalene	91-20-3	160	160	--	4,714	--	--	--	--	--	--	--	--	--	--	--	167	8.9	0.02	**8.9**	Protection of indoor air
Pesticides and Herbicides																					
4,4'-DDD	72-54-8	--	--	0.36	--	0.001	--	--	1.1	--	--	0.001			0.0003	0.001	--	--	0.015	**0.015**	Practical quantitation limit
4,4'-DDE	72-55-9	--	--	0.26	--	0.0004	--	--	1.1	--	--	0.001			0.0002	0.001	--	--	0.004	**0.0036**	Practical quantitation limit
4,4'-DDT	50-29-3	0.30	8.0	0.26	0.02	0.0004	--	--	1.1	1.1	1.1	0.001	0.001	0.001	0.0002	0.001	--	--	0.006	**0.0058**	Practical quantitation limit
alpha-Chlordane[4]	5103-71-9	--	8.0	0.25	0.09	0.001	2.0	2.0	2.4	2.4	2.4	0.004	0.004	0.004	0.001	0.001	--	--	0.04	**0.040**	Practical quantitation limit
Coumaphos	56-72-4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.20	**--**	No risk-based cleanup level available
Delta-BHC[5]	319-86-8	0.20	4.8	0.08	6.0	0.05	0.20	0.20	2.0	0.95	2.0	0.08	--	0.08	0.98	0.02	--	--	0.006	**0.019**	Protection of surface water use
Dieldrin	60-57-1	--	0.80	0.01	0.03	0.0001	--	--	2.5	0.24	2.5	0.002	0.06	0.002	0.0001	0.0001	--	--	0.004	**0.0035**	Practical quantitation limit
Endosulfan sulfate[6]	1031-07-8	--	96	--	58	--	--	--	0.22	--	0.22	0.06	--	0.06	--	--	--	--	0.005	**0.056**	Protection of surface water
gamma-BHC (Lindane)	58-89-9	0.20	4.8	0.08	6.0	0.05	0.20	0.20	2.0	0.95	2.0	0.08	--	0.08	0.98	0.02	--	--	0.004	**0.019**	Protection of surface water use
gamma-Chlordane[4]	5103-74-2	--	8.0	0.25	0.09	0.001	2.0	2.0	2.4	2.4	2.4	0.004	0.004	0.004	0.001	0.001	--	--	0.003	**0.0032**	Practical quantitation limit
Heptachlor epoxide	1024-57-3	--	0.10	0.005	0.003	0.0001	0.20	0.20	--	0.52	0.52	--	0.004	0.004	0.00004	0.0001	--	--	0.003	**0.0032**	Practical quantitation limit
Mevinphos (Phosdrin)	7786-34-7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.70	**--**	No risk-based cleanup level available
Metals																					
Antimony	7440-36-0	--	6.4	--	1,037	--	6.0	6.0	--	--	--	--	--	--	5.6	14	--	--	0.05	**5.6**	Protection of surface water
Arsenic	7440-38-2	5.0	4.8	0.06	18	0.10	10	10	360	340	360	190	150	190	0.02	0.02	--	--	0.5	**10.5**	MTCA C Value[7]
Cadmium	7440-43-9	5.0	8.0	--	--	--	5.0	5.0	--	--	--	--	--	--	--	--	--	--	0.02	**5.0**	Protection of drinking water use
Hexavalent Chromium	18540-29-9	--	48	--	486	--	100	100	15	16	15	10	11	10	--	--	--	--	2	**10**	Protection of surface water
Copper	7440-50-8	--	640	--	2,880	--	1300	1300	4.6	13	17	3.5	9.0	11			--	--	0.1	**3.5**	Protection of surface water
Cyanide	57-12-5	--	9.6	--	1,556	--	200	200	22	22	22	5.2	5.2	5.2	140	700	--	--	0.009	**10**	Area background
Iron	7439-89-6	--	11,200	--	--	--	--	--	--	--	--	--	1,000	--	300	--	--	--	1	**24,500**	MTCA C Value[7]
Manganese	7439-96-5	--	2,240	--	--	--	--	--	--	--	--	--	--	--	50	--	--	--	0.05	**4,900**	MTCA C Value[7]
Mercury	7439-97-6	2.0		--	--	--	2.0	2.0	2.1	1.4	2.1	0.01	0.77	0.01	--	0.14	--	--	0.2	**0.20**	Practical quantitation limit
Selenium	7782-49-2	--	80	--	2,701	--	50	50	20	--	20	5.0	5.0	5.0	4,200	--	--	--	0.02	**5.0**	Protection of surface water
Silver	7440-22-4	--	80	--	25,926	--	--	--	0.32	3.2	3.4	--	--	--	--	--	--	--	0.02	**0.32**	Protection of surface water use
Thallium	7440-28-0	--	0.16	--	0.22	--	2.0	2.0	--	--	--	--	--	--	0.24	1.7	--	--	0.02	**0.16**	Protection of drinking water use
Zinc	7440-66-6	--	4,800	--	16,548	--	--	--	35	120	110	32	120	100	7,400	--	--	--	0.5	**32**	Protection of surface water

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TABLE A-3

SELECTION OF APPLICABLE GROUNDWATER CLEANUP LEVELS
Stericycle Kent Facility
Kent, Washington

concentrations in micrograms per liter (µg/L)

			Groundwater Method B		Surface Water Method B		Groundwater ARAR		Surface Water Aquatic Life Fresh/Acute			Surface Water Aquatic Life Fresh/Chronic			Surface Water Human Health Fresh Water		2015 Groundwater Screening Level Protective of Indoor Air Method B				
Compound	**CAS Number**	**Groundwater Method A^1**	**Non-cancer**	**Cancer**	**Non-cancer**	**Cancer**	**Federal Primary MCL**	**State Primary MCL**	**173-201A WAC**	**CWA §304**	**NTR 40 CFR 131**	**173-201A WAC**	**CWA §304**	**NTR 40 CFR 131**	**CWA §304**	**NTR 40 CFR 131**	**Non-cancer**	**Cancer**	**Final Applicable Practical Quantitation Limit^2**	**Groundwater Screening Level^3**	**Basis**
Total Petroleum Hydrocarbons																					
TPH as gasoline	---	800	--	--	--	--	--	--	--	--	--	--	--	--	--	--	800	--	250	**800**	Protection of drinking water use
TPH as Diesel	---	500	--	--	--	--	--	--	--	--	--	--	--	--	--	--	500	--	110	**500**	Protection of drinking water use
TPH as Lube Oil	---	500	--	--	--	--	--	--	--	--	--	--	--	--	--	--	500	--	280	**500**	Protection of drinking water use

Notes:
1. Groundwater Method A was applied only if there was no Method B value.
2. Provided by ALS, the project laboratory.
3. All screening levels input from CLARC, August 2015.
4. Cleanup levels for chlordane were used for alpha- and gamma-chlordane.
5. Cleanup level for gamma-BHC was used for delta-BHC.
6. Endosulfan values were used for Endosulfan sulfate, since there were no cleanup levels for Endosulfan sulfate.
7. Method C values were selected for constituents where an area background value was calculated but the calculated value was higher than the Method C level, per WAC 173-340-706(1)(a)(i).

Abbreviations:
-- = not established, not applicable, or otherwise not available
ug/L = micrograms per liter
CAS = Chemical Abstract Service
CFR = Code of Federal Regulations
CLARC = Cleanup Levels and Risk Calculation
CWA = Clean Water Act
MCL = maximum contaminant level
MTCA = Model Toxics Control Act
NTR = National Toxics Rule
TPH = total petroleum hydrocarbons
WAC = Washington Administrative Code

TABLE A-4

SELECTION OF SOIL COCS

Stericycle Kent Facility
Kent, Washington

Area of Concern	COPC	Reporting Units	RI Screening Level	Updated FS CUL[1]	Basis[2]	Detected in Groundwater[3]	Revised FS CUL[4]	Maximum Detection	Location Of Maximum Detection	Date of Maximum Detection	Carry COPC Forward to FS[5]	Constituent of Concern[6]
AOC-1	Arsenic	mg/kg	7.3	7.3	NB	yes	NA	1.5	MW-10-S-1	6/15/1989	no	no
	Cadmium	mg/kg	0.8	1.54	GW	NA	3,500	1.0			no	no
	Copper	mg/kg	36	36.4	NB	NA	140,000	12			no	no
	Methylene chloride	µg/kg	24	23.7	GW	no	21,000,000	0.8 J			no	no
	Silver	mg/kg	0.61	0.61	NB	NA	17,500	2.0			no	no
	Zinc	mg/kg	85.1	85.1	NB	NA	1,050,000	24			no	no
AOC-2	1,4-Dichlorobenzene	µg/kg	120	319	GW	no	24,306,000	230	MW-8	6/16/1989	no	no
	2-Methylnaphthalene	µg/kg	27,330	27,300	GW	no	14,000,000	84,000 D	HA-10	7/14/2000	no	no
	Arsenic	mg/kg	7.3	7.3	NB	yes	NA	40	T-2	6/21/1989	yes	yes
	Benzene	µg/kg	8.4	8.4	GW	yes	NA	2,000	MW-23	7/7/2000	yes	yes
	Benzo(a)anthracene	µg/kg	720	715	GW	no	180,000	790 D	MW-23	7/7/2000	no	no
	Benzo(a)pyrene	µg/kg	1,940	1,940	GW	no	18,000	6,800 D	MW-23	7/7/2000	no	no
	Benzo(b)fluoranthene	µg/kg	2,460	2,460	GW	yes	2,460	7,100 D	MW-23	7/7/2000	yes	yes
	Benzo(k)fluoranthene	µg/kg	2,460	2,460	GW	no	1,800,000	3,400 D	MW-23	7/7/2000	no	no
	Cadmium	mg/kg	0.80	1.54	GW	NA	3,500	2.54	HA-8	7/5/2000	no	no
	Carbazole[7]	mg/kg	1,500	none	--	--	--	3.25 D	MW-23	7/7/2000	no	no
	Chrysene	µg/kg	796	796	GW	yes	NA	8,500 D	MW-23	7/7/2000	yes	yes
	Copper	mg/kg	36.4	36.4	NB	NA	140,000	40.4	HA-8	7/5/2000	no	no
	Coumaphos[7]	µg/kg	2,330	none	--	--	--	3,000	MW-8	6/16/1989	no	no
	Cyanide	mg/kg	0.10	0.20	PQL	yes	0.20	0.655	HA-10	7/14/2000	yes	yes
	Diesel	mg/kg	2,000	2,000	--	--	--	15,900 D	HA-10	7/14/2000	yes	yes
	Gasoline	mg/kg	30	30	--	--	--	1,710 DB	HA-9	7/5/2000	yes	yes
	Lube Oil	mg/kg	2,000	2,000	--	--	--	5,720 D	HA-10	7/14/2000	yes	yes
	Mercury	mg/kg	0.07	0.21	GW	NA	2.0	2.03 DB	HA-8	7/5/2000	no	no[8]
	Methylene chloride	µg/kg	24	23.7	GW	no	21,000,000	9,800 B	MW-8	6/16/1989	no	no
	Mevinphos[7]	µg/kg	96	none	--	--	--	190	T-1	6/21/1989	no	no
	Naphthalene	µg/kg	19,700	1,100	GW	no	70,000,000	20,000 D	HA-9	7/5/2000	no	no
	p-Cymene	mg/kg	3,940	350,000	DC	NA	na	4.22	HA-9	7/5/2000	no	no
	sec-Butyl-benzene	mg/kg	1,200	3.94	GW	no	350,000,000	1.48	HA-9	7/5/2000	no	no
	Silver	mg/kg	0.61	0.61	NB	NA	17,500	2.0	T-2	6/21/1989	no	no
	Zinc	mg/kg	85.1	85.1	NB	NA	1,050,000	81.7	HA-8	7/5/2000	no	no
AOC-3	1,4-Dichlorobenzene	µg/kg	120	319	GW	no	24,306,000	21	KT-PIPE-5	1/19/1999	no	no
	2-Methylnaphthalene	µg/kg	27,330	27,300	GW	no	14,000,000	120	S4	11/30/1988	no	no
	Antimony	mg/kg	5.52	5.06	GW	NA	1,400	11 L	S4	11/30/1988	no	no
	Arsenic	mg/kg	7.3	7.3	NB	yes	NA	20	5307-SB-1-20131011-2	10/11/2013	yes	yes
	Benzene	µg/kg	8.4	8.4	GW	yes	NA	12	KT-PIPE-7	1/19/1999	yes	yes
	Benzo(a)anthracene	µg/kg	720	715	GW	no	180,000	260	S4	11/30/1988	no	no
	Benzo(a)pyrene	µg/kg	1,940	1,940	GW	no	18,000	290	S4	11/30/1988	no	no
	Benzo(b)fluoranthene	µg/kg	2,460	2,460	GW	yes	2,460	295	S4	11/30/1988	no	no
	Benzo(k)fluoranthene	µg/kg	2,460	2,460	GW	no	1,800,000	295	S4	11/30/1988	no	no
	Cadmium	mg/kg	0.8	1.54	GW	NA	3,500	1.0	S4	11/30/1988	no	no
	Chrysene	µg/kg	796	796	GW	yes	NA	450	S4	11/30/1988	no	no
	Copper	mg/kg	36.4	36.4	NB	NA	140,000	356	S4	11/30/1988	no	no
	Lube Oil	mg/kg	2,000	2,000	--	--	--	100	KT-PIPE-7	1/19/1999	no	no
	Mercury	mg/kg	0.07	0.21	GW	NA	2.0	0.28	S4	11/30/1988	no	no
	Methylene chloride	µg/kg	24	23.7	GW	no	21,000,000	890 J	5307-SB-1-20131011-2	10/11/2013	no	no
	Naphthalene	µg/kg	19,700	1,100	GW	no	70,000,000	480	KT-PIPE-5	1/19/1999	no	no
	p-Cymene	mg/kg	3,940	350,000	DC	NA	NA	0.19	KT-PIPE-7	1/19/1999	no	no
	sec-Butyl-benzene	mg/kg	1,200	3.94	GW	no	350,000,000	0.22	KT-PIPE-7	1/19/1999	no	no
	Silver	mg/kg	0.61	0.61	NB	NA	17,500	2.00	MW-12	6/26/1989	no	no
	Thallium	mg/kg	0.34	0.23	GW	NA	35	11 L	S4	11/30/1988	no	no
	Zinc	mg/kg	85.10	85.10	NB	NA	1,050,000	194.00	S4	11/30/1988	no	no
	Vinyl Chloride	mg/kg	0.00094	0.0	PQL	yes	NA	0.14	5307-SB-1-20131011-2	10/11/2013	yes	yes

TABLE A-4

SELECTION OF SOIL COCS

Stericycle Kent Facility
Kent, Washington

Area of Concern	COPC	Reporting Units	RI Screening Level	Updated FS CUL[1]	Basis[2]	Detected in Groundwater[3]	Revised FS CUL[4]	Maximum Detection	Location Of Maximum Detection	Date of Maximum Detection	Carry COPC Forward to FS[5]	Constituent of Concern[6]
AOC-4	1,4-Dichlorobenzene	µg/kg	120	319	GW	no	24,306,000	70	S-10	3/14/1990	no	no
	2-Methylnaphthalene	µg/kg	27,330	27,330	GW	no	14,000,000	9,900	KT-SSP-0399-4	3/1/1999	no	no
	4,4'-DDD	µg/kg	2.3	68.8	GW	no	547,000	220	S-10	3/14/1990	no	no
	4,4'-DDE	µg/kg	4.3	31.0	GW	no	386,000	160	S-10	3/14/1990	no	no
	4,4'-DDT	µg/kg	34	393	GW	no	386,000	130	S-1	6/27/1989	no	no
	alpha-Chlordane	µg/kg	2.9	204.0	GW	no	375,000	7.0	S-10	3/14/1990	no	no
	Antimony	mg/kg	5.52	5.06	GW	NA	1,400	21	S1	11/30/1988	no	no
	Arsenic	mg/kg	7.3	7.3	NB	yes	NA	71	S1	11/30/1988	yes	yes
	Benzo(a)anthracene	µg/kg	720	715	GW	no	180,000	30,000	S1	11/30/1988	no	no
	Benzo(a)pyrene	µg/kg	1,940	1,940	GW	no	18,000	29,000	S1	11/30/1988	yes	yes
	Benzo(b)fluoranthene	µg/kg	2,460	2,460	GW	yes	2,460	50,000	S1	11/30/1988	yes	yes
	Benzo(k)fluoranthene	µg/kg	2,460	2,460	GW	no	1,800,000	50,000	S1	11/30/1988	no	no
	Cadmium	mg/kg	0.8	1.54	GW	NA	3,500	21	S1	11/30/1988	no	no
	Chrysene	µg/kg	796	796	GW	yes	NA	50000	S1	11/30/1988	yes	yes
	Copper	mg/kg	36.4	36.4	NB	NA	140,000	582	S1	11/30/1988	no	no
	Coumaphos[7]	µg/kg	2330	none	--	--	--	7.0	S-10	3/14/1990	no	no
	delta-BHC	µg/kg	8.2	8.2	GW	no	119,000	4.5	S-10	3/14/1990	no	no
	Dieldrin	µg/kg	1.3	9.0	GW	no	8,200	12	S-10	3/14/1990	no	no
	Diesel	mg/kg	2,000	2,000				2,900	KT-SSP-0399-4	3/1/1999	yes	yes
	Endosulfan sulfate	µg/kg	0.79	5.53	GW	no	21,000,000	12	S-10	3/14/1990	no	no
	gamma-Chlordane	µg/kg	2.9	16.3	GW	no	375,000	11	S-10	3/14/1990	no	no
	Gasoline	mg/kg	30	30	--	--	--	5.5	KT-SSP-0399-4	3/1/1999	no	no
	Heptachlor epoxide	µg/kg	4.2	26.6	GW	no	14000	3.0	S-10	3/14/1990	no	no
	Lindane	µg/kg	2.6	4.5	PQL	yes	4.5	4.9	S-1	6/27/1989	yes	yes
	Mercury	mg/kg	0.07	0.21	GW	NA	2.0	2.0	S1	11/30/1988	no	no
	Methylene chloride	µg/kg	24	23.7	GW	no	21,000,000	110	KT-SSP-0399-4	3/1/1999	no	no
	Mevinphos[7]	µg/kg	96	none	--	--	--	2.0	S-10	3/14/1990	no	no
	Naphthalene	µg/kg	19,700	1,100	GW	no	70,000,000	4,600	KT-SSP-0399-4	3/1/1999	no	no
	p-Cymene	mg/kg	3,940	350,000	DC	NA	NA	0.7	KT-SSP-0399-4	3/1/1999	no	no
	Silver	mg/kg	0.61	0.61	NB	NA	17,500	3.0	S1	11/30/1988	no	no
	Thallium	mg/kg	0.34	0.23	GW	NA	35	19	S1	11/30/1988	no	no
	Zinc	mg/kg	85.1	85.1	NB	NA	1,050,000	1,360	S1	11/30/1988	no	no
AOC 5	No COPCs Detected											
AOC 2 and 3	2-Methylnaphthalene	µg/kg	27,330	27,300	GW	no	14,000,000	2,300 D	HA-3	7/14/2000	no	no
	Arsenic	mg/kg	7.3	7.3	NB	yes	NA	11.1	HA-3	7/14/2000	yes	yes
	Benzo(a)pyrene	µg/kg	1,940	1,940	GW	no	18,000	130 JD	HA-3	7/14/2000	no	no
	Cadmium	mg/kg	0.8	1.54	GW	NA	3,500	2.39	HA-2	7/14/2000	no	no
	Chrysene	µg/kg	796	796	GW	yes	NA	160 JD	HA-3	7/14/2000	no	no
	Cyanide	mg/kg	0.1	0.2	PQL	yes	0.2	0.087 JB	HA-3	7/14/2000	no	no
	Diesel	mg/kg	2,000	2,000	--	--	--	1850 D	HA-3	7/14/2000	no	no
	Gasoline	mg/kg	30	30	--	--	--	115 DB	HA-3	7/14/2000	yes	yes
	Lube Oil	mg/kg	2,000	2,000	--	--	--	524 D	HA-3	7/14/2000	no	no
	Mercury	mg/kg	0.07	0.21	GW	NA	2.0	0.0625 J	HA-3	7/14/2000	no	no
	Naphthalene	µg/kg	19,700	1,100	GW	no	70,000,000	1000	HA-2	7/14/2000	no	no
	Silver	mg/kg	0.61	0.61	NB	NA	17,500	0.0683 J	HA-3	7/14/2000	no	no

TABLE A-4

SELECTION OF SOIL COCS

Stericycle Kent Facility
Kent, Washington

Area of Concern	COPC	Reporting Units	RI Screening Level	Updated FS CUL[1]	Basis[2]	Detected in Groundwater[3]	Revised FS CUL[4]	Maximum Detection	Location Of Maximum Detection	Date of Maximum Detection	Carry COPC Forward to FS[5]	Constituent of Concern[6]
AOC 2 and 4	2-Methylnaphthalene	µg/kg	27,330	27,300	GW	no	14,000,000	3,900 D	HA-6	7/5/2000	no	no
	Arsenic	mg/kg	7.3	7.3	NB	yes	NA	8.95	HA-5	7/5/2000	yes	yes
	Benzene	µg/kg	8.4	8.5	GW	yes	NA	120	HA-6	7/5/2000	yes	yes
	Benzo(a)pyrene	µg/kg	1940	1940	GW	no	18,000	340	HA-5	7/5/2000	no	no
	Cadmium	mg/kg	0.8	1.54	GW	NA	3,500	1.94	HA-7	7/5/2000	no	no
	Copper	mg/kg	36.4	36.4	NB	NA	140,000	27.9	HA-6	7/5/2000	no	no
	Cyanide	mg/kg	0.1	0.2	PQL	yes	0.2	0.193 JB	HA-6	7/5/2000	no	no
	Diesel	mg/kg	2,000	2000	--	--	--	473	HA-6	7/5/2000	no	no
	Gasoline	mg/kg	30	30	--	--	--	332 DB	HA-6	7/5/2000	yes	yes
	Lube Oil	mg/kg	2,000	2000	--	--	--	248	HA-6	7/5/2000	no	no
	Mercury	mg/kg	0.07	0.21	GW	NA	2.0	0.273	HA-6	7/5/2000	no	no
	Methylene chloride	µg/kg	24	23.7	GW	no	21,000,000	310 J	HA-5	7/5/2000	no	no
	Naphthalene	µg/kg	19,700	1100	GW	no	70,000,000	1,400	HA-6	7/5/2000	no	no
	p-Cymene	mg/kg	3,940	350,000	DC	NA	NA	0.181	HA-6	7/5/2000	no	no
	sec-Butyl-benzene	mg/kg	1,200	3.94	GW	no	350,000,000	0.0608 J	HA-6	7/5/2000	no	no
	Silver	mg/kg	0.61	0.61	NB	NA	17,500	0.133 J	HA-6	7/5/2000	no	no
	Zinc	mg/kg	85.1	85.1	NB	NA	1,050,000	57.4	HA-6	7/5/2000	no	no
10 Day Transfer Yard	4,4'-DDD	µg/kg	2.3	68.6	GW	no	547,000	1,500	GP-4	6/15/2007	no	no
	4,4'-DDE	µg/kg	4.3	31.0	GW	no	386,000	550	GP-3	6/15/2007	no	no
	4,4'-DDT	µg/kg	34	393	GW	no	386,000	150	GP-1	6/15/2007	no	no
	alpha-Chlordane	µg/kg	3	204	GW	no	375,000	120	GP-4	6/15/2007	no	no
	Arsenic	mg/kg	7.3	7.3	NB	yes	NA	14.0	CS-6	7/3/1989	yes	yes
	Copper	mg/kg	36.4	36.4	NB	NA	140,000	31	MW-7S	6/19/1989	no	no
	Dieldrin	µg/kg	1.3	9.0	GW	no	8,200	40	GP-1	6/15/2007	no	no
	Endosulfan sulfate	µg/kg	0.8	5.5	GW	no	21,000,000	48	GP-1	6/15/2007	no	no
	gamma-Chlordane	µg/kg	2.9	16.3	GW	no	375,000	6.8	MW-7S	6/19/1989	no	no
	Heptachlor epoxide	µg/kg	4.2	26.6	GW	no	14,000	8.4 J	GP-1	6/15/2007	no	no
	Lindane	µg/kg	2.6	4.5	PQL	yes	4.5	8.1 J	GP-1	6/15/2007	yes	yes
	Mercury	mg/kg	0.07	0.21	GW	NA	2.0	1.5	MW-7S	6/19/1989	no	no
	Methylene chloride	µg/kg	24	23.7	GW	no	21,000,000	23 B	MW-7S	6/19/1989	no	no
	Zinc	mg/kg	85.1	85.1	NB	NA	1,050,000	66	MW-7S	6/19/1989	no	no
Process and Storage Area	Arsenic	mg/kg	7.3	7.3	NB	yes	NA	7.0	T-3	2/27/1990	no	no
	Copper	mg/kg	36.4	36.4	NB	NA	140,000	26	T-3	2/27/1990	no	no
	Zinc	mg/kg	85.1	85.1	NB	NA	1,050,000	31	T-4	2/27/1990	no	no

Notes:

1. RI and FSWP CULs updated in FS Section 3.0.
2. Basis for the updated CUL. If based on groundwater protection, groundwater data from 2009 through 2015 was evaluated to see if concentrations had exceeded the applicable CUL.
3. Compounds not detected in groundwater at concentrations above the FS cleanup level were evaluated based on direct contact, which resulted in an upward adjustment of the soil CUL.
4. The revised soil FS Cleanup level based on direct contact if the soil screening level based on protection of groundwater was removed due to empirical demonstration that the soil contaminants are not migrating to groundwater (WAC 173-340-747(3)(f)).
5. If RI and FSWP COPC does not exceed the revised soil screening level, it is no longer carried forward.
6. Final FS constituents of concern are based on CUL evaluation.
7. These compounds (identified in the RI) no longer have risk based screening criteria.
8. Mercury not carried forward as a COC here due to the concentration being nearly the same as the CUL. Additionally, the B flag indicates that the sample is possibly biased high due to blank contamination.

Abbreviations:

-- = not established, not applicable, or otherwise not available
µg/kg = micrograms per kilogram
AOC = Area of Concern
COC = compound of concern
COPC = consituent of potential concern
CUL = cleanup level
DC = direct contact
FS = feasibility study
FSWP = Feasibility Study Work Plan
GW = groundwater protection
mg/kg = milligrams per kilogram
NA = not applicable
NB = natural background
PQL = practical quantitation limit
RI = remedial investigation
WAC = Washington Administrative Code

TABLE A-5

SELECTION OF GROUNDWATER COCS [1]

Stericycle Kent Facility
Kent, Washington

concentrations in micrograms per liter (µg/L)

				One or More Exceedance in Last 5 Years				No Exceedance in Last 5 Years							
Area of Concern	**COPC**	**RI Screening Level**	**FS Screening Level**	**Exceeds Screening Level in Last Five Years**	**Date of Most Recent Exceedance**	**Location of Most Recent Exceedance**	**Concentration of Most Recent Exceedance**	**Detected in Last Five Years**	**Date of Last Detection**	**Concentration of Detection**	**Location of Most Recent Detection**	**Most Recent Date Sampled**	**Exceeds Screening Level in Most Recent Sample**	**Carry COPC Forward to FS[2]**	**Constituent of Concern[3]**
AOC-1	Total Arsenic	0.018	10.5	Yes	10/14/2014	MW-118-I1	12.5	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Benzene	0.795	0.80	No	--	--	--	No	4/19/2010	0.060 J	MW-118-I1	October 2014	No	No	No
	Chromium (Hexavalent)	11	10	Yes	10/14/2014	MW-118-I1	17 J	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Cyanide	5.2	10	Yes	10/17/2013	MW-118-I1	6 J	Yes	--	--	--	October 2014	No[5]	Yes	No
	Diesel	500	500	No	--	--	--	No	1/17/2002	297 J	MW-118-I1	January 2009	No	No	No
	Total Iron	300	84430	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Yes
	Dissolved Manganese	50	10590	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Yes
	Pentachlorophenol	0.27	--	No[4]	--	--	--	No	not detected 2001-2014			October 2014	No[5]	No	No
	Trichloroethene	0.11	--	No	--	--	--	No	not detected 2001-2014			October 2014	No[5]	No	No
	Vinyl Chloride	0.025	0.03	No[4]	--	--	--	No	not detected 2001-2014			October 2014	No[5]	Yes	Yes
AOC-2	Total Arsenic	0.018	10.5	Yes	10/7/2014	MW-102-I1 and MW-126-I	26.9 [6]	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Benzene	0.795	0.80	Yes	4/16/2013	MW-123-S	3.7	Yes	--	--	--	October 2014	No	No	No
	Chromium (Hexavalent)	11	10	Yes	10/14/2015	MW-102-I1	15	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Cyanide	5.2	10	Yes	10/8/2014	MW-24D	32 J	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Diesel	500	500	Yes	10/15/2013	MW-123-S	620 J	Yes	--	--	--	October 2014	No	No	No
	Total Iron	300	84430	NA	NA	NA	NA	No	5/7/2009	122,000 [6]	MW-102-I1, MW-16, MW-126-I, MW-123-S, MW-123-I, and MW-102-S	NA	NA	Yes	Yes
	Dissolved Manganese	50	10590	Yes	10/17/2003	MW-16	1700	Yes	--	--	--	October 2013	Yes	Yes	No
	Pentachlorophenol	0.27	--	Yes	10/17/2013	MW-16	0.53 J	Yes	--	--	--	October 2014	No[5]	No	No
	Trichloroethene	0.11	--	Yes	4/17/2012	MW-120-I1	0.16 J	Yes	--	--	--	October 2014	No[5]	No	No
	Vinyl Chloride	0.025	0.03	Yes	10/14/2014	MW-120-I1	0.19 J	Yes	--	--	--	October 2014	Yes	Yes	Yes
AOC-3	Total Arsenic	0.018	10.5	Yes	10/7/2014	MW-112-D	1.9	Yes	--	--	--	October 2014	Yes	Yes	No
	Benzene	0.795	0.80	No	--	--	--	Yes	4/17/2013	0.11 J	MW-112-S	October 2014	No	No	No
	Chromium (Hexavalent)	11	10	Yes	4/17/2013	MW-112-D and MW-112-S	17 J [6]	Yes	--	--	--	October 2013	No	Yes	Yes
	Cyanide	5.2	10	Yes	10/7/2014	MW-112-D	17.0	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Diesel	500	500	No	--	--	--	Yes	10/11/2011	440 J	MW-112-D	October 2014	No	No	No
	Total Iron	300	84430	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Yes
	Dissolved Manganese	50	10590	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Yes
	Pentachlorophenol	0.27	--	No[4]	--	--	--	No	1/14/2005	0.093	MW-112-D	October 2014	No[5]	No	No
	Trichloroethene	0.11	--	No	--	--	--	No	not detected 2001-2014			October 2014	No[5]	No	No
	Vinyl Chloride	0.025	0.03	Yes	4/10/2012	MW-112-S	0.16 J	Yes	--	--	--	October 2014	No[5]	Yes	Yes
AOC-5	Total Arsenic	0.018	10.5	Yes	10/9/2014	17-D and MW-1	36.3 [6]	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Benzene	0.795	0.80	No	--	--		Yes	4/19/2010	0.040 J	MW-117-I2	October 2014	No	No	No
	Chromium (Hexavalent)	11	10	Yes	4/17/2014	MW-117-D and MW-117-I2	21 J [6]	Yes	--	--	--	April 2014	Yes	Yes	Yes
	Cyanide	5.2	10	Yes	10/9/2014	MW-117-D	17	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Diesel	500	500	NA	NA	NA	NA	No	not detected 2001-2009			NA	NA	No	No
	Total Iron	300	84430	NA	NA	NA	NA	Yes	5/7/2009	40400	MW-117-I2	NA	NA	Yes	No
	Dissolved Manganese	50	10590	NA	NA	NA	NA	Yes	5/7/2009	5840	MW-117-I2	NA	NA	Yes	No
	Pentachlorophenol	0.27	--	Yes	4/22/2013	MW-117-I2	0.39 J	Yes	--	--	--	October 2014	No[5]	No	No
	Trichloroethene	0.11	--	No	--	--	--	No	not detected 2001-2014			October 2014	No[5]	No	No
	Vinyl Chloride	0.025	0.03	No	--	--	--	Yes	1/13/2009	0.13 J	MW-117-I2	October 2014	No[5]	Yes	Yes

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TABLE A-5

SELECTION OF GROUNDWATER COCS [1]

Stericycle Kent Facility
Kent, Washington

concentrations in micrograms per liter (µg/L)

Area of Concern	COPC	RI Screening Level	FS Screening Level	One or More Exceedance in Last 5 Years				No Exceedance in Last 5 Years				Most Recent Date Sampled	Exceeds Screening Level in Most Recent Sample	Carry COPC Forward to FS[2]	Constituent of Concern[3]
				Exceeds Screening Level in Last Five Years	Date of Most Recent Exceedance	Location of Most Recent Exceedance	Concentration of Most Recent Exceedance	Detected in Last Five Years	Date of Last Detection	Concentration of Detection	Location of Most Recent Detection				
10 Day Transfer Yard	Total Arsenic	0.018	10.5	Yes	October 2014	MW-122-I2, MW-130-I, MW-131-I, and MW-133-D	14.5 [6]	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Benzene	0.795	0.80	No	--	--	--	No	not detected 2001-2014			October 2014	No	No	No
	Chromium (Hexavalent)	11	10	Yes	October 2014	MW-122-I2, MW-130-I, MW-131-I	23 J [6]	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Cyanide	5.2	10	Yes	4/15/2014	MW-122-S	14.0	Yes	--	--	--	October 2014	No[5]	Yes	Yes
	Diesel	500	500	No	--	--	--	Yes	10/22/2013	19 J	MW-130-I	October 2014	No	No	No
	Total Iron	300	84430	NA	NA	NA	NA	Yes	5/11/2009	51300	MW-131-I	NA	NA	Yes	No
	Dissolved Manganese	50	10590	Yes	4/18/2012	MW-131-I	1170	Yes	--	--	--	April 2012	Yes	Yes	No
	Pentachlorophenol	0.27	--	Yes	4/18/2013	MW-133-S	0.34 J	Yes	--	--	--	October 2014	No[5]	No	No
	Trichloroethene	0.11	--	No	--	--	--	No	4/18/2003	1.07	MW-122-S	October 2014	No[5]	No	No
	Vinyl Chloride	0.025	0.03	No	--	--	--	No	not detected 2001-2014			October 2014	No[5]	Yes	Yes
Other	Total Arsenic	0.018	10.5	Yes	10/14/2014	MW-128-I	9.4	Yes	--	--	--	October 2014	Yes	Yes	No
	Benzene	0.795	0.80	No	--	--	--	No	not detected 2003-2014			October 2014	No	No	No
	Chromium (Hexavalent)	11	10	Yes	4/21/2014	MW-128-I	32 J	Yes	--	--	--	October 2014	No	Yes	Yes
	Cyanide	5.2	10	No	--	--	--	No	1/22/2007	6.0	MW-128-I	October 2014	No[5]	Yes	No
	Diesel	500	500	NA	NA	NA	NA	No	not detected 2003-2009			NA	NA	No	No
	Total Iron	300	84430	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Yes
	Dissolved Manganese	50	10590	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Yes
	Pentachlorophenol	0.27	--	No[4]	--	--	--	No	4/16/2004	0.225	MW-128-I	October 2014	No[5]	No	No
	Trichloroethene	0.11	--	No	--	--	--	No	not detected 2003-2014			October 2014	No[5]	No	No
	Vinyl Chloride	0.025	0.03	No	--	--	--	No	not detected 2003-2014			October 2014	No[5]	Yes	Yes
Off-Site	Total Arsenic	0.018	10.5	Yes	10/9/2014	MW-114-I1 and MW-129-I	12.6 [6]	Yes	--	--	--	October 2014	Yes	Yes	Yes
	Benzene	0.795	0.80	No	--	--	--	Yes	10/13/2011	0.070	MW-114-I1	October 2014	No	No	No
	Chromium (Hexavalent)	11	10	Yes	4/17/2014	MW-114-I1 and MW-129-I	21 J [6]	Yes	--	--	--	April 2014	Yes	Yes	Yes
	Cyanide	5.2	10	Yes	1/12/2010	GP2010-1	435	Yes	10/22/2013	0.004	MW-114-I1	October 2014	No[5]	Yes	Yes
	Diesel	500	500	No	--	--	--	No	7/11/2003	0.65	MW-114-I1	October 2014	No	No	No
	Total Iron	300	84430	NA	NA	NA	NA	Yes	5/11/2009	92,000 [6]	MW-114-I1 and MW-129-I	NA	NA	Yes	Yes
	Dissolved Manganese	50	10590	NA	NA	NA	NA	Yes	5/11/2009	7,610 [6]	MW-114-I1 and MW-129-I	NA	NA	Yes	No
	Pentachlorophenol	0.27	--	Yes	4/22/2013	MW-114-I1	0.36 J	Yes	--	--	--	October 2014	No[5]	No	No
	Trichloroethene	0.11	--	No	--	--	--	No	not detected 2001-2014			October 2014	No[5]	No	No
	Vinyl Chloride	0.025	0.03	No	--	--	--	No	not detected 2001-2014			October 2014	No[5]	Yes	Yes

Notes:

1. Data qualifiers are as follows:
   J = the result is estimated
2. If RI and FSWP COPC does not exceed the revised groundwater screening level, it is no longer carried forward
3. Final FS COCs based on CUL evaluation.
4. Non-detect at this AOC for past five years, but reporting limit exceeds screening level.
5. Does not currently exceed, but reporting limit of nondetected value is greater than screening level.
6. Represents the maximum detected concentration for all exceedances in this AOC.

Abbreviations:

-- = not established, not applicable, or otherwise not available
µg/L = micrograms per liter
AOC = Area of Concern
COC = constituent of concern
COPC = constituent of potential concern
FS = Feasibility Study
NA = not analyzed
RI = remedial investigation

APPENDIX B

Background Calculations

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

Arsenic MW-129-I

data in ug/L

9
9
9.1
9.13
9.21
9.43
9.6
9.8
9.8
9.93
10.4
10.5
10.6
10.8
11
11.1
11.2
11.4
11.7
12
12

MTCA*Stat* 3.0

Number of samples		Uncensored values	
Uncensored	21	Mean	10.32
Censored	0	Lognormal mean	10.32
TOTAL	21	Std. devn.	1.01
		Median	10.4
		Min.	9
		Max.	12

Lognormal distribution?	Normal distribution?
r-squared is: 0.95	r-squared is: 0.95

Recommendations:

Use lognormal distribution.

Distribution selection	Enter percentile	Value corresponding to that percentile is:
1	90	11.74
1 = Lognormal	50th	10.27
2 = Normal	4 X 50th	41.09
3 = Nonparametric method		

Coefficient of Variation = 0.1

Background calculations

Cyanide at MW-129-I

<0.002
<0.002
<0.003
<0.003
<0.003
<0.003
<0.003
<0.003
<0.003
<0.003
<0.003
<0.003
0.002
0.002
0.003
0.003
0.003
<0.01
<0.01
0.006
0.01

MTCA*Stat* 3.0

Number of samples		Uncensored values	
Uncensored	7	Mean	0.00
Censored	14	Lognormal mean	0.00
TOTAL	21	Std. devn.	0.00
		Median	0.003
		Min.	0.002
		Max.	0.01

Lognormal distribution?	Normal distribution?
r-squared is: 0.97	r-squared is: 0.94

Recommendations:

Use lognormal distribution.

Distribution selection	Enter percentile	Value corresponding to that percentile is:
1	90	0.01
1 = Lognormal	50th	0.00
2 = Normal	4 X 50th	0.01
3 = Nonparametric method	Coefficient of Variation = 1.28	

49.1
53
58
65.4
65.6
66.4
66.6
82.8
86.7

Iron MW-129-I

data in mg/L

MTCA*Stat* 3.0

Number of samples		Uncensored values	
Uncensored	9	Mean	65.96
Censored	0	Lognormal mean	66.08
TOTAL	9	Std. devn.	12.40
		Median	65.6
		Min.	49.1
		Max.	86.7

Lognormal distribution?	Normal distribution?
r-squared is: 0.94	r-squared is: 0.92

Recommendations:

Use lognormal distribution.

Distribution selection			Value corresponding
	Enter percentile		to that percentile is:
1	90		84.43
1 = Lognormal		50th	64.95
2 = Normal		4 X 50th	259.78
3 = Nonparametric method		Coefficient of Variation = 0.21	

Background calculations

Manganese MW-129-I and MW-114-I

1.60972
1.66
1.75
1.78
1.8
1.87
2.13
2.41
4.7
7.1
7.34
7.61
7.97
8.14
8.27098
8.43
8.5
8.69
8.77
8.85
9.47
9.6
10.5
10.5
10.8
14.3

MTCA*Stat* 3.0

Number of samples		Uncensored values	
Uncensored	26	Mean	6.71
Censored	0	Lognormal mean	7.15
TOTAL	26	Std. devn.	3.67
		Median	8.055
		Min.	1.60972
		Max.	14.3

Lognormal distribution?	Normal distribution?
r-squared is: 0.80	r-squared is: 0.89

Recommendations:

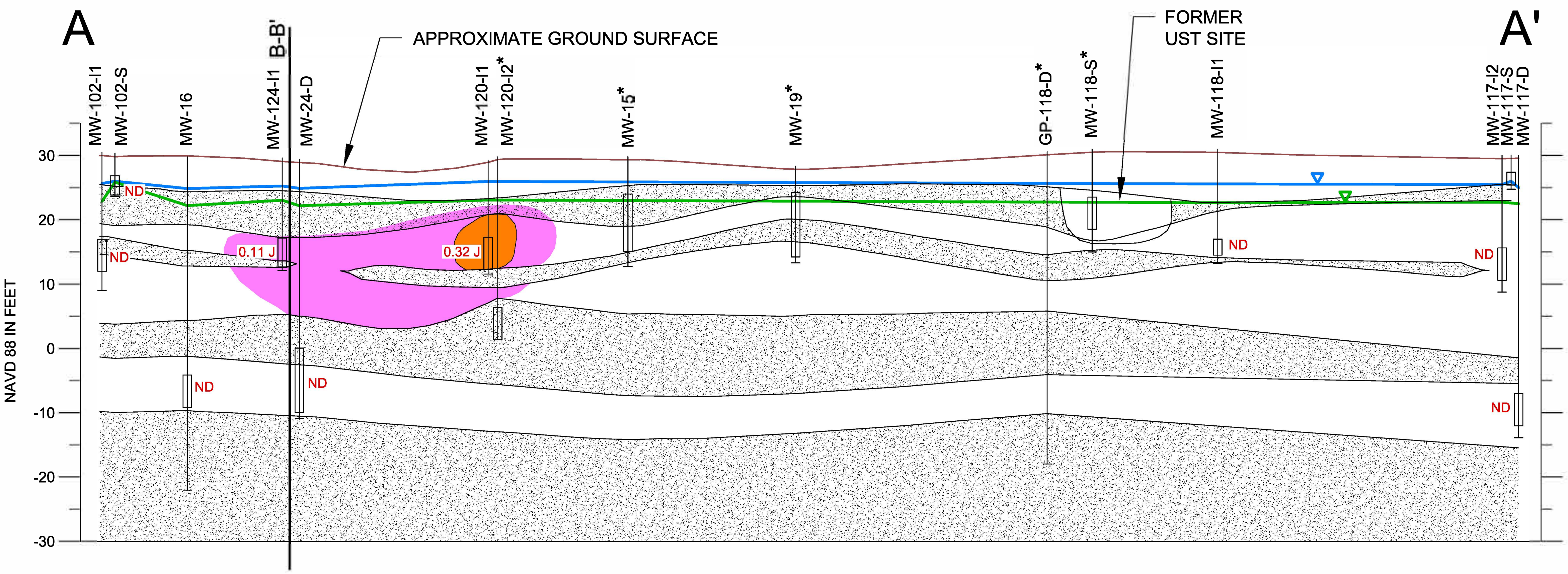
Use nonparametric method.

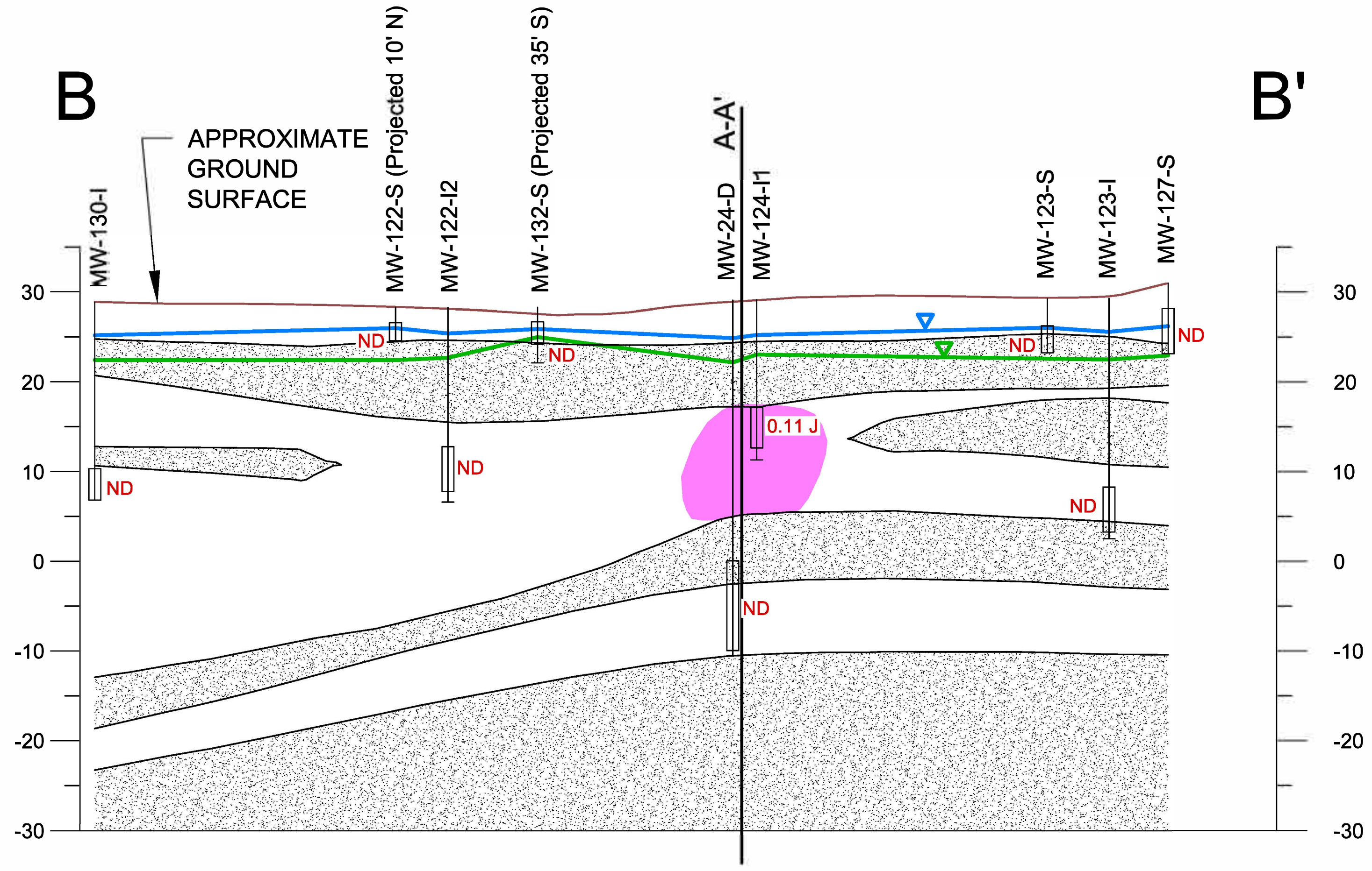
Distribution selection	Enter percentile	Value corresponding to that percentile is:
3	90	10.59
1 = Lognormal	50th	8.06
2 = Normal	4 X 50th	32.22
3 = Nonparametric method	Coefficient of Variation = N/A	

APPENDIX C

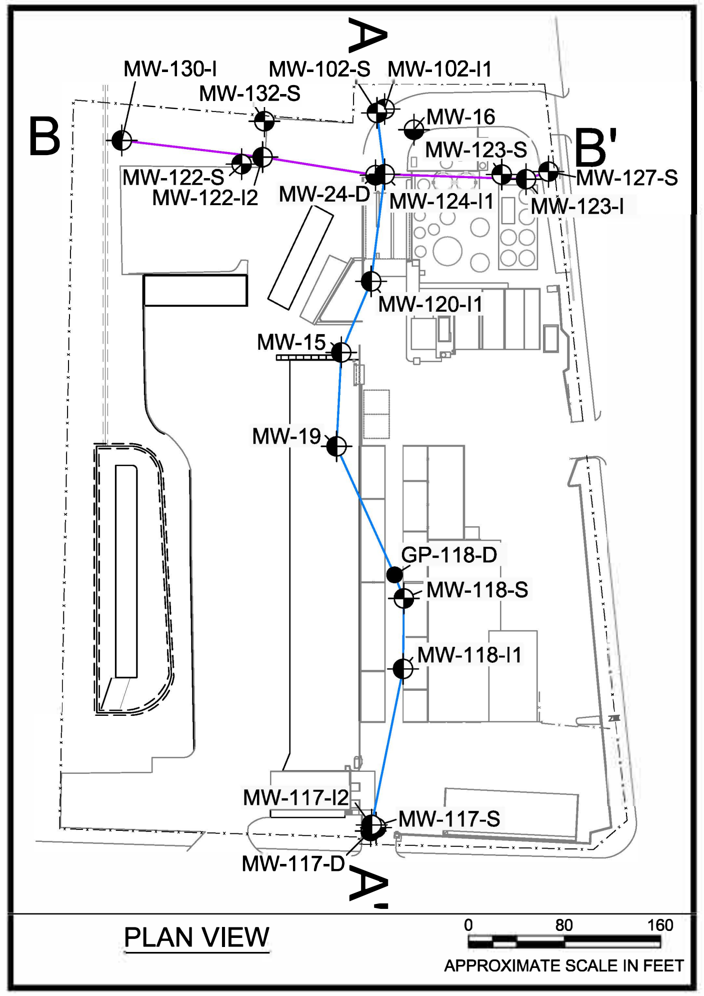
COCs Isopach Maps

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)





Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)



PLAN VIEW

EXPLANATION

MW-124-I1 — WELL NAME

BLANK CASING

PERFORATED CASING

110 J CONCENTRATIONS ARE THE MAXIMUM DETECTION FROM 2015 SAMPLING EVENTS (µg/L)

J = VALUE IS ESTIMATED

ND = NOT DETECTED

* ABANDONED WELL OR TEMPORARY WELL, ONLY SHOWN FOR GEOLOGIC INTERPRETATION.

APPROXIMATE ELEVATION OF GENERALIZED POTENTIOMETRIC SURFACE (APRIL 6, 2015)

APPROXIMATE ELEVATION OF GENERALIZED POTENTIOMETRIC SURFACE (OCTOBER 5, 2015)

☐ SHALLOW WATER-BEARING UNIT, INTERMEDIATE AQUIFER AND DEEP AQUIFER UNITS

▨ AQUITARD CONTAINING SILT AND CLAY

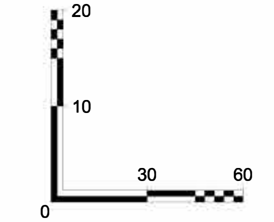
FS CLEANUP LEVEL

VINYL CHLORIDE CUL = 0.025 µg/L

KEY

🟪 ≥ 0.025 µg/L

🟧 ≥ 0.3 µg/L

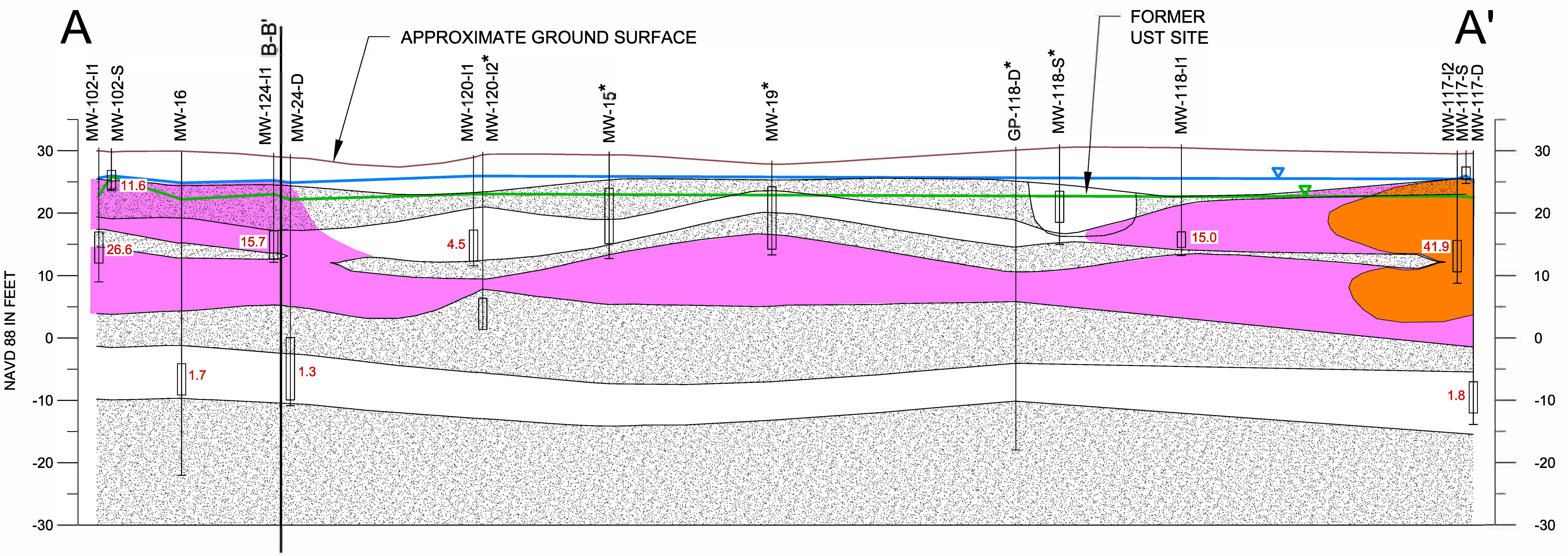


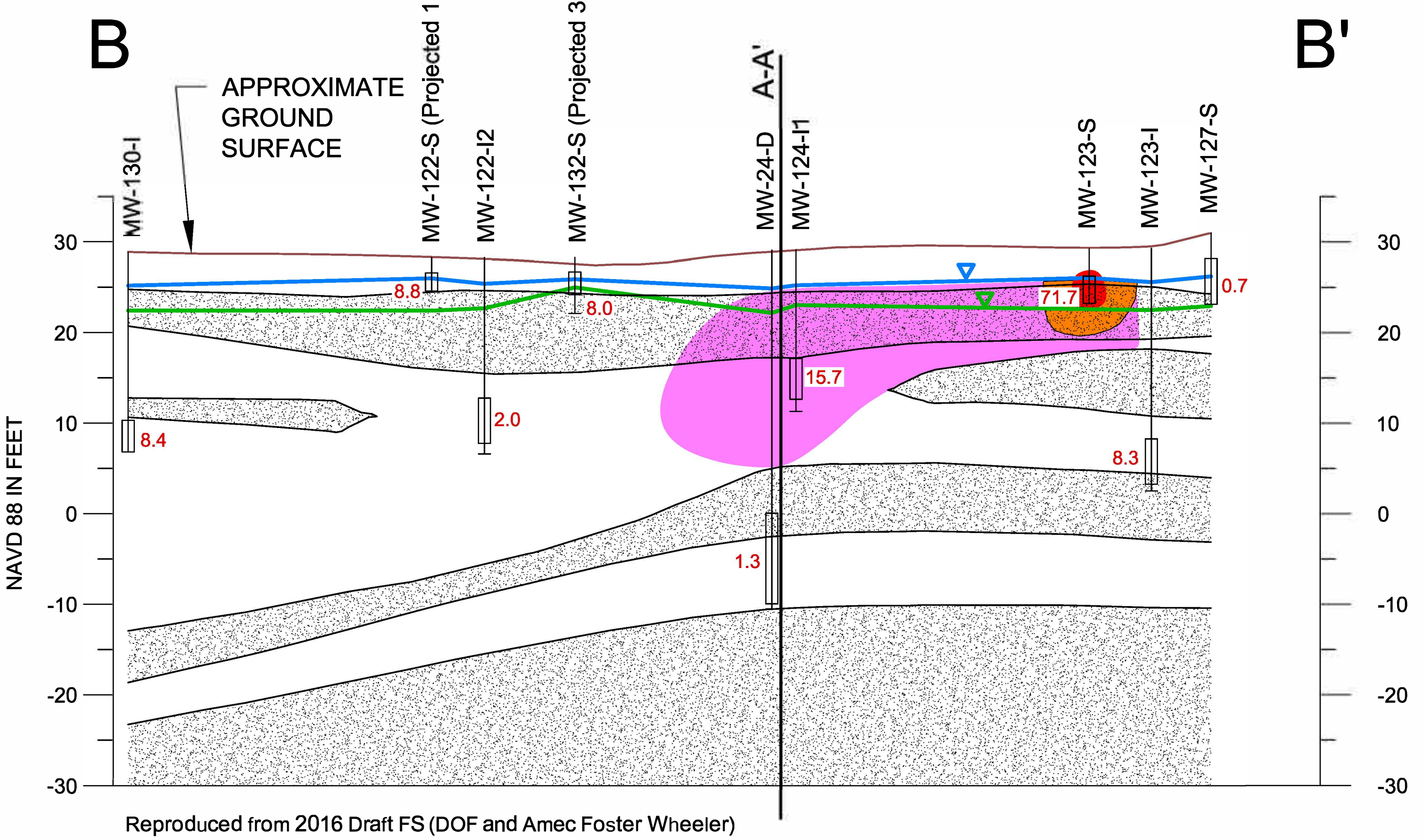
APPROXIMATE SCALE IN FEET
VERTICAL EXAGGERATION = 3X

CROSS SECTIONS A-A' AND B-B'
VINYL CHLORIDE
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Appendix **C-1**

Plot Date: 03/23/16 - 3:56pm, Plotted by: adam.stenberg
Drawing Path: S:\9464\009_2015\CAD\, Drawing Name: StericycleKent-SitePlan_032216.dwg





Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

EXPLANATION

MW-118-I1 — WELL NAME

BLANK CASING

PERFORATED CASING

15.0 CONCENTRATIONS ARE THE MAXIMUM DETECTION FROM 2015 SAMPLING EVENTS (mg/L)

* ABANDONED WELL OR TEMPORARY WELL, ONLY SHOWN FOR GEOLOGIC INTERPRETATION.

APPROXIMATE ELEVATION OF GENERALIZED POTENTIOMETRIC SURFACE (APRIL 6, 2015)

APPROXIMATE ELEVATION OF GENERALIZED POTENTIOMETRIC SURFACE (OCTOBER 5, 2015)

☐ SHALLOW WATER-BEARING UNIT, INTERMEDIATE AQUIFER AND DEEP AQUIFER UNITS

▨ AQUITARD CONTAINING SILT AND CLAY

FS CLEANUP LEVEL

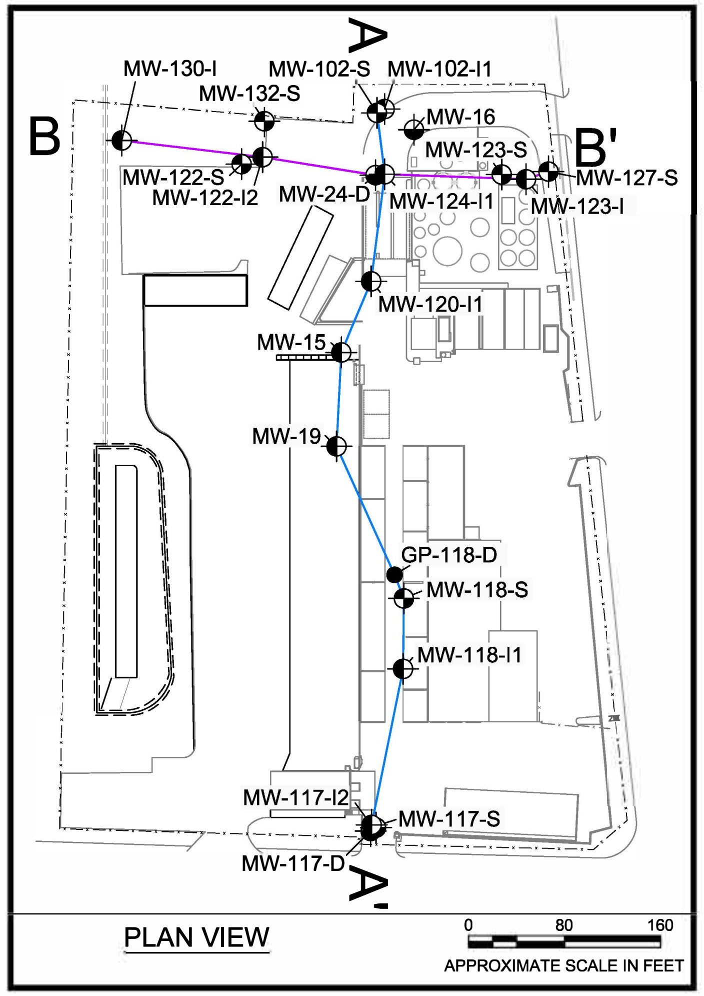
ARSENIC CUL = 10.5 µg/L

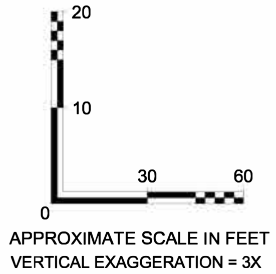
KEY

🟪 ≥ 10.5 µg/L

🟧 ≥ 40 µg/L

🟥 ≥ 70 µg/L



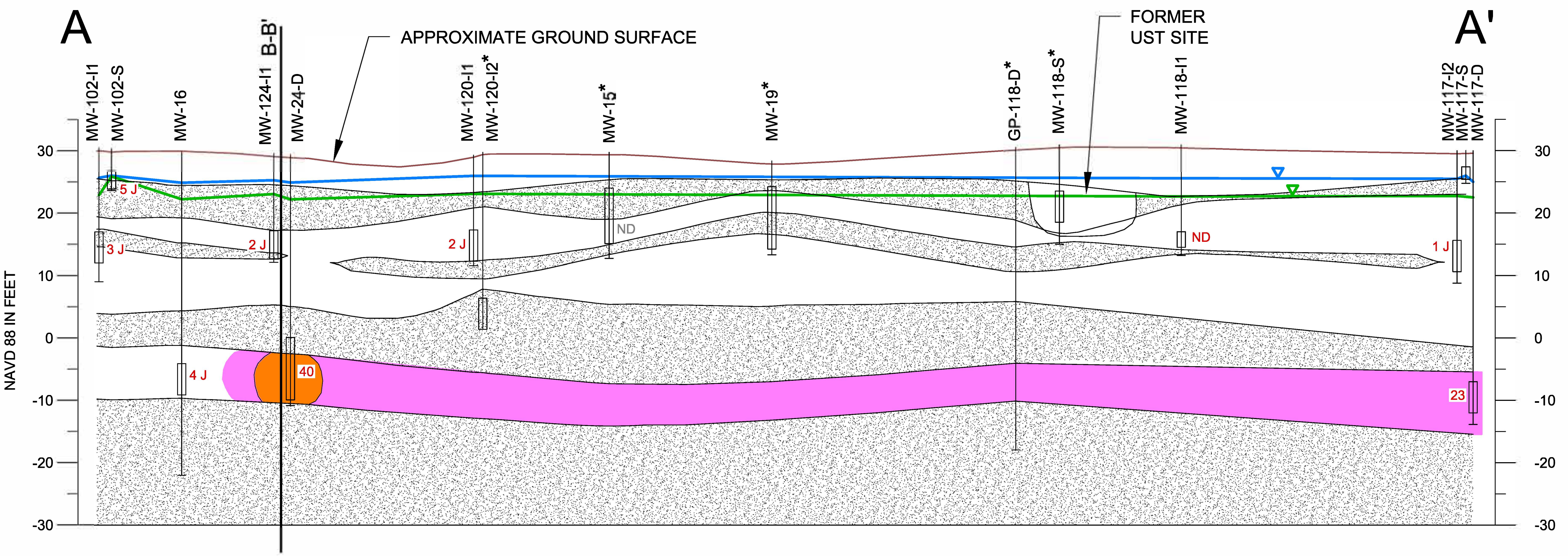


APPROXIMATE SCALE IN FEET
VERTICAL EXAGGERATION = 3X

CROSS SECTIONS A-A' AND B-B'
ARSENIC
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Appendix C-2

Plot Date: 03/23/16 - 3:56pm, Plotted by: adam.stenberg
Drawing Path: S:\9464\009_2015\CAD\, Drawing Name: StericycleKent-SitePlan_032216.dwg



EXPLANATION

WELL NAME

BLANK CASING

PERFORATED CASING

CONCENTRATIONS ARE THE MAXIMUM DETECTION FROM 2015 SAMPLING EVENTS (µg/L)

J = VALUE IS ESTIMATED

ND = NOT DETECTED

* ABANDONED WELL OR TEMPORARY WELL, ONLY SHOWN FOR GEOLOGIC INTERPRETATION.

APPROXIMATE ELEVATION OF GENERALIZED POTENTIOMETRIC SURFACE (APRIL 6, 2015)

APPROXIMATE ELEVATION OF GENERALIZED POTENTIOMETRIC SURFACE (OCTOBER 5, 2015)

☐ SHALLOW WATER-BEARING UNIT, INTERMEDIATE AQUIFER AND DEEP AQUIFER UNITS

▨ AQUITARD CONTAINING SILT AND CLAY

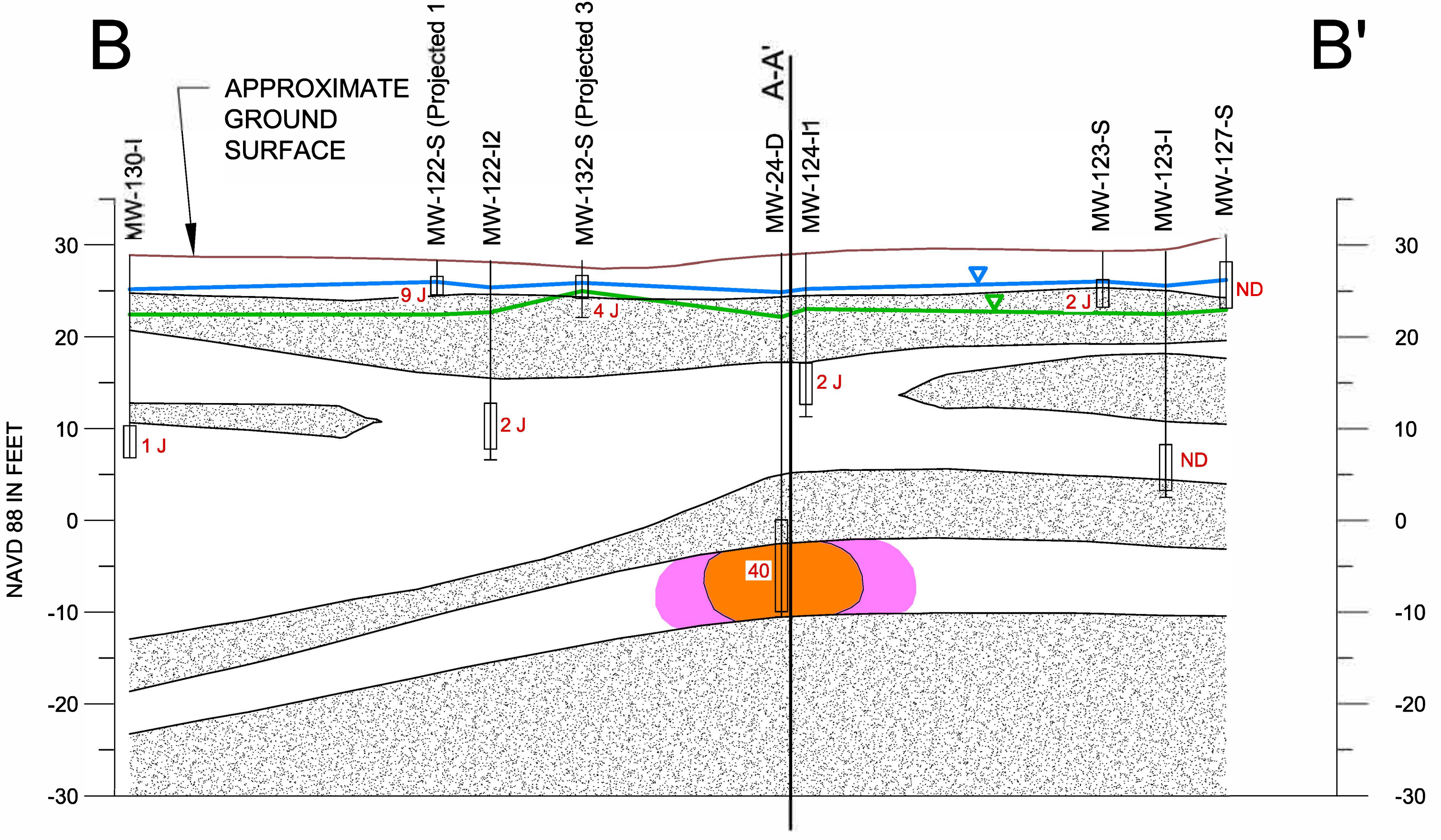
FS CLEANUP LEVEL

CYANIDE CUL = 10 µg/L

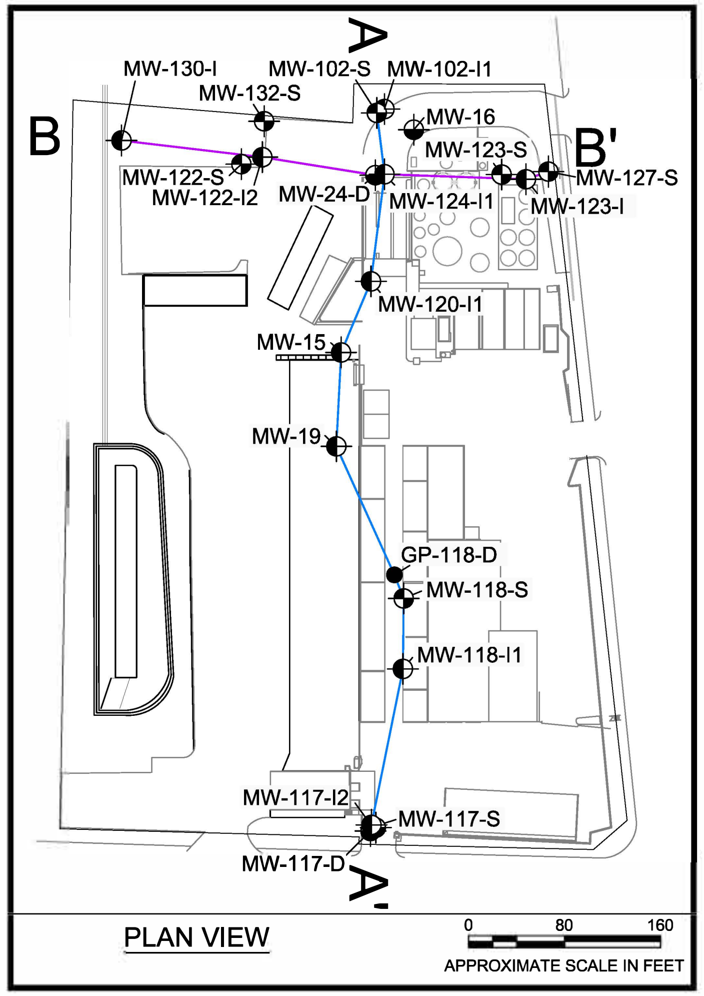
KEY

🟪 ≥ 10 µg/L

🟧 ≥ 30 µg/L



Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)



PLAN VIEW

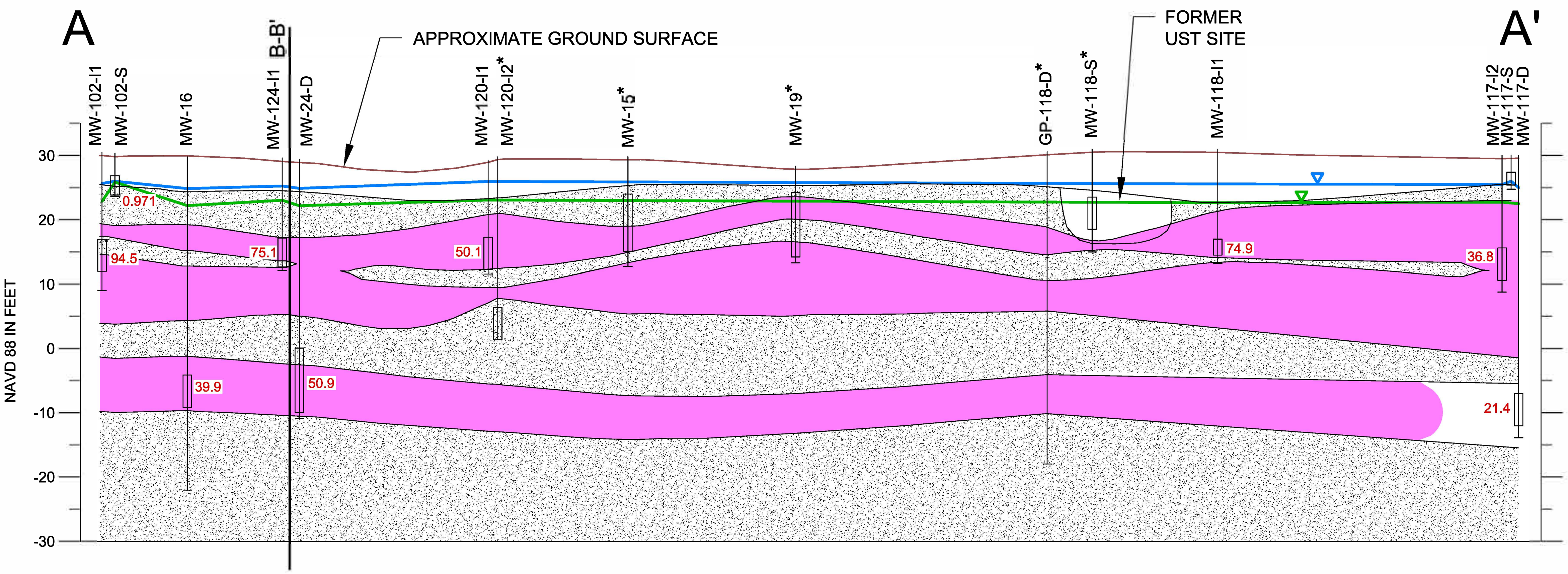
20
10
0 30 60

APPROXIMATE SCALE IN FEET
VERTICAL EXAGGERATION = 3X

CROSS SECTIONS A-A' AND B-B'
CYANIDE
Stericycle Kent Facility
Kent, Washington

By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Appendix **C-3**

Plot Date: 03/23/16 - 3:57pm, Plotted by: adam.stenberg
Drawing Path: S:\9464\009_2015\CAD\, Drawing Name: StericycleKent-SitePlan_032216.dwg



EXPLANATION

WELL NAME
BLANK CASING
PERFORATED CASING
74.9 CONCENTRATIONS ARE THE MAXIMUM DETECTION FROM 2015 SAMPLING EVENTS (mg/L)

NA = NOT ANALYZED

* ABANDONED WELL OR TEMPORARY WELL, ONLY SHOWN FOR GEOLOGIC INTERPRETATION.

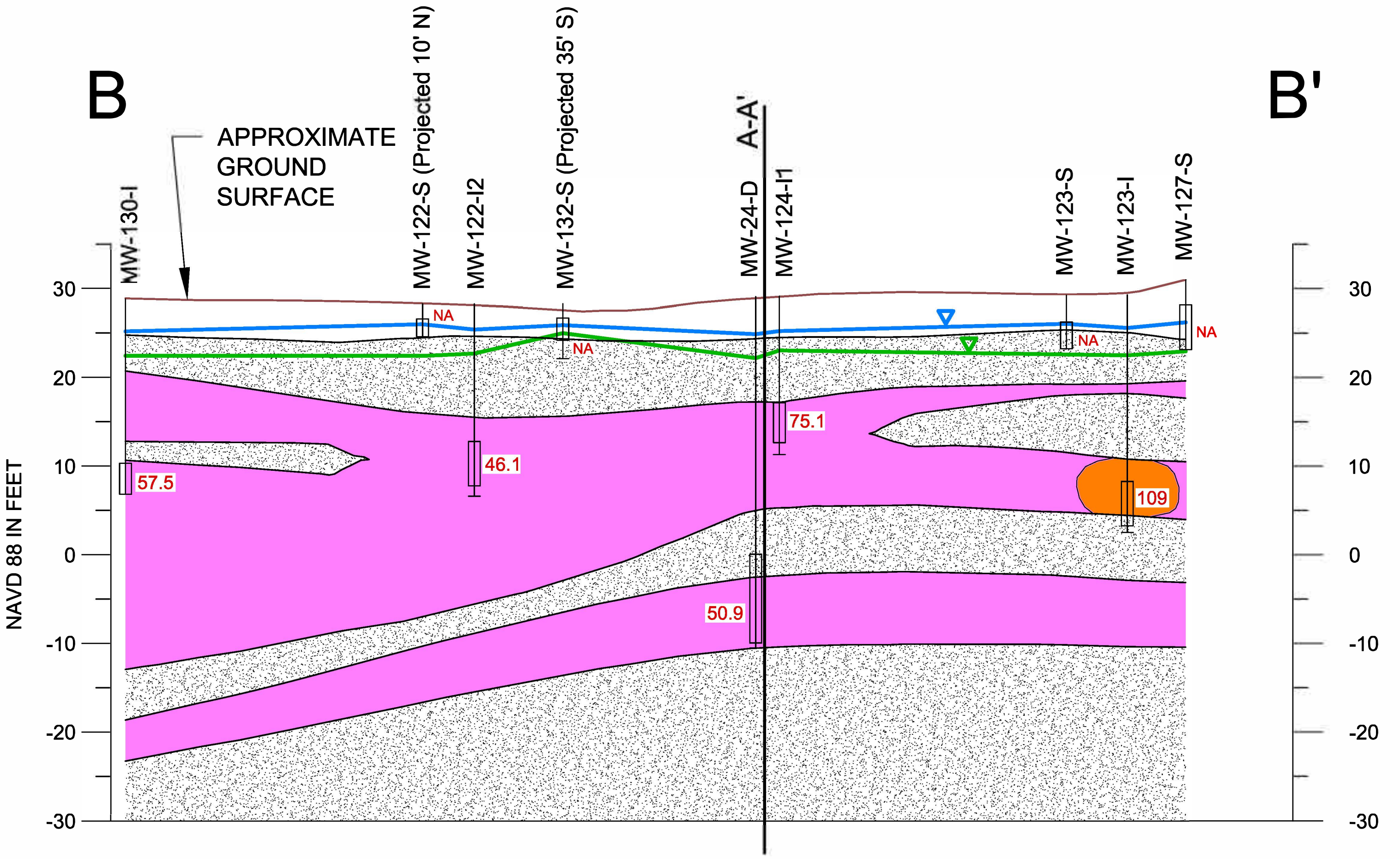
▽	APPROXIMATE ELEVATION OF GENERALIZED POTENTIOMETRIC SURFACE (APRIL 6, 2015)
▽	APPROXIMATE ELEVATION OF GENERALIZED POTENTIOMETRIC SURFACE (OCTOBER 5, 2015)
☐	SHALLOW WATER-BEARING UNIT, INTERMEDIATE AQUIFER AND DEEP AQUIFER UNITS
▨	AQUITARD CONTAINING SILT AND CLAY

FS CLEANUP LEVEL

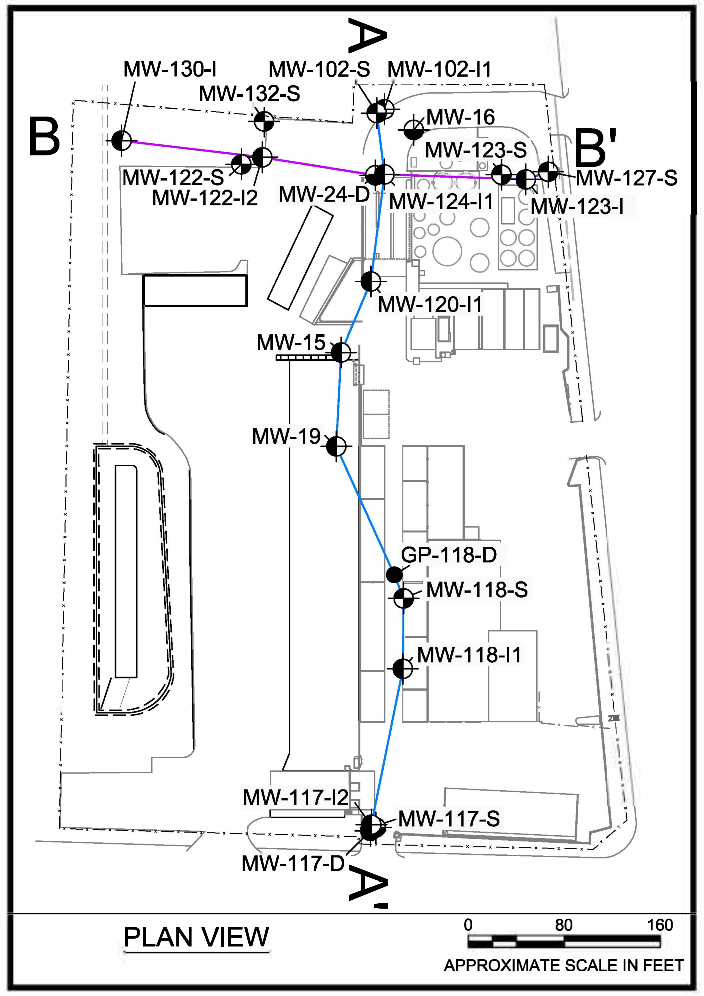
IRON CUL = 24.50 mg/L

KEY

🟪	≥ 24.50 mg/L
🟧	≥ 100 mg/L



Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

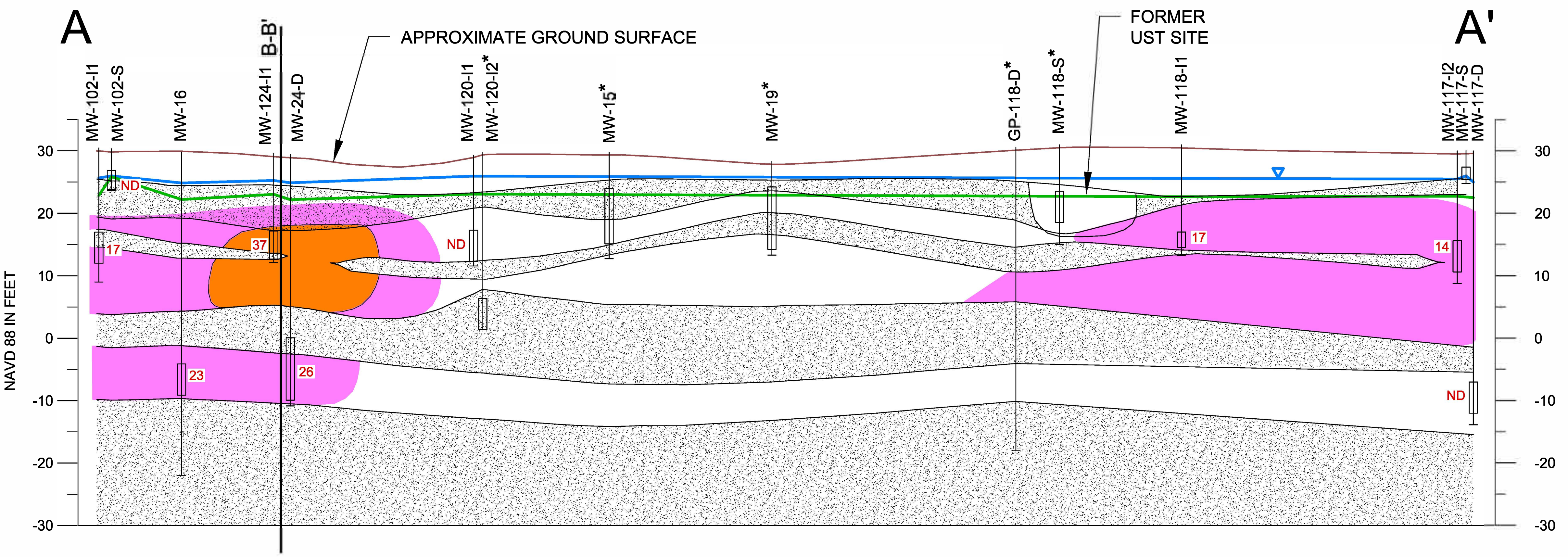


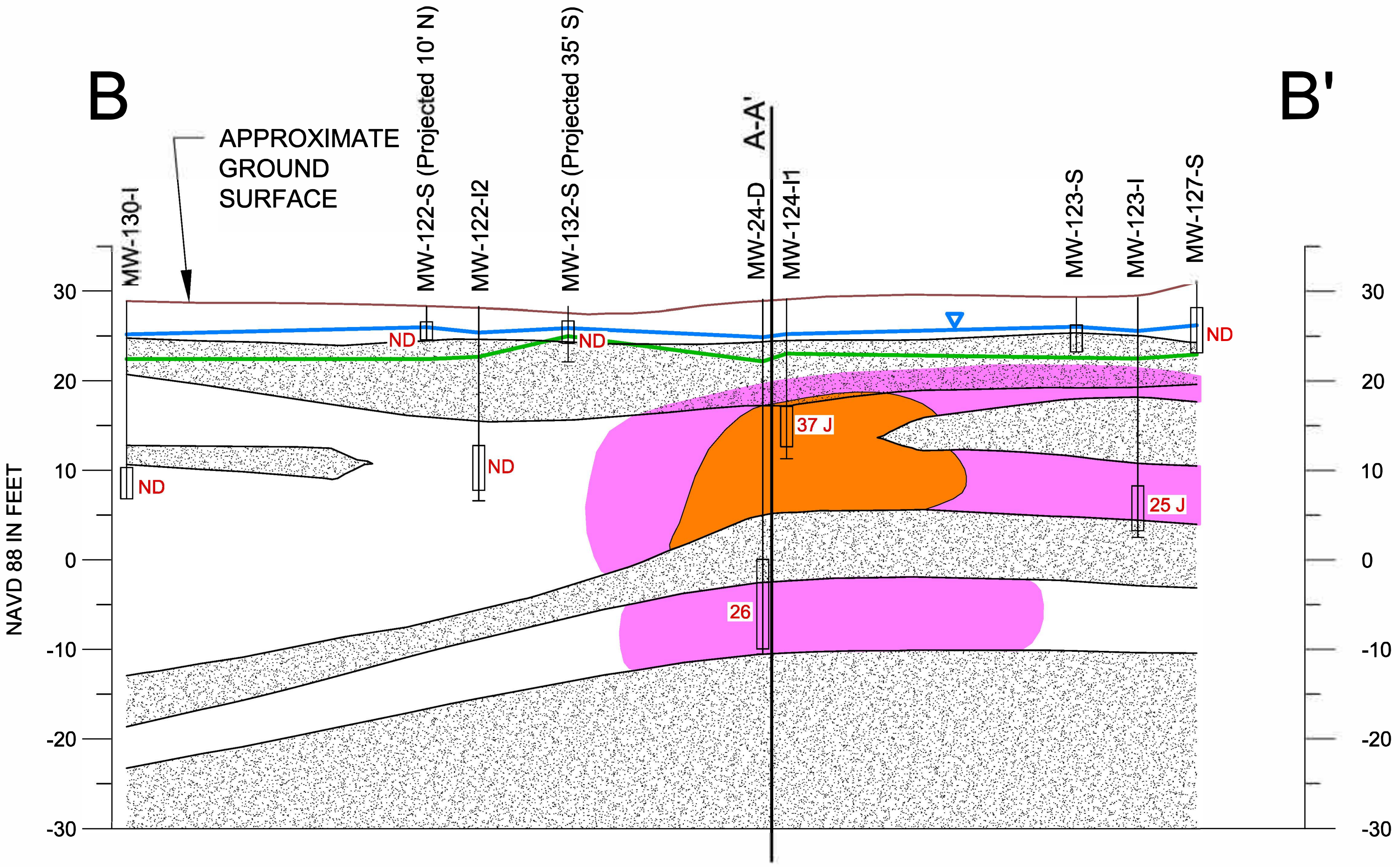
0 10 20
0 30 60
APPROXIMATE SCALE IN FEET
VERTICAL EXAGGERATION = 3X

CROSS SECTIONS A-A' AND B-B'
IRON
Stericycle Kent Facility
Kent, Washington

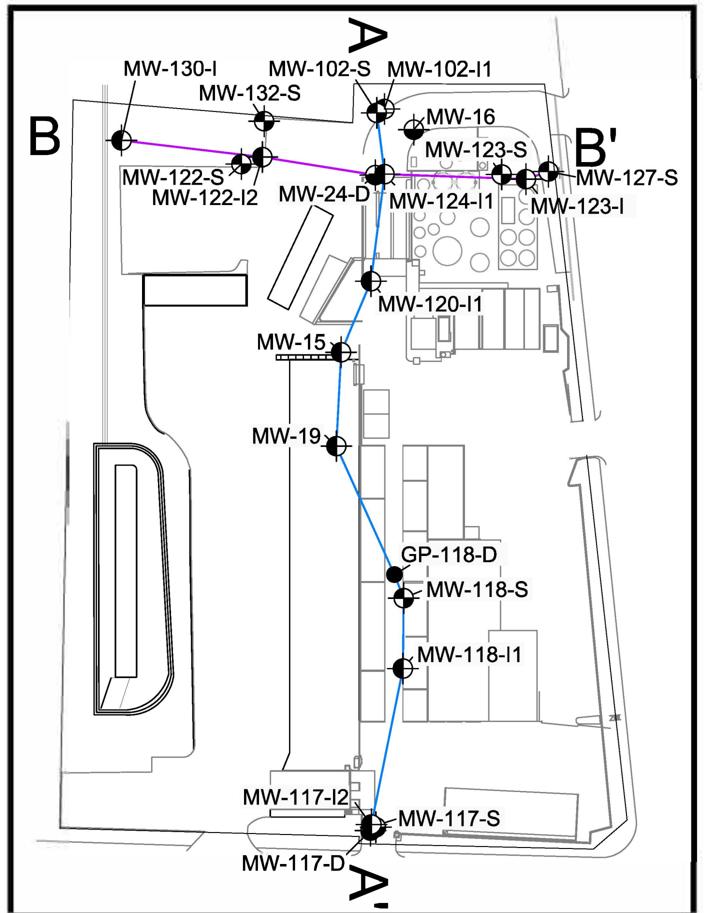
By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Appendix C-4

Plot Date: 03/23/16 - 3:58pm, Plotted by: adam.stenberg
Drawing Path: S:\9464\009_2015\CAD\, Drawing Name: StericycleKent-SitePlan_032216.dwg





Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)



PLAN VIEW

EXPLANATION

MW-118-I1 — WELL NAME

BLANK CASING

PERFORATED CASING

17 CONCENTRATIONS ARE THE MAXIMUM DETECTION FROM 2015 SAMPLING EVENTS (µg/L)

J = VALUE IS ESTIMATED

ND = NOT DETECTED

* ABANDONED WELL OR TEMPORARY WELL, ONLY SHOWN FOR GEOLOGIC INTERPRETATION.

APPROXIMATE ELEVATION OF GENERALIZED POTENTIOMETRIC SURFACE (APRIL 6, 2015)

APPROXIMATE ELEVATION OF GENERALIZED POTENTIOMETRIC SURFACE (OCTOBER 5, 2015)

☐ SHALLOW WATER-BEARING UNIT, INTERMEDIATE AQUIFER AND DEEP AQUIFER UNITS

▨ AQUITARD CONTAINING SILT AND CLAY

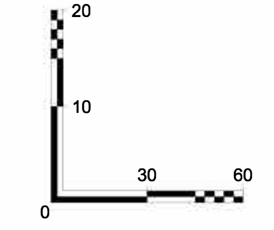
FS CLEANUP LEVEL

HEX CHROMIUM CUL = 10.0 µg/L

KEY

🟪 ≥ 10 µg/L

🟧 ≥ 30 µg/L



APPROXIMATE SCALE IN FEET
VERTICAL EXAGGERATION = 3X

CROSS SECTIONS A-A' AND B-B'
HEX CHROMIUM
Stericycle Kent Facility
Kent, Washington

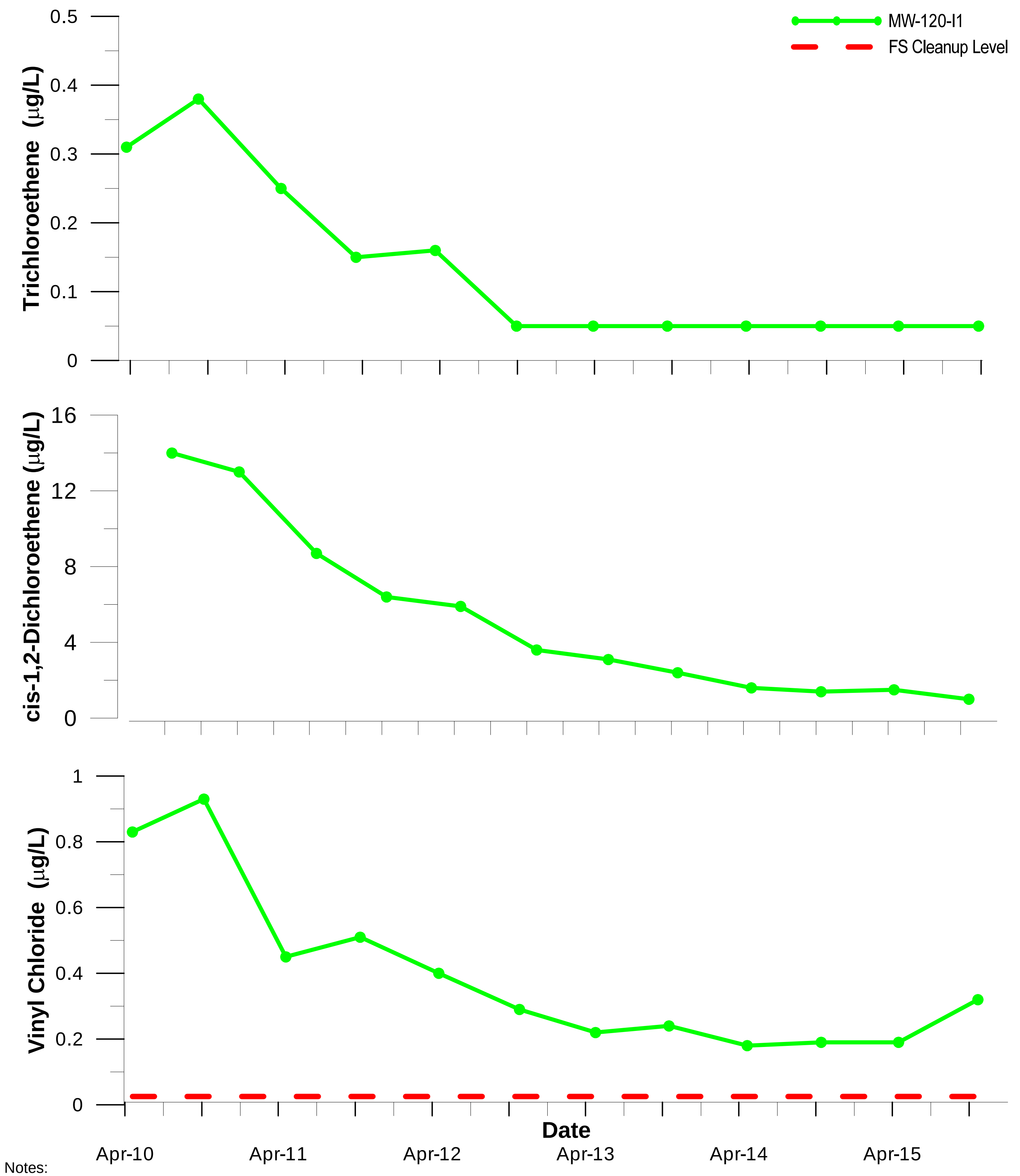
By: APS	Date: 03/23/16	Project No. 9464.002
Amec Foster Wheeler Environment & Infrastructure, Inc.		Appendix **C-5**

Plot Date: 03/23/16 - 3:58pm, Plotted by: adam.stenberg
Drawing Path: S:\9464\009_2015\CAD\, Drawing Name: StericycleKent-SitePlan_032216.dwg

APPENDIX D

Groundwater COCs Trend Chart

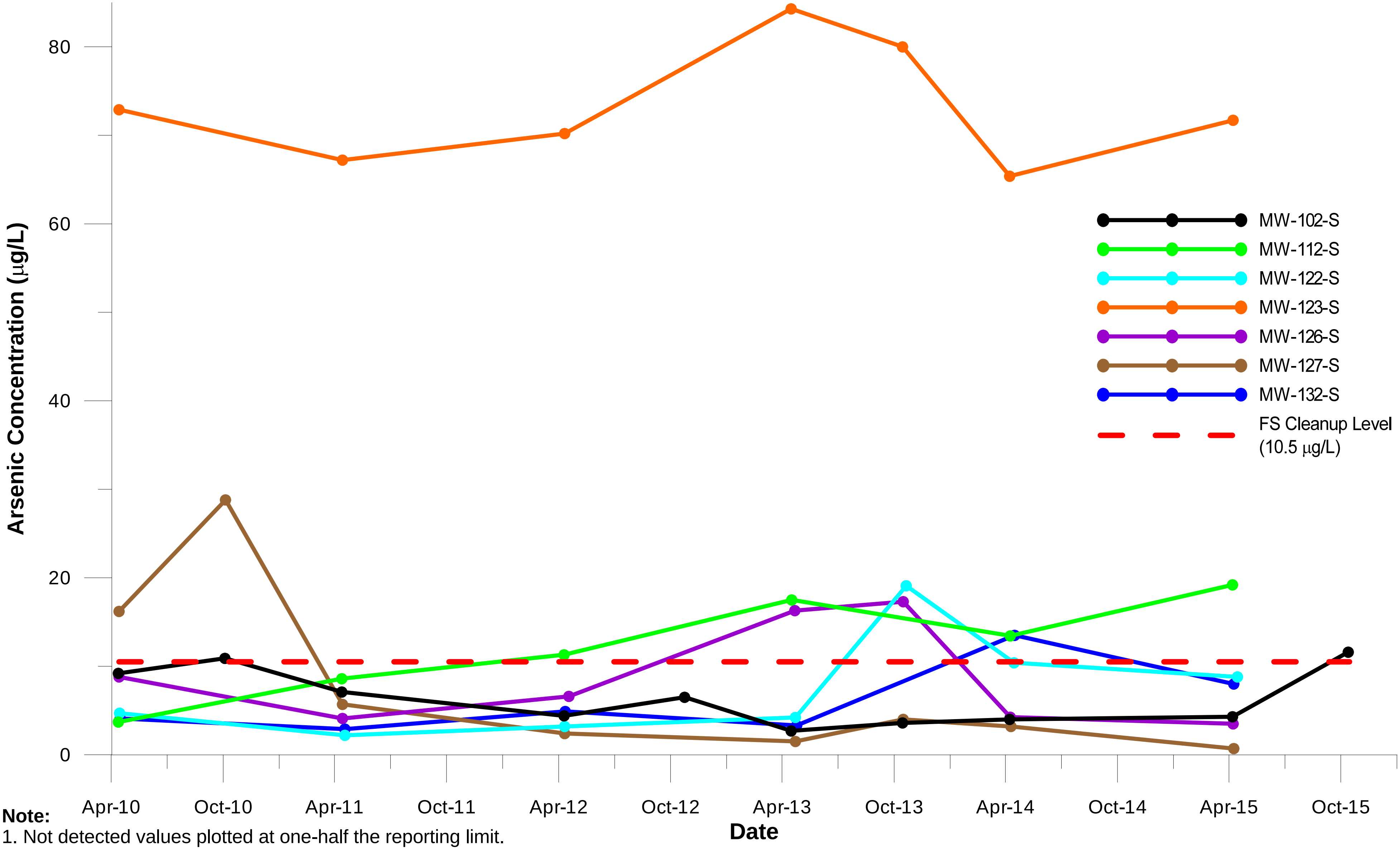
Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)



Notes:

1. Not detected values plotted at one-half the reporting limit.
2. The trichloroethene screening level identified in the RI Report is 0.11 µg/L (Geomatrix, 2007l).
3. The cis-1,2-dichlorethene screening level identified in the RI Report is 70.0 µg/L (Geomatrix, 2007).
4. The vinyl chloride FS cleanup level is 0.025 µg/L (Amec Foster Wheeler, 2016).

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)	TRICHLOROETHENE, CIS-1,2-DICHLOROETHENE, AND VINYL CHLORIDE CONCENTRATIONS AT MW-120-I1 2010 TO 2015 Stericycle Kent Facility Kent, Washington	Project No. 9464.002 Figure No. D-1



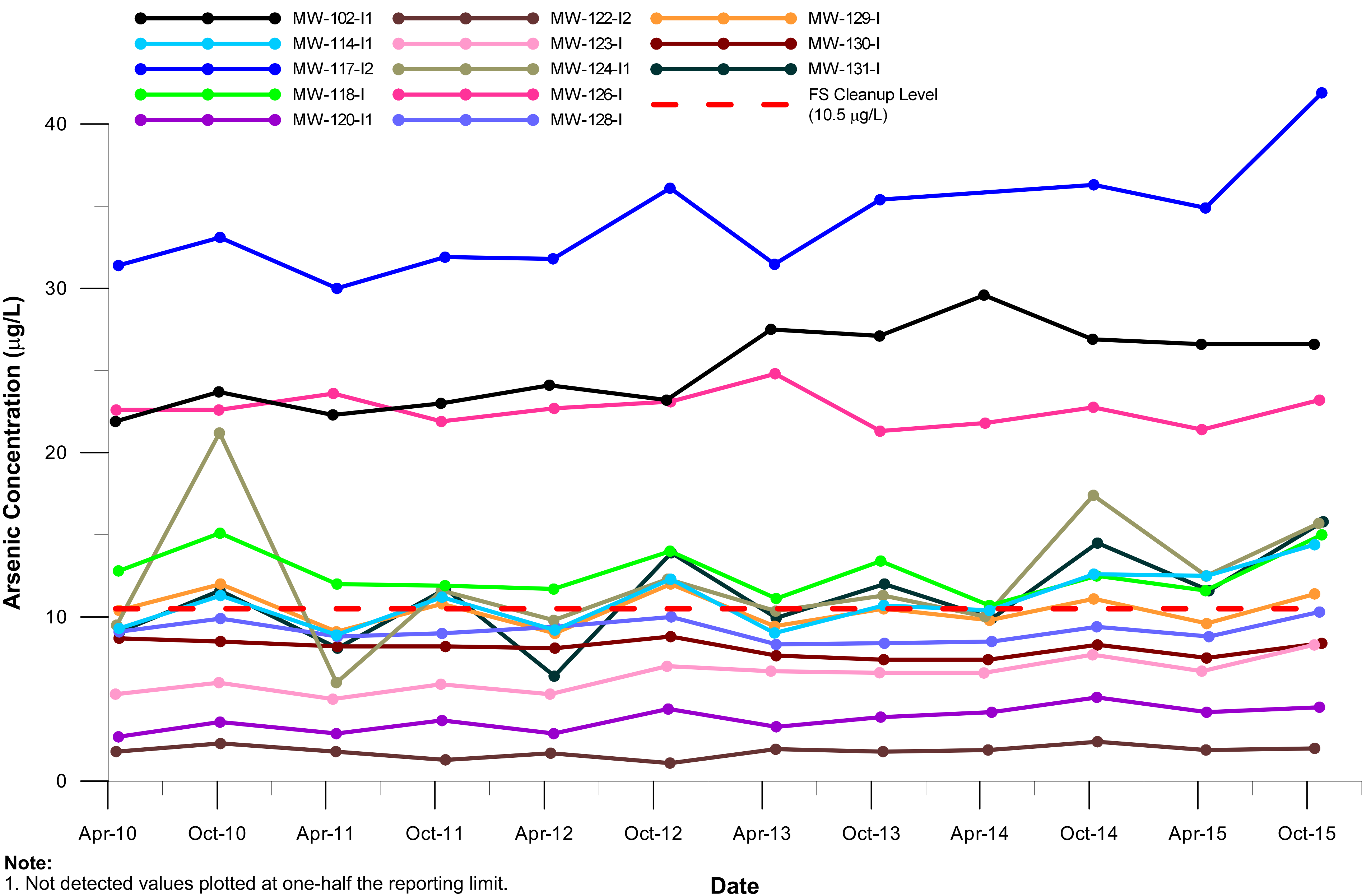
Note:
1. Not detected values plotted at one-half the reporting limit.

Reproduced from
2016 Draft FS (DOF
and Amec Foster
Wheeler)

TOTAL ARSENIC CONCENTRATIONS IN SHALLOW WELLS
2010 TO 2015
Stericycle Kent Facility
Kent, Washington

Project No.
9464.002

Figure No.
D-2



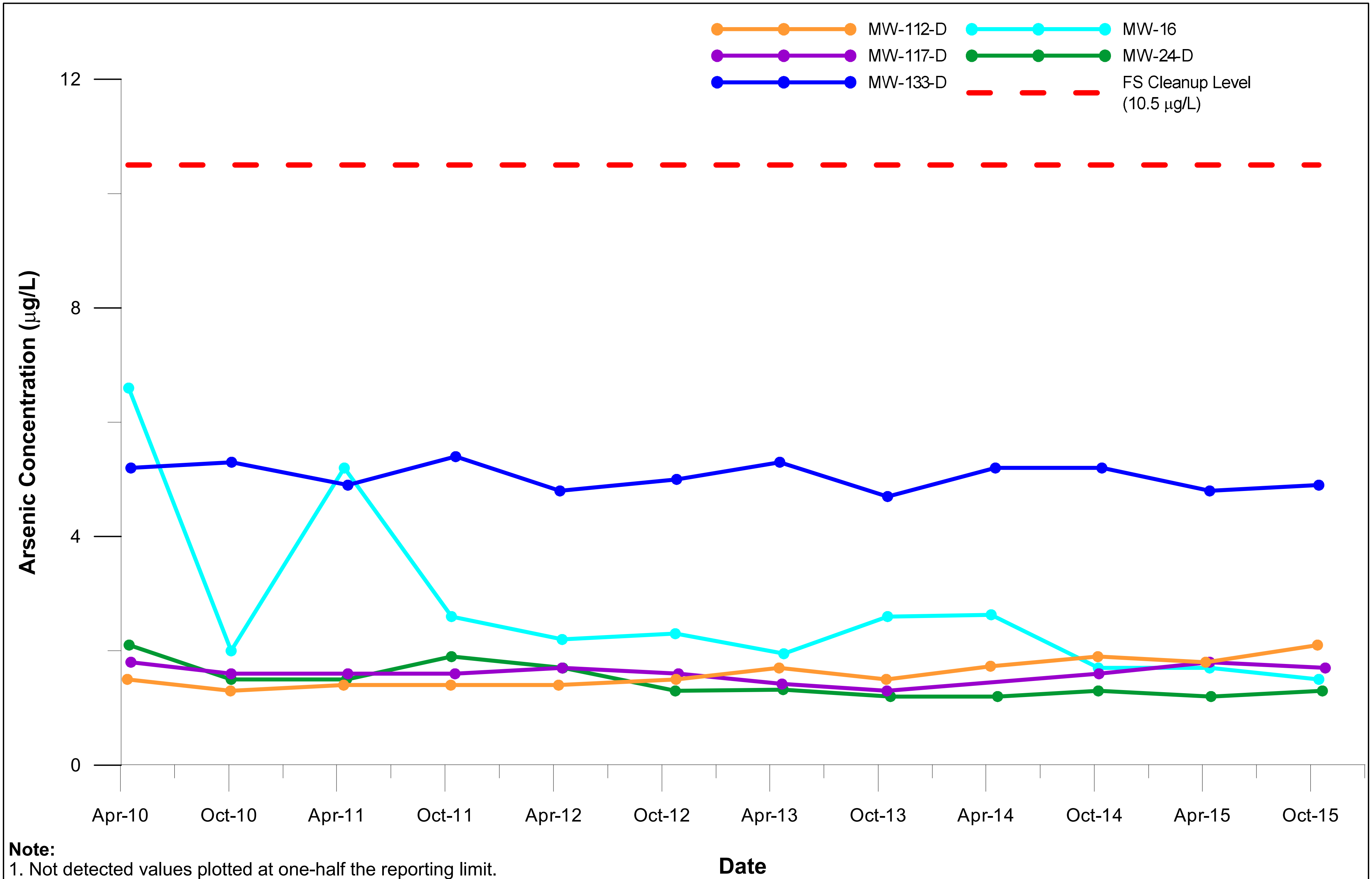
Note:
1. Not detected values plotted at one-half the reporting limit.

Reproduced from
2016 Draft FS
(DOF and Amec
Foster Wheeler)

TOTAL ARSENIC CONCENTRATIONS IN INTERMEDIATE WELLS
2010 TO 2015
Stericycle Kent Facility
Kent, Washington

Project No.
9464.002

Figure No.
D-3



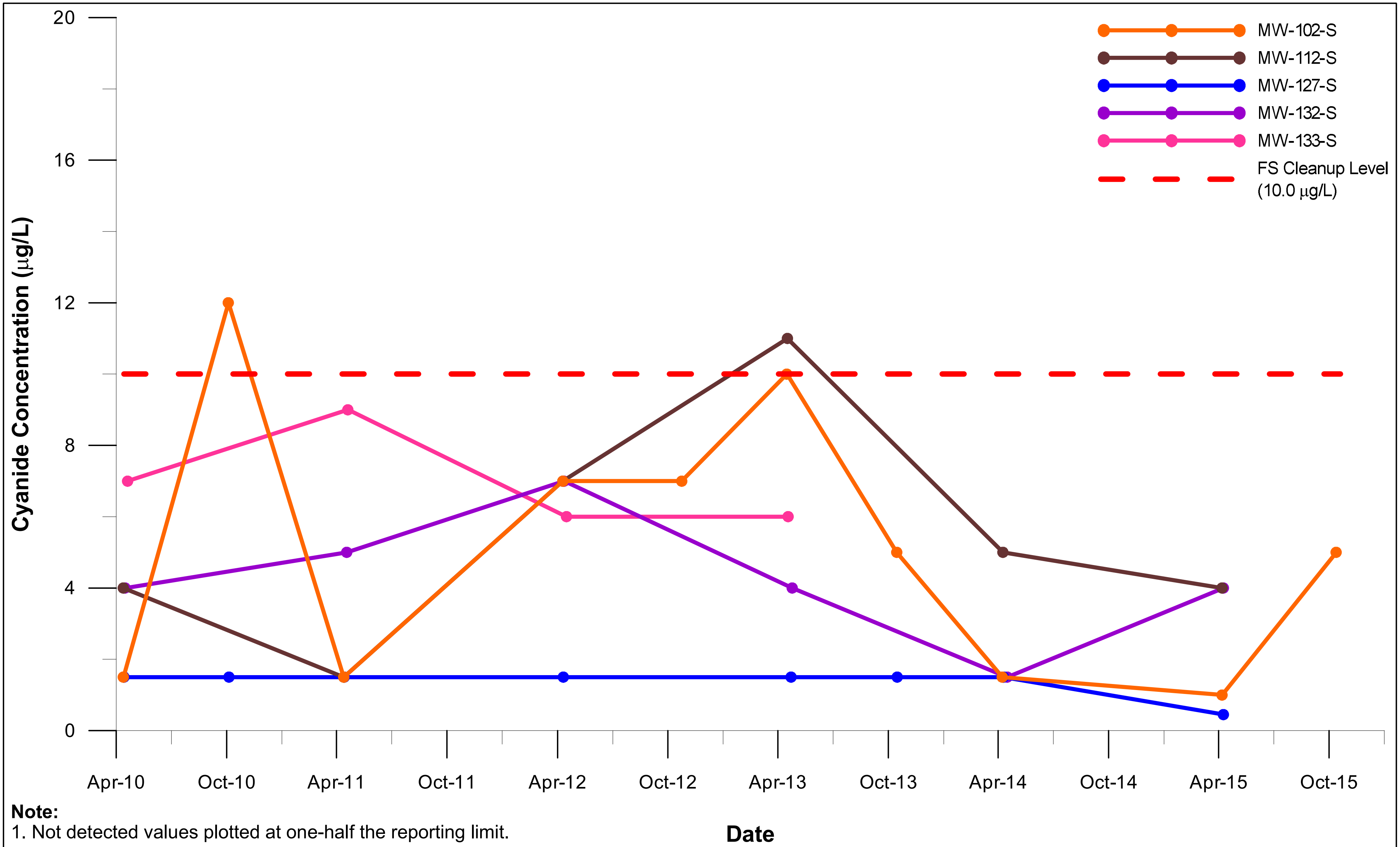
Note:
1. Not detected values plotted at one-half the reporting limit.

Reproduced from
2016 Draft FS
(DOF and Amec
Foster Wheeler)

TOTAL ARSENIC CONCENTRATIONS IN DEEP WELLS
2010 TO 2015
Stericycle Kent Facility
Kent, Washington

Project No.
9464.002

Figure No.
D-4



Note:
1. Not detected values plotted at one-half the reporting limit.

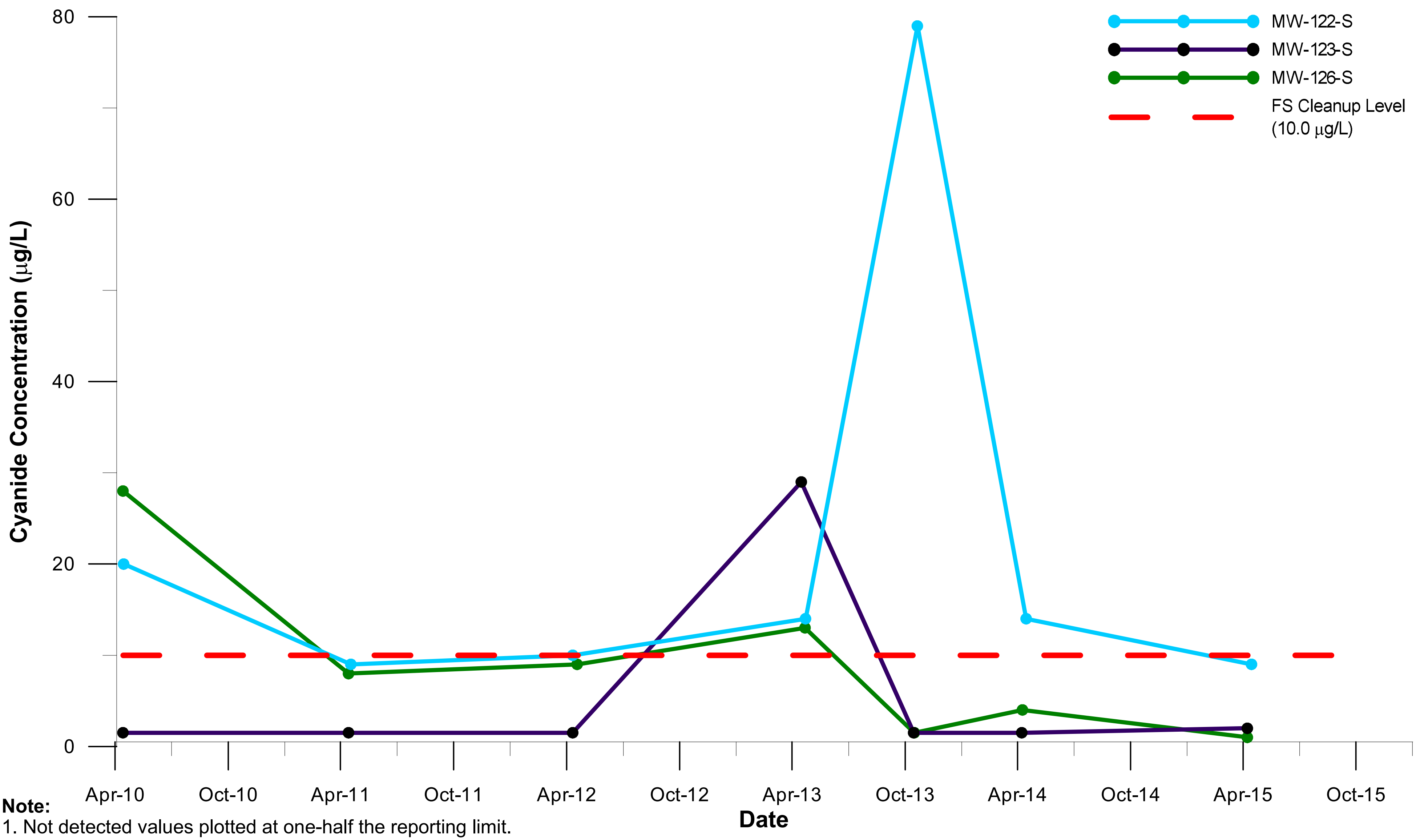
Reproduced from
2016 Draft FS (DOF
and Amec Foster
Wheeler)

CYANIDE CONCENTRATIONS IN SHALLOW WELLS
MW-102-S, MW-112-S, MW-127-S, MW-132-S, AND MW-133-S
2010 TO 2015

Stericycle Kent Facility
Kent, Washington

Project No.
9464.002

Figure No.
D-5



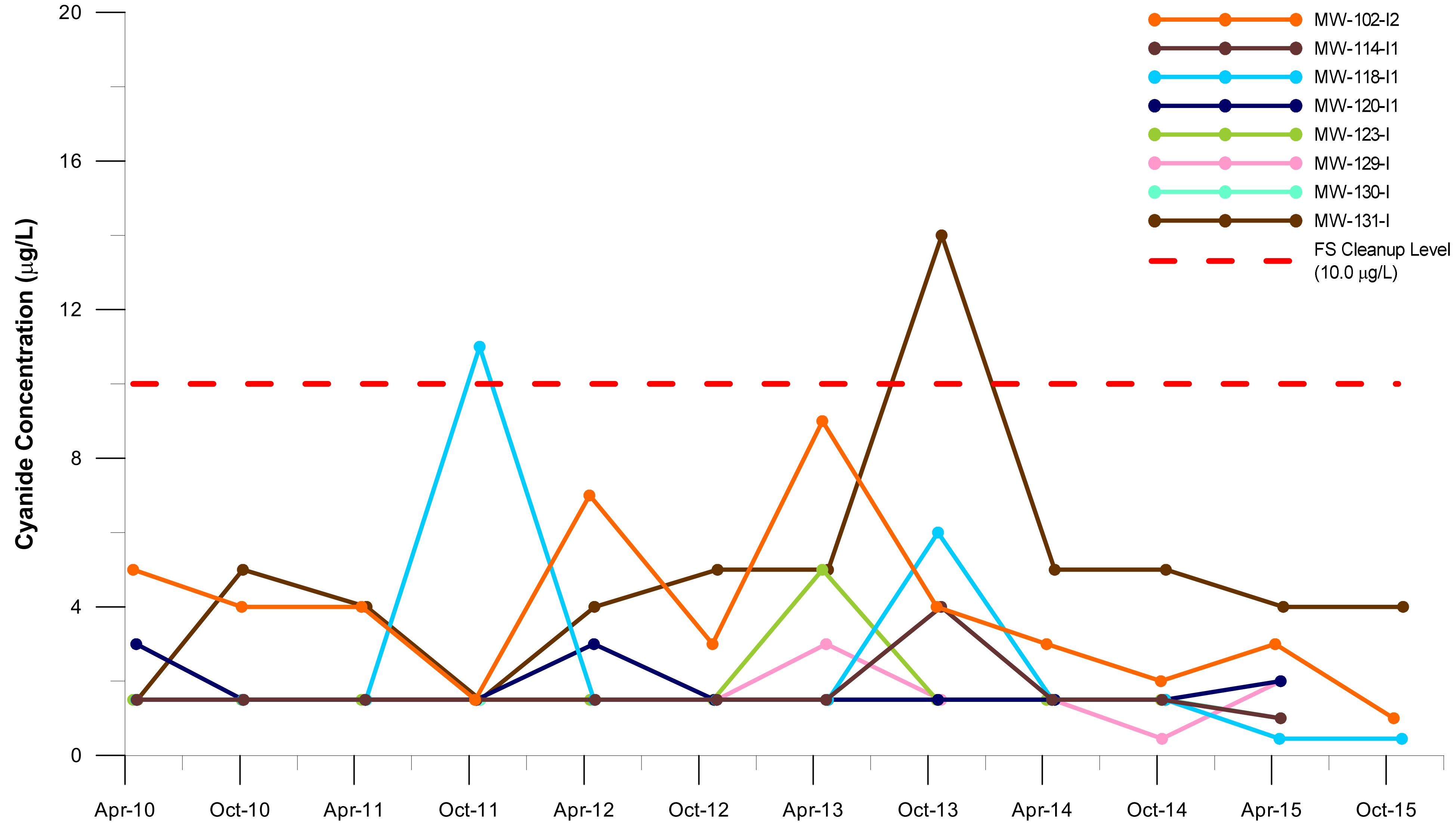
Note:
1. Not detected values plotted at one-half the reporting limit.

Reproduced from
2016 Draft FS
(DOF and Amec
Foster Wheeler)

CYANIDE CONCENTRATIONS IN SHALLOW WELLS
MW-122-S, MW-123-S, AND MW-126-S
2010 TO 2015
Stericycle Kent Facility
Kent, Washington

Project No.
9464.002

Figure No.
D-6



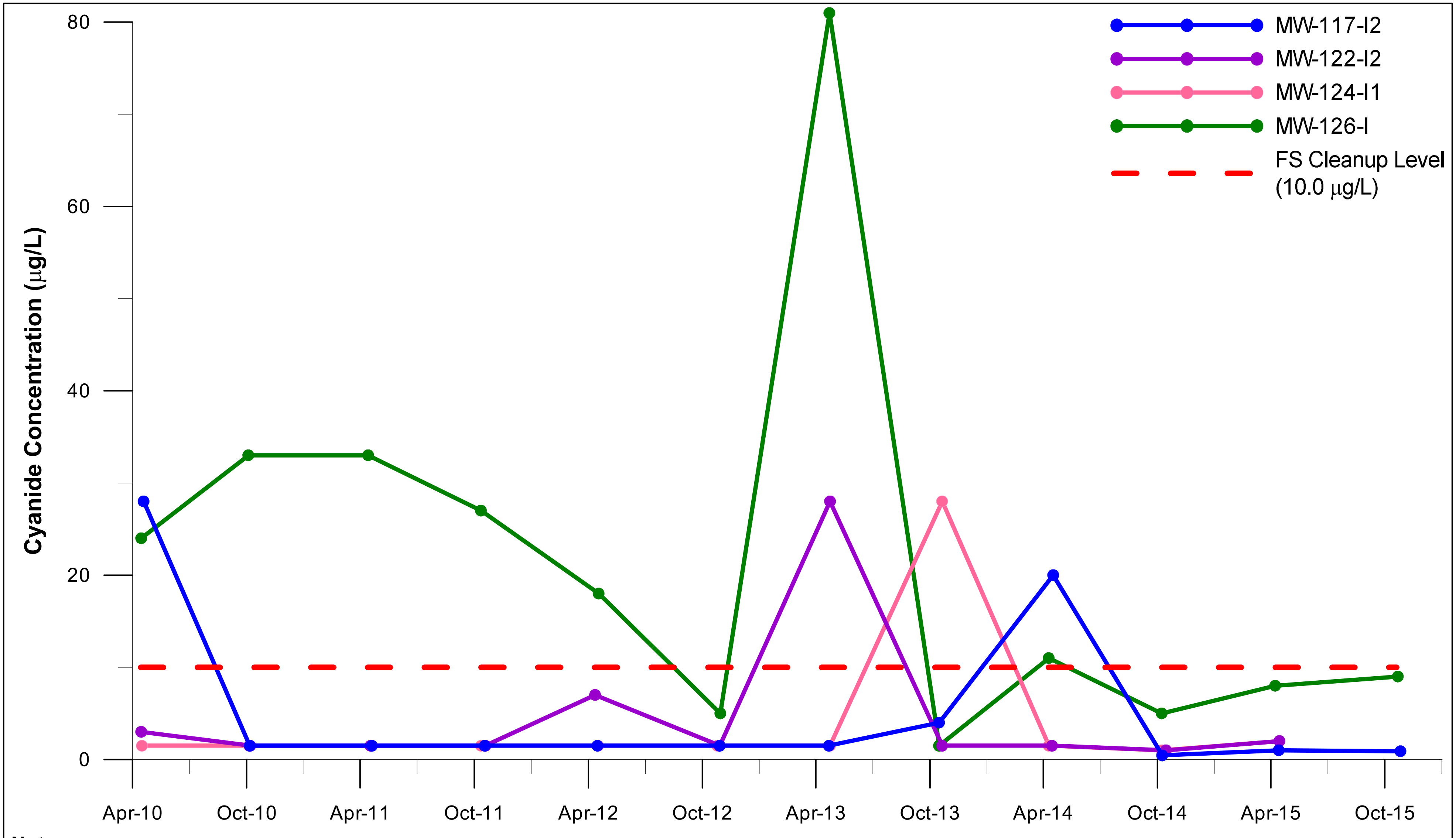
Note:
1. Not detected values plotted at one-half the reporting limit.

Reproduced from 2016
Draft FS (DOF and
Amec Foster Wheeler)

CYANIDE CONCENTRATIONS IN IMTERMEDIATE WELLS MW-102-I2, MW-114-I1, MW-118-I1, MW-120-I1, MW-123-I, MW-129-I, MW-130-I, AND MW-131-I
2010 TO 2015
Stericycle Kent Facility
Kent, Washington

Project No.
9464.002

Figure No.
D-7



Note:
1. Not detected values plotted at one-half the reporting limit.

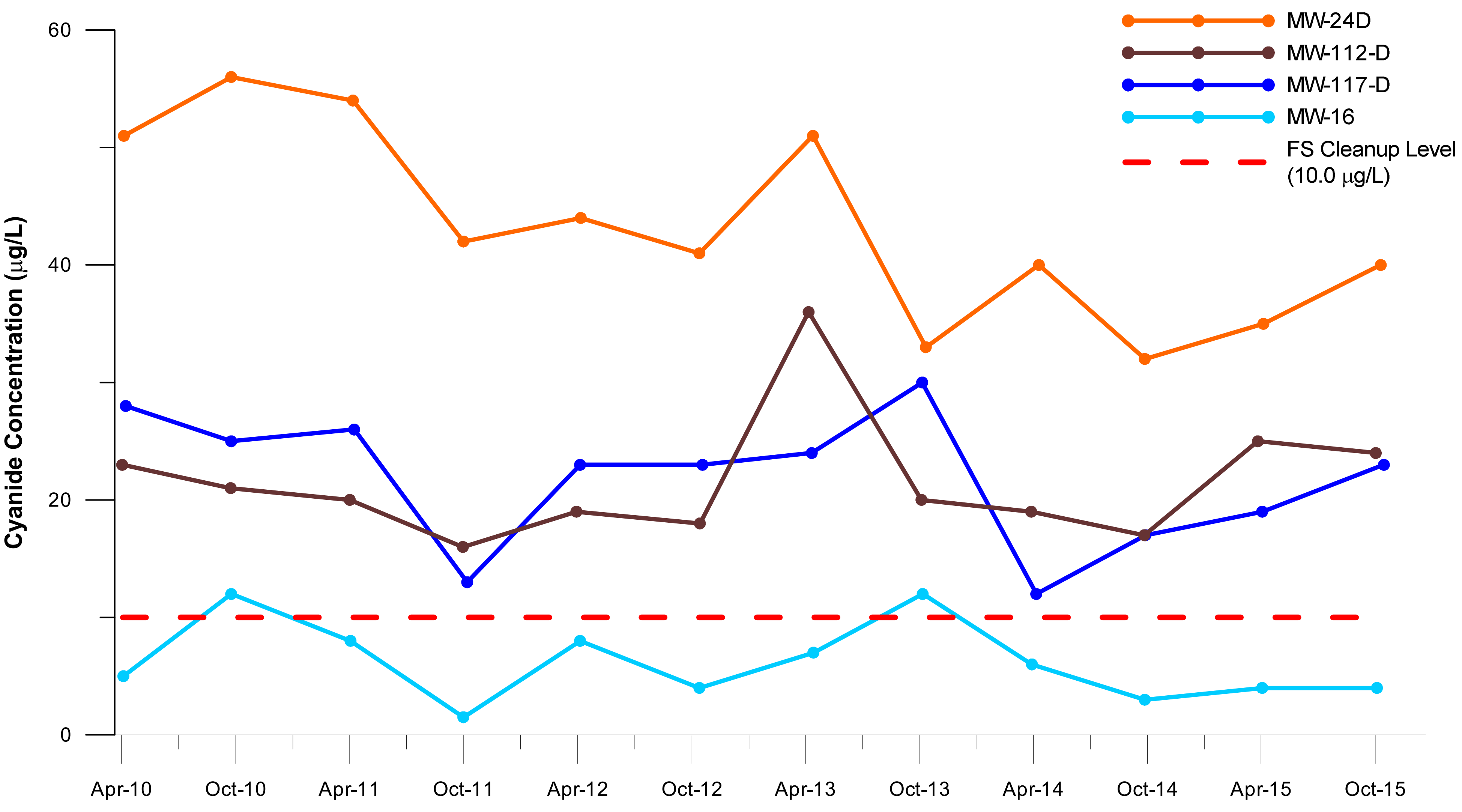
Date

Reproduced from 2016
Draft FS (DOF and Amec
Foster Wheeler)

CYANIDE CONCENTRATIONS IN INTERMEDIATE WELLS
MW-117-I2, MW-122-I2, MW-124-I1, AND MW-126-I
2010 TO 2015
Stericycle Kent Facility
Kent, Washington

Project No.
9464.002

Figure No.
D-8



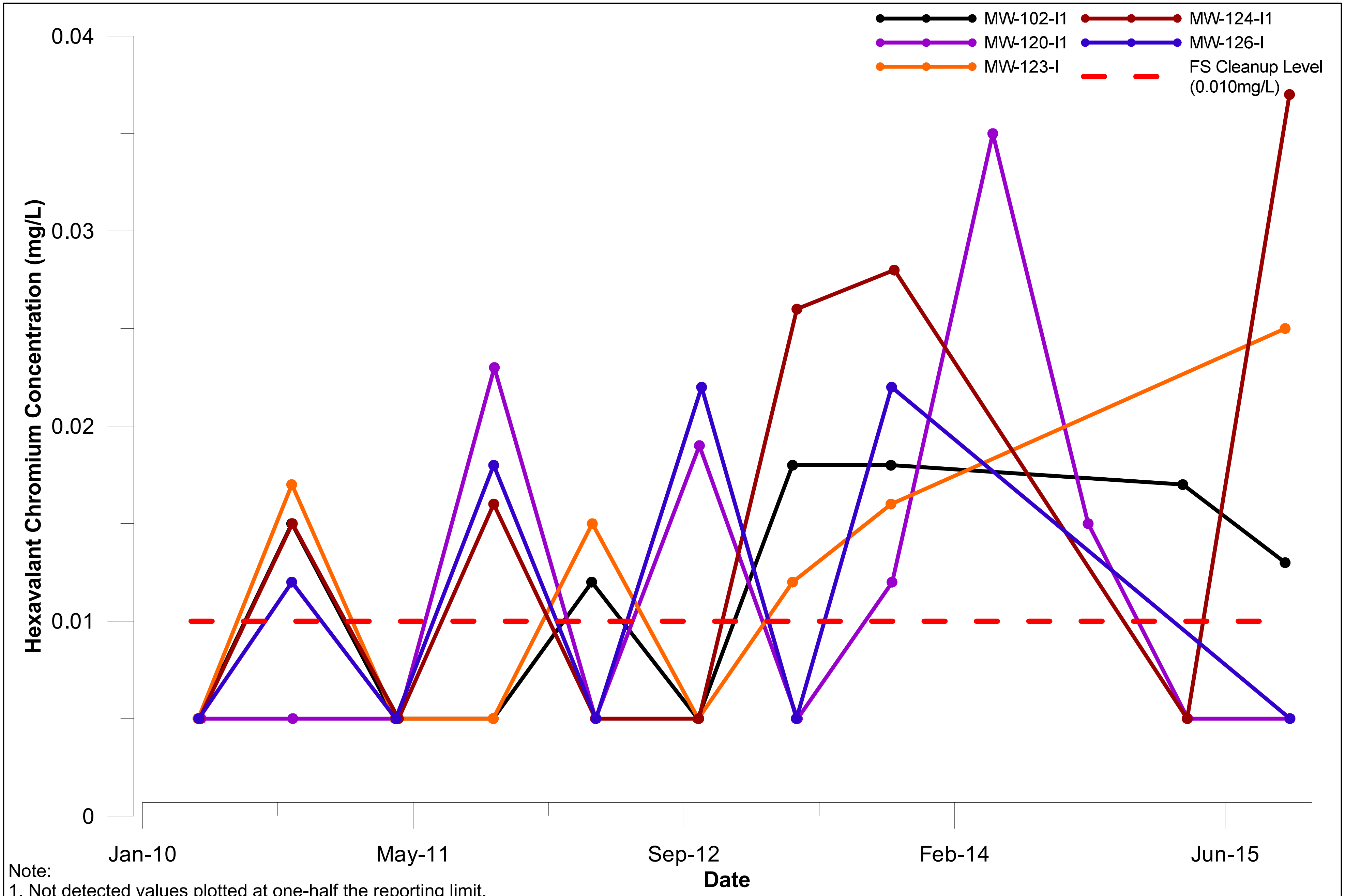
Note:
1. Not detected values plotted at one-half the reporting limit.

Reproduced from 2016
Draft FS (DOF and Amec
Foster Wheeler)

CYANIDE CONCENTRATIONS IN DEEP WELLS
2010 TO 2015
Stericycle Kent Facility
Kent, Washington

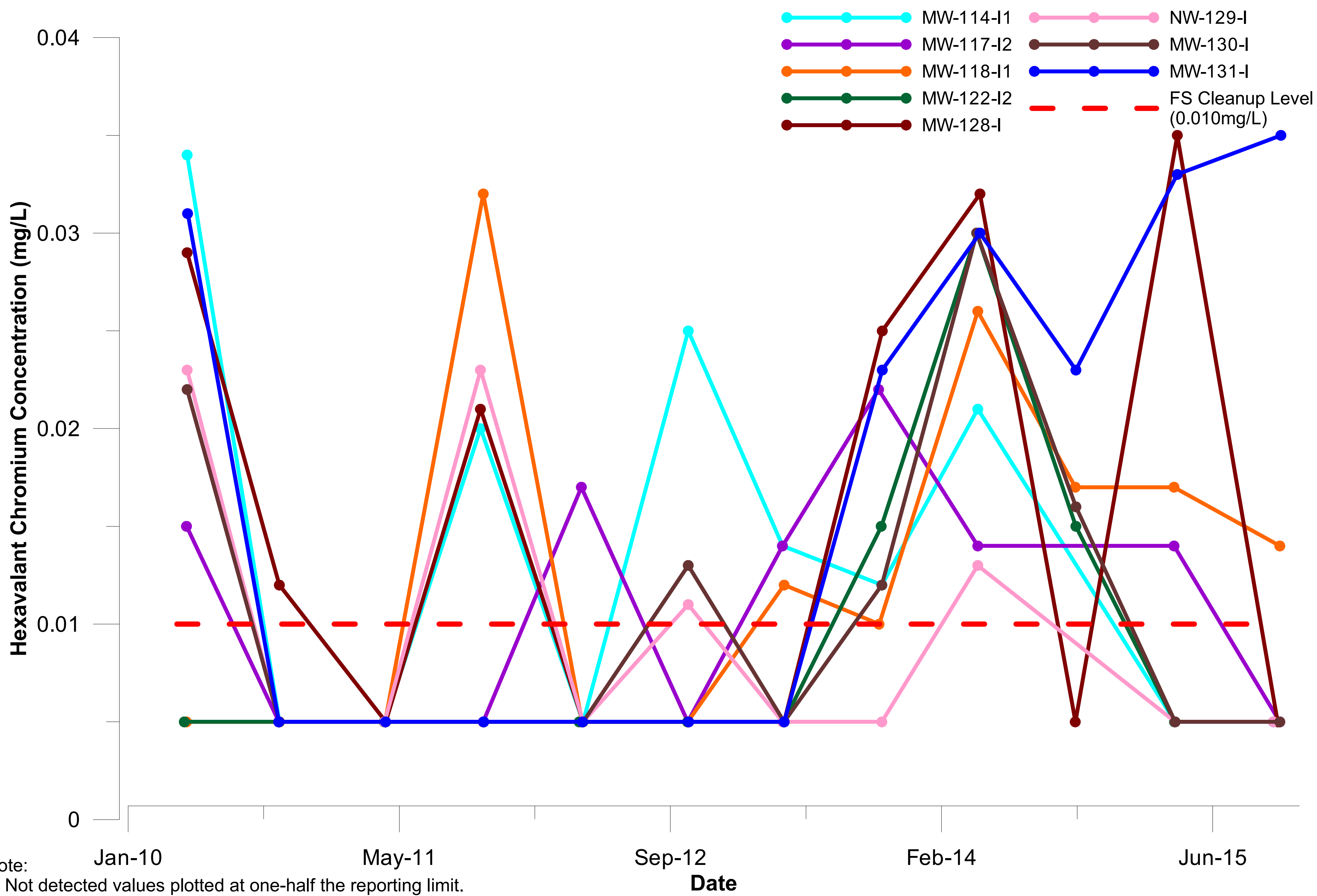
Project No.
9464.002

Figure No.
D-9



Note:
1. Not detected values plotted at one-half the reporting limit.

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)	HEXAVALENT CHROMIUM CONCENTRATIONS IN INTERMEDIATE WELLS LOCATED IN AOC-2 2010 TO 2015 Stericycle Kent Facility Kent, Washington	Project No. 9464.002 Figure No. D-10



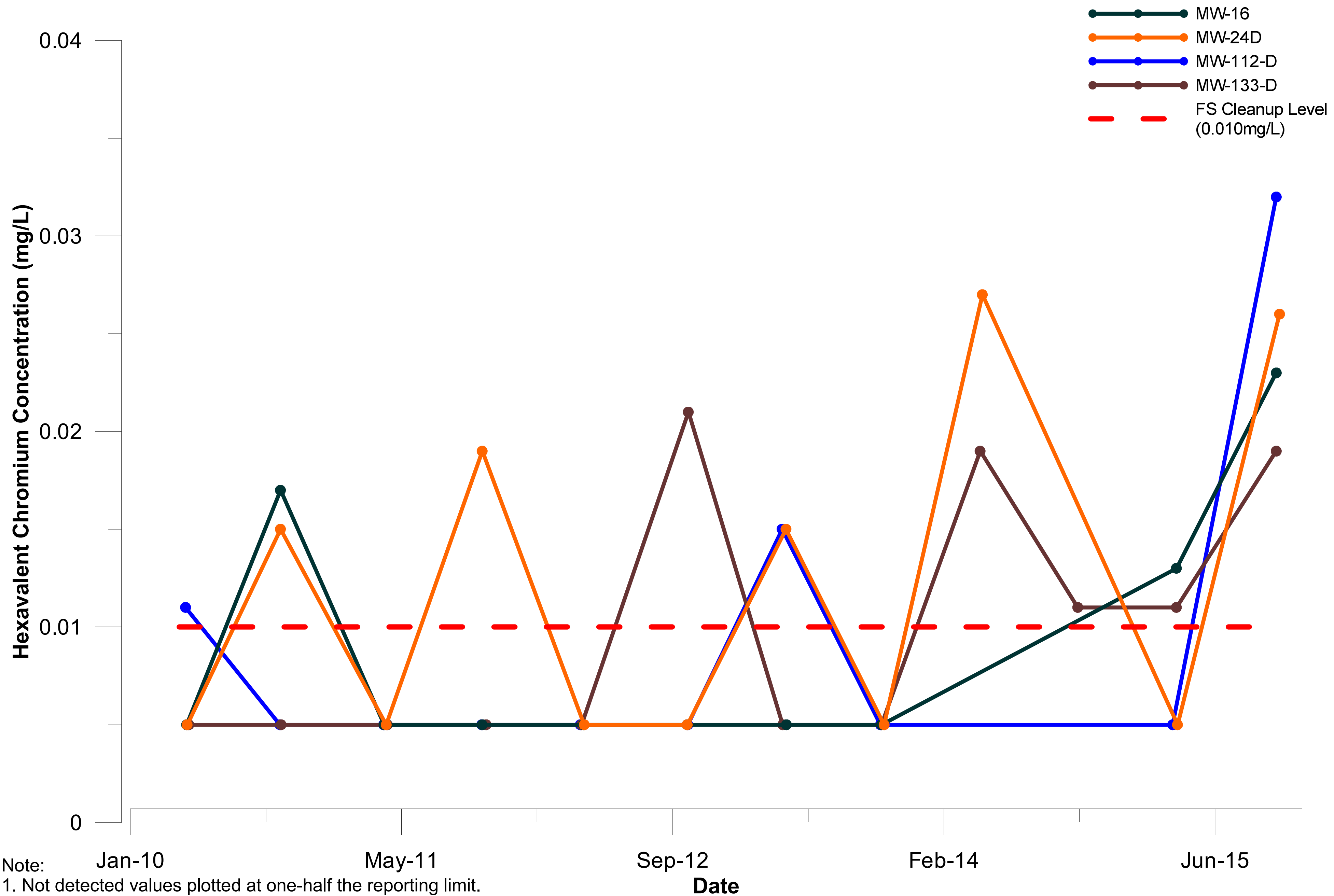
Note:
1. Not detected values plotted at one-half the reporting limit.

Reproduced from
2016 Draft FS
(DOF and Amec
Foster Wheeler)

HEXAVALENT CHROMIUM CONCENTRATIONS IN INTERMEDIATE WELLS LOCATED OUTSIDE AOC-2
2010 TO 2015
Stericycle Kent Facility
Kent, Washington

Project No.
9464.002

Figure No.
D-11



Note:
1. Not detected values plotted at one-half the reporting limit.

Reproduced from
2016 Draft FS
(DOF and Amec
Foster Wheeler)

HEXAVALENT CHROMIUM CONCENTRATIONS IN DEEP WELLS LOCATED INSIDE AOC-2 AND AOC-3
2010 TO 2015
Stericycle Kent Facility
Kent, Washington

Project No.
9464.002

Figure No.
D-12

APPENDIX E

MTCAStat Arsenic in Soil – Stericycle Kent

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

MTCAStat Arsenic in Soil Stericycle Kent

Number of samples		Uncensored values	
Uncensored	69	Mean	6.63
Censored	21	Lognormal mean	6.06
Detection limit or PQL	2.3	Std. devn.	9.61136582
Method detection limit		Median	4
TOTAL	90	Min.	0.773
		Max.	71

Lognormal distribution?		Normal distribution?	
r-squared is:	0.949	r-squared is:	0.464

Recommendations:
Use lognormal distribution.

UCL (Land's method) is 6.0794576999198
Cohen's method applied.

71
40
20
15.1
14
12
11.1
11
9.44
9
9
9
8.95
8.67
8
7.9
7.79
7.4
7.2
7
7
6
6
5.31
5
4.87
4.81
4.8
4.71
4.57
4.4
4.31
4.17
4
4
3.77
3.54
3.48
3.47
3.41
3.4
3.39
3.26
3.16
3.15
3.06
3
2.92
2.89
2.8
2.78
2.75
2.74
2.72
2.71

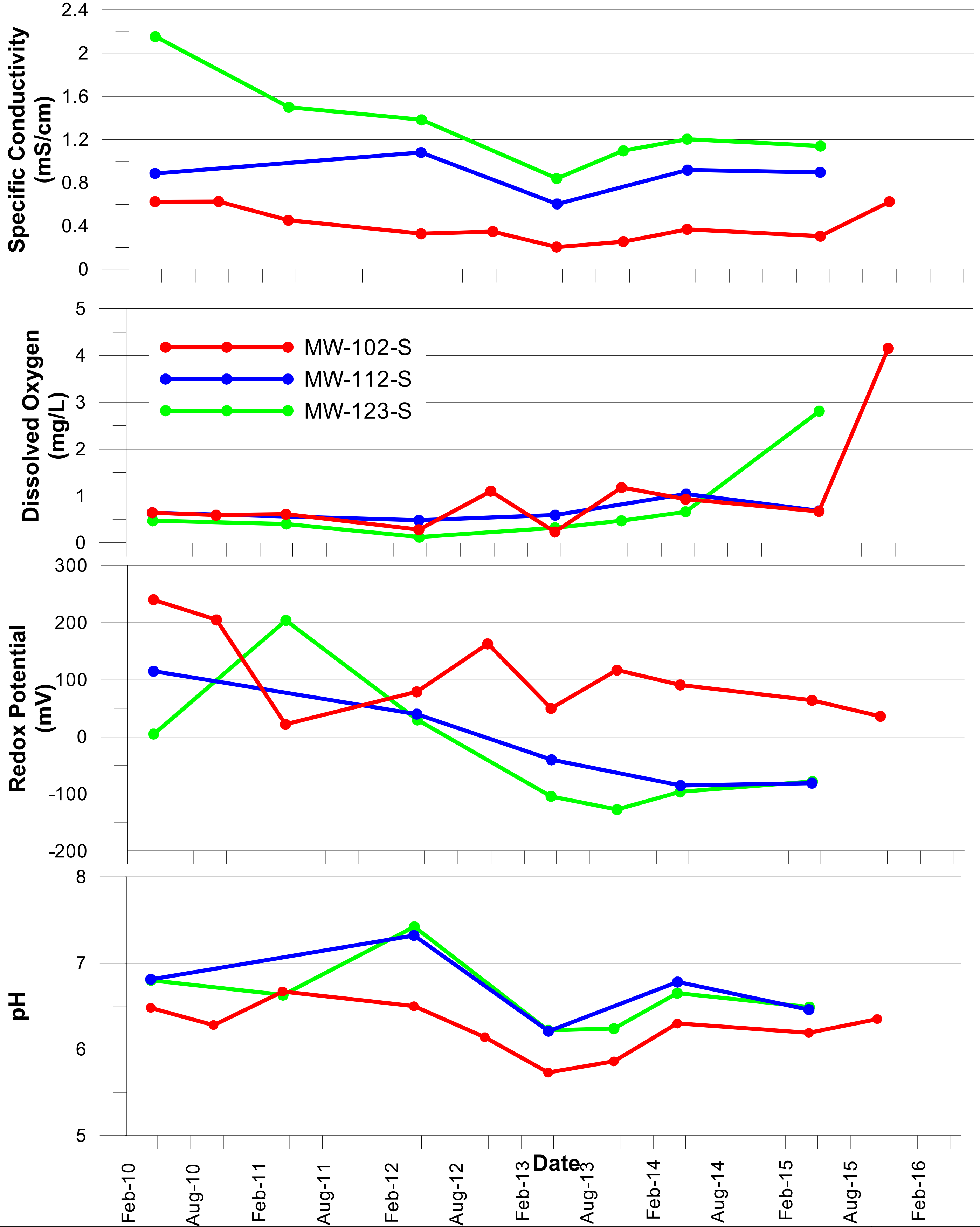
Compliance calculations

2.5
2.46
2.36
2.23
2.2
2.2
2.09
2
1.88
1.8
1.68
1.56
1.5
0.773

APPENDIX F

General Groundwater Parameters

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

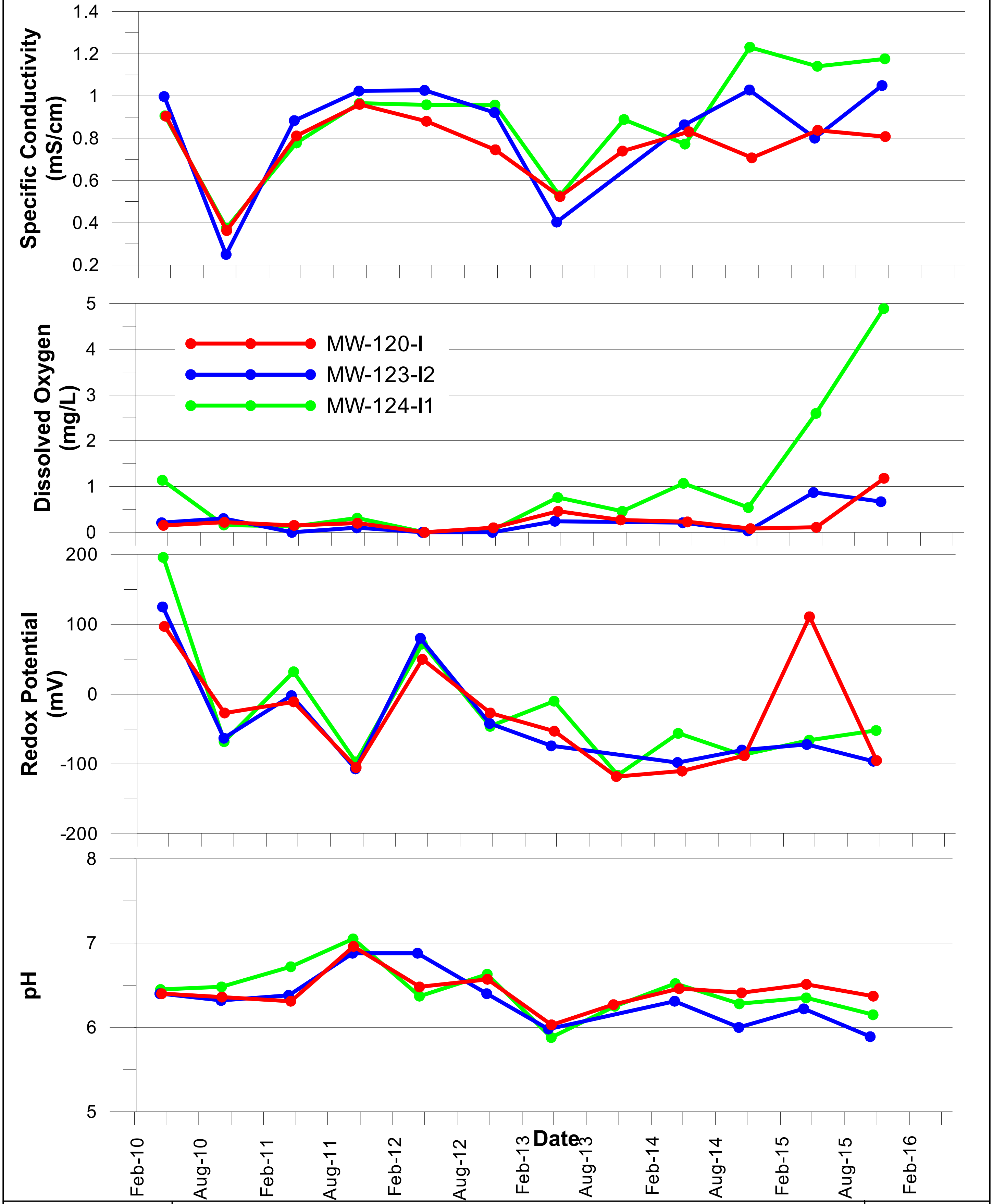


Reproduced from
2016 Draft FS
(DOF and Amec
Foster Wheeler)

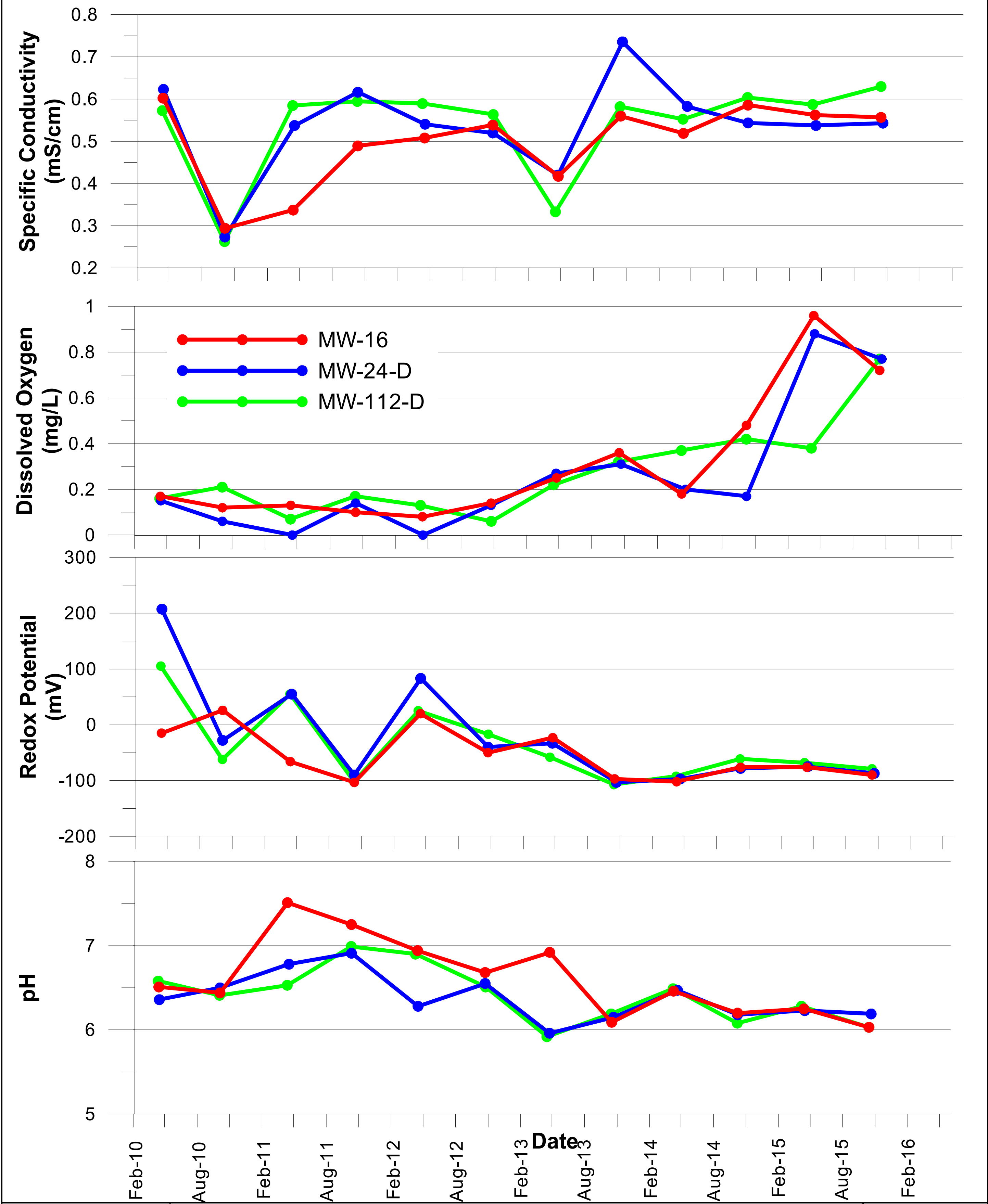
GENERAL PARAMETERS MW-102-S, MW-112-S, AND MW-123-S
2010 TO 2015
Stericycle Kent Facility
Kent, Washington

Project No.
9464

Figure No.
F-1



Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)	GENERAL PARAMETERS MW-120-I, MW-123-I2, AND MW-124-I1 2010 TO 2015 Stericycle Kent Facility Kent, Washington	Project No. 9464 Figure No. F-2



Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)	GENERAL PARAMETERS MW-16, MW-24-D, AND MW-112-D 2010 TO 2015 Stericycle Kent Facility Kent, Washington	Project No. 9464 Figure No. F-3

APPENDIX G

Remedial Alternative Cost Estimates

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APPENDIX G
REMEDIAL ALTERNATIVE COST ESTIMATES

Stericycle Kent Facility
Kent, Washington

1.0 INTRODUCTION

This appendix has been prepared on behalf of Burlington Environmental, LLC, a wholly owned subsidiary of Stericycle Environmental Solutions, Inc. (hereafter referred to as Stericycle). This appendix presents detailed cost estimates for each of the remedial alternatives developed for the Stericycle site in Kent, Washington. The cost estimates were developed based on the conceptual designs for the alternatives described in Section 8 and shown in Figures 18, 19, and 20 of the Feasibility Study report. The cost estimates were prepared in accordance with the U.S. Environmental Protection Agency (EPA) methods (EPA, 2000). General assumptions and details applied for preparation of the costs estimates for all of the remedial alternatives are presented in Section 2. Specific assumptions applied to individual alternatives are described in detail in Section 3.

2.0 GENERAL ASSUMPTIONS

Net present value (NPV) cost estimates were prepared for each alternative. A summary of the estimated NPV cost for each remedial alternative is presented in Table 15 in the FS report. The NPV cost estimates combine initial implementation costs, as well as long-term recurring costs. The initial implementation costs involve the cost to design, build, and implement the remedial alternative, and include permitting, engineering design, purchase of facilities and equipment, bench-scale studies, construction, and construction management costs. Recurring costs are the costs that would be incurred over the life of the remedial action and would include costs for inspection, project management, repair and maintenance, groundwater monitoring, materials, and monitoring well abandonment.

Detailed estimates of implementation costs, recurring operational costs, and NPV costs for each of the remedial alternatives are presented in Tables G-1 through G-9. All costs in the tables are presented in constant 2016 dollars. The total NPV costs shown in Table G-1 are rounded to the nearest thousand.

The quantities shown in the cost tables were estimated based on the assumed scope of the remedial alternatives and preliminary conceptual designs, as described in Section 8 of the FS report. The cost estimates are based on the areas where remedial actions would occur as shown in Figures 18, 19, and 20 of the FS report.

Reasonable assumptions based on professional judgment were made as appropriate to estimate quantities for individual line items. The cost estimates based on these quantities are, therefore, preliminary estimates suitable for use in this FS report to compare the alternatives only. These cost estimates are not suitable for final design or for budgeting.

The unit prices for most line items in the cost estimate tables were based on Means Costworks Online (http://www.meanscostworks.com/Promotion/CostworksOverview.aspx?mailDrop=ZMCW&pCode=2000), accessed from September to December 2009, vendor quotes, or experience with similar work.

The following general assumptions were made in estimating costs for each of the alternatives.

- Costs for soil remediation are not included in the FS as discussed in Section 8. Soil remediation will be conducted as part of future maintenance to the tank farm area and is the same for all three alternatives described in Section 8 and shown in Figures 18, 19, and 20 of the FS report.
- Production rates and prices are based on a standard 40-hour work week; no overtime or shift differential were included.
- The personal protective equipment would be Level D, unless otherwise noted.
- Any waste generated would be nonhazardous solid waste, except as otherwise noted.
- Any surface asphalt and concrete removed as part of remediation would be uncontaminated and would be recycled to the extent practicable.
- No unique or specialty equipment or approaches were considered, unless otherwise noted.
- Costs for potable water have not been estimated and have not been included in the remediation cost estimates.
- No security guards would be required.
- Work would be performed without interruptions or multiple mobilizations and setups, unless noted otherwise.
- No prevailing wage or union standby labor costs have been included.

As noted in Section 8.1.1.2 of the FS report, remediation of some of the source material soils in AOC-2 and AOC-3 is not expected to be completed as part of the initial implementation under any of the alternatives. During future development, each alternative would have the same soil remediation costs at facility closure (or whenever soils become accessible), so this cost should not differentiate them for comparison purposes. Costs for soil remediation at facility closure have not been included as part of the alternative comparison, but will be included in the Corrective Action Plan in order to meet requirements for financial assurance under the Model Toxics Control Act.

The implementation cost estimates include the consultant cost (professional technical services) for individual tasks. The professional technical services were estimated as a specified percentage of the remediation construction cost (see detailed cost estimates for each alternative). The specific line items for professional technical services have been divided into permitting, engineering design, construction management, and project management, as appropriate. The assigned percentages were obtained from EPA guidance (EPA, 2000) and from professional experience.

The estimated recurring costs have also been generalized for simplicity. The unit prices used for recurring cost estimates include consultant and contractor costs, as appropriate. Annual project management costs were estimated as $10,000 for all the alternatives, since the long-term operation of each alternative consists basically of groundwater monitoring and surface cover maintenance.

The NPV cost for each alternative (Table 15 in the FS report) was calculated using a net discount (interest) rate of 2.5 percent based on recommendations provided by the Washington State Department of Ecology, although EPA guidance recommends a net discount rate of 7 percent.

3.0 SPECIFIC ASSUMPTIONS:

Specific, detailed assumptions made for each remedial alternative are described in the following subsections.

3.1 ASSUMPTIONS FOR ALTERNATIVE 1

Detailed cost estimates for Alternative 1 are presented in Tables G-1 through G-3. Detailed assumptions for remedial Alternative 1 are as follows:

- A conditional point of compliance (CPOC) would be designated at the property boundary along the southern, eastern, and northern boundaries, and along the eastern edge of the containment pond on the western portion of the site (see Figure 11 of the FS report). Performance monitoring for the CPOC will use:
    - Three additional monitoring wells installed in all three groundwater units, as shown on Figure 18, and

  - The existing monitoring well network.

- The area for surface cover is the same as those listed as soil source areas and totals approximately 11,500 square feet. Surface cover construction and replacement costs were based on this area.

- Groundwater monitoring would be necessary for at least 30 years, with volatile organic compounds (VOCs) assumed to decline to below cleanup levels (CULs) at the CPOC after five years and inorganics assumed to decline to levels consistent with natural total organic carbon geochemistry after 10 years. After 20 years, groundwater monitoring would be performed chiefly to confirm that surface cover and containment is sufficient to protect groundwater from the remaining sources in AOC-2. The number of monitoring wells will decrease over time, as will the frequency of monitoring:

  - Years 0–5, 30 wells;
  - Years 5–10,20 wells;
  - Years 10–20, 15 wells, with a decrease to monitoring every two years; and
  - Years > 20, 10 wells, with a decrease to monitoring every five years.

- Contingency for implementation of this remedy was set at 10 percent, since the remedy components are low risk.

3.2 ASSUMPTIONS FOR ALTERNATIVE 2

Detailed cost estimates for Alternative 2 are presented in Tables G-4 through G-6. Detailed assumptions for remedial Alternative 2 are as follows:

- A CPOC would be designated at the property boundary along the southern, eastern, and northern boundaries, and along the eastern edge of the containment pond on the western portion of the site (see Figure 11 of the FS report). Performance monitoring for the CPOC will use:

  - Five additional monitoring wells installed in all three groundwater units as shown on Figure 18, and
  - The existing monitoring well network.

- The area for surface cover is the same as those listed as soil source areas and totals approximately 11,500 square feet. Surface cover construction and replacement costs were based on this area. Reducing agents would be added to 38 injection locations to produce a permeable reactive barrier; and multiple injection depths per point would spread reducing agents throughout the treatment area.

- Groundwater monitoring would be necessary for at least 30 years, with VOCs assumed to decline to below CULs at the CPOC after one year and in the source areas after five years, and inorganics assumed to decline to levels consistent with natural total organic carbon geochemistry after 10 years. After 20 years, groundwater monitoring would be performed chiefly to confirm that surface cover and containment are sufficient to protect groundwater from the remaining sources in AOC-2. The number of monitoring wells will decrease over time, as will the frequency of monitoring:

  - Years 0–5, 32 wells;
  - Years 5–10, 20 wells;
  - Years 10–20, 15 wells, with a decrease to monitoring every two years; and
  - Years > 20, 10 wells, with a decrease to monitoring every five years.

- Contingency for implementation of this remedy was set at 30 percent, since the remedy components are medium risk with possible complications due to refusal for drilling or chemistry of substrate.

3.3 ASSUMPTIONS FOR ALTERNATIVE 3

Detailed cost estimates for Alternative 3 are presented in Tables G-7 through G-9. Detailed assumptions were made as follows for remedial Alternative 3.

- A CPOC would be designated at the property boundary along the southern, eastern, and northern boundaries, and along the eastern edge of the containment pond on the western portion of the site (see Figure 11 of the FS report). Performance monitoring for the CPOC will use:
  - Five additional monitoring wells installed in all three groundwater units as shown on Figure 18, and
  - The existing monitoring well network,
- The area for surface cover is the same as those listed as soil source areas and totals approximately 11,500 square feet. Surface cover construction and replacement costs were based on this area. An initial treatment for in situ chemical reduction would be performed in year zero, split between the wet and dry seasons. Twenty-six injection points with multiple injection depths would be targeted in the dry season with an additional 20 injection points with multiple injection depths targeted in the wet season. It is assumed that reinjection would be necessary every 10 years to maintain strong reducing conditions.
- Groundwater monitoring would be necessary for at least 30 years, with VOCs assumed to decline to below CULs at the CPOC and in the source areas after two years, and inorganics assumed to decline to levels consistent with natural total organic carbon geochemistry after five years. After 20 years, groundwater monitoring would be performed chiefly to confirm that surface cover and containment are sufficient to protect groundwater

from the remaining sources in AOC-2. The number of monitoring wells will decrease over time, as will the frequency of monitoring:

  - Years 0–5, 30 wells;
  - Years 5–10, 15 wells;
  - Years 10–20, 10 wells, with a decrease to monitoring every two years; and
  - Years > 20, five wells, with a decrease to monitoring every five years.

- Contingency for implementation of this remedy was set at 30 percent, since the remedy components are medium risk, with possible complications due to refusal for drilling or chemistry of substrate.

4.0 REFERENCES

U.S. Environmental Protection Agency, (EPA), 2000, A Guide to Developing and Documenting Cost Estimates During the Feasibility Study.

TABLE G-1

IMPLEMENTATION COSTS FOR ALTERNATIVE 1

Stericycle Kent Facility
Kent, Washington

Item	Unit	Unit Cost	Quantity	Cost	Sources/Notes
Task 1 - Cap Maintenance					
Asphalt Paving	SY	$15	425	$6,400	R.S. Means, 2009, line 312216130460 (3-inch, 4,900 SY per day 1 days)
Existing Surface Inspection	day	$100	1	$100	R.S. Means, 2009, line 023219100020 (2 people + equipment)
Construction Oversight	day	$950	1	$1,000	1 engineer/scientist, Amec Foster Wheeler standard rate
Equipment	day	$100	1	$100	PID rental, Amec Foster Wheeler standard rate
Task 2 Subtotal				**$8,000**	
Task 2 - Monitored Natural Attenuation					
Well Installation, Shallow	each	$3,500	1	$3,500	Based on 2015 drilling quotes for a similar job
Well Installation, Intermediate	each	$4,500	1	$4,500	Based on 2015 drilling quotes for a similar job
Well Installation, Deep	each	$6,000	1	$6,000	Based on 2015 drilling quotes for a similar job
Installation Waste Disposal (nonhazardous)	per drum	$509	6	$3,200	Estimate from similar job, includes characterization costs
Construction Oversight	day	$1,000	1	$1,000	1 engineer/geologist, Amec Foster Wheeler standard rate
Equipment	day	$100	1	$100	PID rental, Amec Foster Wheeler standard rate
Task 3 Subtotal				**$18,000**	
Implementation Subtotal				**$26,000**	
Task 3 - Professional Services					
Permitting and Reporting	LS	$20,000	1	$20,000	Costs for CAP and Ecology communications
Engineering Design Costs	%	15%	$26,000	$3,900	from EPA (2000), Exhibit 5-8
Construction Management	%	10%	$26,000	$2,600	from EPA (2000), Exhibit 5-8
Project Management	%	8%	$26,000	$2,100	from EPA (2000), Exhibit 5-8
Task 4 Subtotal				**$28,600**	
Subtotal Initial Implementation Cost				**$55,000**	
Contingency	%	10%	$55,000	**$6,000**	
TOTAL INITIAL IMPLEMENTATION COST				**$70,000**	

Abbreviations:
CAP = Cleanup Action Plan
CY = cubic yard
Ecology = Washington State Department of Ecology
EPA = Environmental Protection Agency
LF = linear feelt
LS = lump sum
PID = photoionization detector
SF = square feet
SY = square yard

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TABLE G-2

RECURRING COSTS FOR ALTERNATIVE 1[1, 2]

Stericycle Kent Facility
Kent, Washington

Item	Unit	Unit Cost	Annual Quantity	Annual Cost	Sources
1 Annual Cap and Site Inspection					
Site Inspection	each	$550	1	$550	Engineer's Estimate
Subtotal				**$550**	
2 Groundwater Monitoring					
Existing Monitoring Plan	each	$1,700	27	$45,900	Current groundwater monitoring costs
Monitoring for COCs only	each	$800	30	$24,000	Reduced monitoring for COCs only, including 3 new compliance monitoring wells
Monitoring for COCs only, after 5 years	each	$800	20	$16,000	after 5 years[3]
Monitoring for COCs only, after 10 years	each	$800	15	$12,000	after 10 years[3]
Monitoring for COCs only, after 20 years	each	$800	10	$8,000	after 20 years[3]
3 Repairs					
Pavement replacement every 10 years	LS	$10,000	1	$10,000	Engineer's Estimate
Well replacement/fouling every 10 years	LS	$2,500	2	$5,000	Engineer's Estimate
Subtotal				**$15,000**	
4 Well Abandonment					
Monitoring Well Abandonment (after 5 years)	each	$800	10	$8,000	Engineer's Estimate
Monitoring Well Abandonment (every 10 years)	each	$800	5	$4,000	Engineer's Estimate
5 Project Management					
Project Management (while above CULs)	year	$10,000	1	$10,000	Engineer's Estimate
Project Management (after below CULs)	year	$5,000	1	$5,000	Engineer's Estimate
Project Management (after below CULs, no GW monitoring)	year	$2,500	1	$2,500	Engineer's Estimate
5-Year Review Costs	year	$2,500	1	$2,500	Engineer's Estimate

Notes:

1. Assumes 40-hour work week.
2. No taxes have been included.
3. Wells remaining include three depths. Annual/semi-annual reporting not included.

Abbreviations:

COCs = constituents of concern
CULs = cleanup levels
GW = groundwater
LS = lump sum

TABLE G-3

NET PRESENT VALUE FOR ALTERNATIVE 1

Stericycle Kent Facility
Kent, Washington

Year	Implementation and Repair Cost	Inspection and Project Management	Groundwater Monitoring[1]	Yearly Total
0	$70,000	$10,550	$45,900	$126,000
1		$10,550	$24,000	$35,000
2		$10,550	$24,000	$35,000
3		$10,550	$24,000	$35,000
4		$10,550	$24,000	$35,000
5	$8,000	$13,050	$24,000	$45,000
6		$10,550	$16,000	$27,000
7		$10,550	$16,000	$27,000
8		$10,550	$16,000	$27,000
9		$10,550	$16,000	$27,000
10	$19,000	$13,050	$16,000	$48,000
11		$3,050		$3,000
12		$5,550	$12,000	$18,000
13		$3,050		$3,000
14		$5,550	$12,000	$18,000
15		$5,550		$6,000
16		$5,550	$12,000	$18,000
17		$3,050		$3,000
18		$5,550	$12,000	$18,000
19		$3,050		$3,000
20	$19,000	$8,050	$8,000	$35,000
21		$3,050		$3,000
22		$3,050		$3,000
23		$3,050		$3,000
24		$3,050		$3,000
25		$8,050	$8,000	$16,000
26		$3,050		$3,000
27		$3,050		$3,000
28		$3,050		$3,000
29		$3,050		$3,000
30	$19,000	$8,050	$8,000	$35,000
TOTAL	$135,000	$210,000	$318,000	$667,000
Net Discount rate:		2.5%	**NPV**	**$550,000**

Notes

1. Implementation and repair costs include costs for monitoring well abandonment.
2. Contingency estimate is included for implementation costs, repairs, inspection, and project management; groundwater monitoring is not included in contingency estimate.

Abbreviations:

NPV = net present value

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TABLE G-4

IMPLEMENTATION COSTS FOR ALTERNATIVE 2

Stericycle Kent Facility
Kent, Washington

Item	Unit	Unit Cost	Quantity	Cost	Sources/Notes
Task 1 - Cap Maintenance					
Asphalt Paving	SY	$15	425	$6,400	R.S. Means, 2009, line 312216130460 (3-inch, 4,900 SY per day 1 days)
Existing Surface Inspection	day	$100	1	$100	R.S. Means, 2009, line 023219100020 (2 people + equipment)
Construction Oversight	day	$950	1	$1,000	1 engineer/scientist, Amec Foster Wheeler standard rate
Equipment	day	$100	1	$100	PID rental, Amec Foster Wheeler standard rate
Task 2 Subtotal				**$8,000**	
Task 2 - PRB Installation					
Sample Collection for Bench Study	LS	$2,500	1	$2,500	Assume added sampling costs during normal monitoring event
Bench Scale Study	LS	$5,000	1	$5,000	Estimate from vendor, 2016
Bench Scale Study Reporting/Results Analysis	LS	$10,000	1	$10,000	Estimate from similar job
Mobilization to Site/Site Swtup	LS	$15,800	1	$15,800	Assume 10% of cost
Concrete Coring (per point)	each	$55	38	$2,100	Estimate from similar job
Washington State Injection fee (per point)	each	$100	38	$3,800	Estimate from similar job
Injections to Shallow and Intermediate Units	each	$2,800	31	$86,800	Engineering estimate based on 2016 vendor phone quote
Injections to Intermediate and Deep Units	each	$2,800	4	$11,200	Engineering estimate based on 2016 vendor phone quote
Injections to All Groundwater Units	each	$3,000	3	$9,000	Engineering estimate based on 2016 vendor phone quote
Non-hazardous Solid Waste (Direct Push Soil)	drum	$234	20	$4,700	Estimate from vendor, 2015
Non-hazardous Liquid Waste (Direct Push Decon Water)	drum	$246	10	$2,500	Estimate from vendor, 2015
Waste Profiling	LS	$3,500	2	$7,000	Estimate from vendor, 2015
Construction Oversight	day	$1,200	20	$24,000	1 engineer/geologist, Amec Foster Wheeler standard rate
Equipment	day	$150	20	$3,000	Engineering estimate
GPS Survey Equipment	LS	$2,000	2	$4,000	Estimate from similar job
Task 3 Subtotal				**$191,000**	
Task 3 - Monitored Attenuation					
Well Installation, Shallow	each	$3,500	2	$7,000	Estimate from similar job
Well Installation, Intermediate	each	$4,500	2	$9,000	Estimate from similar job
Well Installation, Deep	each	$6,000	1	$6,000	Estimate from similar job
Installation Waste Disposal (nonhazardous)	per drum	$509	9	$4,700	Estimate from similar job, includes characterization costs
Construction Oversight	day	$1,000	2	$2,000	1 engineer/geologist, Amec Foster Wheeler standard rate
Equipment	day	$100	2	$200	PID rental, Amec Foster Wheeler standard rate
Task 4 Subtotal				**$29,000**	
Implementation Subtotal				**$228,000**	
Task 4 - Professional Services					
Permitting and Reporting	%	10%	$228,000	$22,800	Engineer estimate for UIC registration, CAP and Ecology Communications
Engineering Design Costs	%	15%	$228,000	$34,200	from EPA, 2000, Exhibit 5-8
Construction Management	%	10%	$228,000	$22,800	from EPA, 2000, Exhibit 5-8
Project Management	%	8%	$228,000	$18,200	from EPA, 2000, Exhibit 5-8
Task 5 Subtotal				**$98,000**	
Subtotal Initial Implementation Cost				**$326,000**	
Contingency	%	30%	$326,000	**$98,000**	
TOTAL INITIAL IMPLEMENTATION COST				**$430,000**	

Abbreviations:

CAP = Cleanup Action Plan
CY = cubic yard
EPA = Environmental Protection Agency
Ecology = Washington State Department of Ecology
GPS = Global Positioning System
LF = linear feelt
LS = lump sum
PID = photoionization detector
SF = square feet
SY = square yard

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TABLE G-5

RECURRING COSTS FOR ALTERNATIVE 2[1,2]

Stericycle Kent Facility
Kent, Washington

Item	Unit	Unit Cost	Annual Quantity	Annual Cost	Sources
1 **Annual Cap and Site Inspection**					
Site Inspection	each	$550	1	$550	2009 R.S. Means
Subtotal				**$550**	
2 **Groundwater Monitoring**					
Existing Monitoring Plan	each	$1,700	27	$45,900	Current groundwater monitoring costs
Monitoring for COCs only	each	$800	32	$25,600	Reduced monitoring for COCs only, including 3 new compliance monitoring wells
Monitoring for COCs only, after 5 years	each	$800	20	$16,000	after 5 years[3]
Monitoring for COCs only, after 10 years	each	$800	15	$12,000	after 10 years[3]
Monitoring for COCs only, after 20 years	each	$800	10	$8,000	after 20 years[3]
3 **Repairs**					
Pavement replacement every 10 years	LS	$10,000	1	$10,000	Engineer's Estimate
Well replacement/fouling every 10 years	LS	$2,500	2	$5,000	Engineer's Estimate
Subtotal				**$15,000**	
4 **Well Abandonment**					
Monitoring Well Abandonment (after 5 yrs)	each	$800	12	$9,600	Engineer's Estimate
Monitoring Well Abandonment (every 10 yrs)	each	$800	5	$4,000	Engineer's Estimate
5 **Project Management**					
Project Management (while above CULs)	year	$10,000	1	$10,000	Engineer's Estimate
Project Management (after below CULs)	year	$5,000	1	$5,000	Engineer's Estimate
Project Management (after below CULs, no GW monitoring)	year	$2,500	1	$2,500	Engineer's Estimate
5-Year Review Costs	year	$2,500	1	$2,500	Engineer's Estimate

Notes

1. Assumes 40-hour work week.
2. No taxes have been included.
3. Wells remaining include three depths. Assumes injections are performed via 2-inch direct push drill rig.

Abbreviations:

COCs = constituents of concern
CULs = cleanup levels
GW = groundwater
LS = lump sum

TABLE G-6

NET PRESENT VALUE FOR ALTERNATIVE A-3

Stericycle Kent Facility
Kent, Washington

Year	Implementation and Repair Cost	Inspection and Project Management	Groundwater Monitoring[1]	Yearly Total
0	$430,000	$10,550	$45,900	$486,000
1		$10,550	$25,600	$ 36,000
2		$10,550	$25,600	$ 36,000
3		$10,550	$25,600	$ 36,000
4		$10,550	$25,600	$ 36,000
5	$9,600	$13,050	$25,600	$ 48,000
6		$10,550	$16,000	$ 27,000
7		$10,550	$16,000	$ 27,000
8		$10,550	$16,000	$ 27,000
9		$10,550	$16,000	$ 27,000
10	$19,000	$13,050	$16,000	$ 48,000
11		$3,050		$ 3,000
12		$5,550	$12,000	$ 18,000
13		$3,050		$ 3,000
14		$5,550	$12,000	$ 18,000
15		$5,550		$ 6,000
16		$5,550	$12,000	$ 18,000
17		$3,050		$ 3,000
18		$5,550	$12,000	$ 18,000
19		$3,050		$ 3,000
20	$19,000	$8,050	$8,000	$ 35,000
21		$3,050		$ 3,000
22		$3,050		$ 3,000
23		$3,050		$ 3,000
24		$3,050		$ 3,000
25		$8,050	$8,000	$ 16,000
26		$3,050		$ 3,000
27		$3,050		$ 3,000
28		$3,050		$ 3,000
29		$3,050		$ 3,000
30	$19,000	$8,050	$8,000	$35,000
TOTAL	$497,000	$210,000	$326,000	$1,034,000
Net Discount rate:		2.5%	**NPV**	**$910,000**

Notes
1. Implementation and repair costs include costs for monitoring well abandonment.
2. Contingency estimate is included for implementation costs, repairs, inspection, and project management; groundwater monitoring is not included in contingency estimate.

Abbreviations:
NPV = net present value

TABLE G-7

IMPLEMENTATION COSTS FOR ALTERNATIVE 3

Stericycle Kent Facility
Kent, Washington

Item	Unit	Unit Cost	Quantity	Cost	Sources/Notes
Task 1 - Cap Maintenance					
Asphalt Paving	SY	$15	425	$6,400	R.S. Means, 2009, line 312216130460 (3-inch, 4,900 SY per day 1 days)
Existing Surface Inspection	day	$100	1	$100	R.S. Means, 2009, line 023219100020 (2 people + equipment)
Construction Oversight	day	$950	1	$1,000	1 engineer/scientist, Amec Foster Wheeler standard rate
Equipment	day	$100	1	$100	PID rental, Amec Foster Wheeler standard rate
Task 2 Subtotal				**$8,000**	
Task 2 - ISCR/ISB Injections					
Sample Collection for Bench Study	LS	$2,500	1	$2,500	Assume added sampling costs during normal monitoring event
Bench Scale Study	LS	$10,000	1	$10,000	Estimate from vendor, 2016
Bench Scale Study Reporting/Results	LS	$15,000	1	$15,000	Estimate from similar job
Mobilization to Site/Site Setup	LS	$35,200	1	$35,200	Assume 10% of cost
Concrete Coring (per point)	each	$55	46	$2,500	Estimate from similar job
Washington State Injection fee (per point)	each	$100	46	$4,600	Estimate from similar job
Injections to Shallow and Intermediate Zones	each	$6,200	37	$229,400	Engineering estimate based on 2016 vendor phone quote
Injections to Intermediate and Deep Zones	each	$6,200	3	$18,600	Engineering estimate based on 2016 vendor phone quote
Injections to All Groundwater Zones	each	$7,500	6	$45,000	Engineering estimate based on 2016 vendor phone quote
Non-hazardous Solid Waste (Direct Push Soil)	Drum	$234	25	$5,900	Estimate from vendor, 2015
Non-hazardous Liquid Waste (Direct Push Decon Water)	Drum	$246	15	$3,700	Estimate from vendor, 2015
Waste Profiling	LS	$3,500	2	$7,000	Estimate from vendor, 2015
Construction Oversight	day	$1,200	23	$27,600	1 engineer/geologist, Amec Foster Wheeler standard rate
Equipment	day	$150	23	$3,500	Engineering estimate
GPS Survey Equipment	LS	$2,000	2	$4,000	Estimate from similar job
Task 3 Subtotal				**$415,000**	
Task 3 - Monitored Attenuation					
Well Installation, Shallow	each	$3,500	1	$3,500	Estimate from similar job
Well Installation, Intermediate	each	$4,500	1	$4,500	Estimate from similar job
Well Installation, Deep	each	$6,000	1	$6,000	Estimate from similar job
Installation Waste Disposal (nonhazardous)	per drum	$509	6	$3,200	Estimate from similar job, includes characterization costs
Construction Oversight	day	$1,000	1	$1,000	1 engineer/geologist, Amec Foster Wheeler standard rate
Equipment	day	$100	1	$100	PID rental, Amec Foster Wheeler standard rate
Task 4 Subtotal				**$18,000**	
Implementation Subtotal				**$441,000**	
Task 4 - Professional Services					
Permitting	%	10%	$441,000	$44,100	Engineer estimate for UIC registration, CAP and Ecology communications
Engineering Design Costs	%	12%	$441,000	$52,900	from EPA, 2000, Exhibit 5-8
Construction Management	%	8%	$441,000	$35,300	from EPA, 2000, Exhibit 5-8
Project Management	%	6%	$441,000	$26,500	from EPA, 2000, Exhibit 5-8
Task 5 Subtotal				**$159,000**	
Subtotal Initial Implementation Cost				**$600,000**	
Contingency	%	30%	$600,000	**$180,000**	
TOTAL INITIAL IMPLEMENTATION COST				**$780,000**	

Abbreviations
CAP = Cleanup Action Plan
CY = cubic yard
Ecology = Washington State Department of Ecology
EPA = Environmental Protection Agency
GPS = Global Positioning System
ISB = in situ bioremediation
ISCR = in situ chemical reduction
LF = linear feelt
LS = lump sum
PID = photoionization detector
SF = square feet
SY = square yard
UIC =underground injection control

Reproduced from 2016 Draft FS (DOF and Amec Foster Wheeler)

TABLE G-8

RECURRING COSTS FOR ALTERNATIVE 3[1,2]

Stericycle Kent Facility
Kent, Washington

Item	Unit	Unit Cost	Annual Quantity	Annual Cost	Sources
1 Annual Cap and Site Inspection					
Site Inspection	each	$550	1	$550	2009 R.S. Means
Subtotal				**$550**	
2 Groundwater Monitoring					
Existing Monitoring Plan	each	$1,700	27	$45,900	Current groundwater monitoring costs
Monitoring for COCs only	each	$800	30	$24,000	Reduced monitoring for COCs only, including 3 new compliance monitoring wells
Monitoring for COCs only, after 5 years	each	$800	15	$12,000	after 5 years[3]
Monitoring for COCs only, after 10 years	each	$800	10	$8,000	after 10 years[3]
Monitoring for COCs only, after 20 years	each	$800	5	$4,000	after 20 years[3]
3 Repairs					
Pavement replacement every 10 years	LS	$10,000	1	$10,000	Engineer's Estimate
Well replacement/fouling every 10 years	LS	$2,500	2	$5,000	Engineer's Estimate
Construction Oversight				**$15,000**	
4 Well Abandonment					
Monitoring Well Abandonment (after 5 yrs)	each	$800	15	$12,000	Engineer's Estimate
Monitoring Well Abandonment (every 10 yrs)	each	$800	5	$4,000	Engineer's Estimate
5 Project Management					
Project Management (while above CULs)	year	$10,000	1	$10,000	Engineer's Estimate
Project Management (after below CULs)	year	$5,000	1	$5,000	Engineer's Estimate
Project Management (after below CULs, no GW monitoring)	year	$2,500	1	$2,500	Engineer's Estimate
5-Year Review Costs	year	$2,500	1	$2,500	Engineer's Estimate

Notes:

1. Assumes 40-hour work week.
2. No taxes have been included.
3. Wells remaining include three depths. Assumes injections are performed via 2-inch direct push drill rig.

Abbreviations:

COCs = constituents of concern
CULs = cleanup levels
GW = groundwater
LS = lump sum

TABLE G-9

NET PRESENT VALUE FOR ALTERNATIVE 3

Stericycle Kent Facility
Kent, Washington

Year	Implementation and Repair Cost	Inspection and Project Management	Groundwater Monitoring[1]	Yearly Total
0	$780,000	$10,550	$45,900	$836,000
1		$10,550	$24,000	$ 35,000
2		$10,550	$24,000	$ 35,000
3		$10,550	$24,000	$ 35,000
4		$10,550	$24,000	$ 35,000
5	$12,000	$13,050	$24,000	$ 49,000
6		$5,550	$12,000	$ 18,000
7		$3,050	$12,000	$ 15,000
8		$5,550	$12,000	$ 18,000
9		$5,550	$12,000	$ 18,000
10	$19,000	$8,050	$12,000	$ 39,000
11		$3,050		$ 3,000
12		$5,550	$8,000	$ 14,000
13		$3,050		$ 3,000
14		$5,550	$8,000	$ 14,000
15		$5,550		$ 6,000
16		$5,550	$8,000	$ 14,000
17		$3,050		$ 3,000
18		$5,550	$8,000	$ 14,000
19		$3,050		$ 3,000
20	$19,000	$8,050	$4,000	$ 31,000
21		$3,050		$ 3,000
22		$3,050		$ 3,000
23		$3,050		$ 3,000
24		$3,050		$ 3,000
25		$8,050	$4,000	$ 12,000
26		$3,050		$ 3,000
27		$3,050		$ 3,000
28		$3,050		$ 3,000
29		$3,050		$ 3,000
30	$15,000	$8,050	$4,000	$27,000
TOTAL	$845,000	$182,000	$270,000	$1,301,000
Net Discount rate:		2.5%	**NPV**	**$1,210,000**

Notes
1. Implementation and repair costs include costs for monitoring well abandonment.
2. Contingency estimate is included for implementation costs, repairs, inspection, and project management; groundwater monitoring is not included in contingency estimate.

Abbreviations:
NPV = net present value

APPENDIX H

Public Water Information and Data

DALTON
OLMSTED
FUGLEVAND

February 13, 2017

Mr. Neal Hines
nhin461@ECY.WA.GOV
Hazardous Waste and Toxics Reduction Program
Washington State Department of Ecology
3190 160th Ave SE
Bellevue, Washington 98008-5452

RE: Stericycle Kent Feasibility Study Supplemental Information

Dear Neal,

This memorandum was prepared by Dalton, Olmsted and Fuglevand (DOF) on behalf of Stericycle Environmental Solutions (Stericycle) in response to the letter dated October 18, 2016 (Ecology, 2016) and a subsequent telephone conference held on November 16, 2016 to discuss Ecology's letter and next steps. This memorandum provides additional information requested by Ecology related to public supply wells in the vicinity of the Stericycle Kent Facility. This information will be incorporated in a Revised Remedial Investigation/Feasibility Study (RI/FS) Report to be submitted later in 2017.

In Ecology's October letter they commented that:

> "Ecology places high importance on identifying if site COCs are present in surrounding wells. The direction of nearest public water supply wells was also requested and is presented on Figure 9. Ecology reviewed the location of these wells relative to the Stericycle Kent site and the direction of groundwater flow at the monitored elevations (shallow, intermediate, and deep). The nearest Group A well on Figure 9 lies to the east of the site by about 3500 ft. while the groundwater flow direction is generally towards the West and/or North. **Ecology requests that it be determined if the nearest wells identified on this figure and downgradient of the site have an active data record or whether they are able to be sampled. This would include the wells on Figure 9 whose depths are listed as 155 ft., 20 ft., 19 ft., 19 ft., and 22 ft. (in the downgradient direction). If any of these listed wells have sampling data of any kind, it needs to be summarized for the record, particularly with respect to the Stericycle Kent identified COCs (both soil and groundwater)**. Ecology checked the State of Washington Dept. of Health Sentry database (Sentry, https://fortress.wa.gov/doh/eh/portal/odw/si/findwatersystem.aspx) to see if any Safe Drinking Water Act data indicates impacts to the City of Kent water supply (Water Supply ID 381501) for the COCs that coincide with the Stericycle Kent site. The past 2 years' of Safe Drinking Water Act data was checked for As, CN, Cr regarding detections and/or exceedances under SDWA. The only detection of

> these 3 analytes was for As (detected at 0.003 mg/L in several samples), reporting limit 0.001 mg/L, and WA drinking water criteria (EPA MCL) = 0.0104 mg/L. **Ecology requests Stericycle to check this work with complete list of COCs in groundwater and soil and to assess the Sentry record more thoroughly (going back to the first recorded data into Sentry**). This is requested as a matter of due diligence, and will be a potential question during the public comment period."[i]

We reviewed four data sources to address the due diligence comment above. These included:

- King County's Groundwater Protection Program Groundwater Well Data Search (http://green2.kingcounty.gov/groundwater/well-data-search.aspx)
- State of Washington Dept. of Health Sentry database (https://fortress.wa.gov/doh/eh/portal/odw/si/findwatersystem.aspx)
- Ecology's Environmental Information Management database (https://fortress.wa.gov/ecy/eimreporting/Groundwater)
- City of Kent water supply (http://www.kentwa.gov/government/public-works/water-master-plan)

King County Data

The 5 wells identified in Figure 9 of the Feasibility Study were searched in the King County database. All 5 wells were found and available data is summarized in the attached Table 1. The well identifications (IDs) are shown on the attached Figure 1. Water level data was available for one of the wells, the deepest one (155 feet); while water quality data was not available for any of them in King County's database.

Department of Health Sentry Data

Data for the City of Kent water supply (Supply ID 381501) was reviewed using the Sentry database to verify the review completed by Ecology and expand it to look at a longer time range and all Stericycle constituents of concern (COCs). Each Stericycle COC (both soil and groundwater) were searched in the database.

The database categorizes a sample as an "exceedance" when at least one analyte in the sample test exceeds criteria (the Maximum Contaminant Level [MCL]), i.e., the analyte being searched for may not be the analyte that exceeded the MCL. For example, a search of "All WQ Data" for "arsenic" for the Kent water supply data yielded 159 samples. Of those, 37 samples were listed as exceedances. However when each of those 37 results were reviewed, all arsenic concentrations fell below the MCL (0.0104 mg/L), ranging in concentration from 0.002 to 0.0100 mg/L with reporting limits ranging from 0.001 to 0.02 mg/L.

For iron, the search yielded 161 samples, with 39 of the samples listed as "exceedances"; however, the MCL shown in comparison to the result was only actually exceeded for iron

---

[i] **Bold** added to highlight specific requests.

in four of those samples. In the rest, another analyte run as part of the sample is what appears to have led to the sample being designated as an "exceedance".

With this in mind, results of the database queries are summarized in Table 2 for Stericycle Kent COCs, including:

- Number of samples with results in Sentry (using the full date range available);
- The date range of samples found;
- The number "exceedances" that Sentry showed for the compound;
- The number of actual exceedances of the MCL since "exceedance" seems to reflect any hit the sample run method group when querying;
- Concentration range of any results that were above the MCL;
- Concentrations and reporting limits for the most recent 5 samples (relevant since most analytes were not ever detected above the MCL).
- Comments – It was noted that the system does not seem to distinguish non-detect results from detects and values listed as "result" may be the reporting limit for results that were not detected above that reporting limit.

Iron was the only Stericycle COC, in soil or groundwater, that has been detected above the MCL. This occurred in 4 of 161 samples and concentrations ranged from 0.74 to 3.07 mg/L.

Ecology EIM Database

A search of the area of the Stericycle facility was completed in EIM, based on Section, Township, and Range for the facility and surrounding Sections. Groundwater studies identified by this search (other than Stericycle data), are summarized in Table 3. Seven separate sites were identified that tested for several of the Stericycle COCs, with detections of petroleum-related compounds at most and solvent related compounds detected at two.

City of Kent Water Supply

The City's 2015 Water Quality Report is the most recent water quality report available on the City's website. Iron was the only Stericycle COC reported in the 2015 report. The maximum detection of iron was 0.005 mg/L and reported as in compliance, and well below the proposed Stericycle groundwater cleanup level proposed in the draft FS (24.5 mg/L).

Conclusions

The information presented in this letter expanded on the previous area-wide water resource information that Stericycle and Ecology have collectively researched and reviewed as part of the RI/FS process. It confirmed:

- Water quality records are not readily available for any sampling recorded at the 5 nearest downgradient water wells identified in the Draft FS.
- Historical City of Kent Sentry water quality data do not exceed the MCL for any Stericycle COCs except iron, for which 4 out of 161 (2%) results were above the MCL. More recently, the City of Kent's 2015 Water Quality Report stated that iron concentrations were in compliance.
- Several other sites exist with detections of Stericycle COCs in groundwater, primarily petroleum related, in the vicinity of the Stericycle site and are readily reviewable in Ecology's EIM database.

Stericycle looks forward to discussing a schedule for submittal of the Final Remedial Investigation and Feasibility Study for the Stericycle Kent Facility. Please let us know if you have any questions remaining prior to moving onto submission of that document.

Thank you,

Natasya DD Gray
Tasya Gray, LG
Senior Geologist
DOF

Attachments:
Table 1 - King County Groundwater Protection Program Well Summary
Table 2 - Washington Department of Health Sentry Water Quality Data Summary
Table 3 - Ecology Environmental Information System Groundwater Data Summary
Figure 1 – Nearby Groundwater Wells and EIM Groundwater Data Locations

cc: Hideo Fujita, Ecology

TABLE 1

King County Groundwater Protection Program Well Summary

Stericycle Kent Facility

Kent, Washington

<table>
<tr><th>Well ID</th><th>S_472536122143101</th><th>S_472535122143301</th><th>S_472534122143301</th><th>S_472450122143501</th><th colspan="5">S_472509122143401</th></tr>
<tr><td>Location Name</td><td>US EPA</td><td>USEPA</td><td>US EPA</td><td>TANAKA</td><td colspan="5">USEPA</td></tr>
<tr><td>Well Type</td><td>Well</td><td>Well</td><td>Well</td><td>Well</td><td colspan="5">Well</td></tr>
<tr><td>Well Depth (ft)</td><td>20</td><td>22</td><td>19</td><td>20</td><td colspan="5">155</td></tr>
<tr><td>Surface Elevation (ft)</td><td>24.03</td><td>24.46</td><td>23.35</td><td>26</td><td colspan="5">22.14</td></tr>
<tr><td>X Coord (WAN-SPF)</td><td>1291753.5</td><td>1291613</td><td>1291611.125</td><td>1291390.875</td><td colspan="5">1291495.5</td></tr>
<tr><td>Y Coord (WAN-SPF)</td><td>158828.0781</td><td>158728.5</td><td>158626.375</td><td>154172.2344</td><td colspan="5">156096.5938</td></tr>
<tr><td>Has Water Level Data?</td><td>No</td><td>No</td><td>No</td><td>No</td><td colspan="5">Yes</td></tr>
<tr><td>Has Water Quality Data?</td><td>No</td><td>No</td><td>No</td><td>No</td><td colspan="5">No</td></tr>
<tr><td>Local Number</td><td>22N/04E-01F03</td><td>22N/04E-01F01</td><td>22N/04E-01F02</td><td>22N/04E-12D01</td><td colspan="5">22N/04E-01N01</td></tr>
<tr><td>Ecology Well Tag</td><td>Unknown</td><td>Unknown</td><td>Unknown</td><td>Unknown</td><td colspan="5">Unknown</td></tr>
<tr><td>Parcel Number</td><td></td><td></td><td></td><td></td><td colspan="5"></td></tr>
<tr><td>GWMA Code</td><td>South King County</td><td>South King County</td><td>South King County</td><td>South King County</td><td colspan="5">South King County</td></tr>
<tr><td>Basin</td><td>Black River</td><td>Black River</td><td>Black River</td><td>Black River</td><td colspan="5">Black River</td></tr>
<tr><td>CARA Area</td><td>None</td><td>None</td><td>None</td><td>None</td><td colspan="5">None</td></tr>
<tr><td>City</td><td>Kent</td><td>Kent</td><td>Kent</td><td>Kent</td><td colspan="5">Kent</td></tr>
<tr><td rowspan="3">Water Level Data</td><td rowspan="3">No water level sampling data exists for the searched well.</td><td rowspan="3">No water level sampling data exists for the searched well.</td><td rowspan="3">No water level sampling data exists for the searched well.</td><td rowspan="3">No water level sampling data exists for the searched well.</td><td>Measurement Date</td><td>Measurement Time</td><td>Water Level Depth (ft)</td><td>Well Depth (ft)</td><td>Measure Method</td></tr>
<tr><td>4/29/1987</td><td>8:50</td><td>4.12</td><td>155</td><td>Steel tape</td></tr>
<tr><td>9/4/1986</td><td>10:00</td><td>6.41</td><td>155</td><td>Electric tape</td></tr>
<tr><td>Water Quality Data</td><td>No water quality sampling data exists for the searched well.</td><td>No water quality sampling data exists for the searched well.</td><td>No water quality sampling data exists for the searched well.</td><td>No water quality sampling data exists for the searched well.</td><td colspan="5">No water quality sampling data exists for the searched well.</td></tr>
</table>

DOF

TABLE 2

Washington Department of Health Sentry Water Quality Data Summary

Stericycle Kent Facility
Kent, Washington

						5 most recent samples		
	Number of Samples Returned in Sentry	Date Range of Samples	Number of Exceedances Listed	Number of Actual MCL Exceedances	Concentration Range of MCL Exceedances mg/L	Concentration Range mg/L	Range of Reporting Limits mg/L	Comments
Groundwater COCs								
Arsenic	159	3/21/77 - 7/12/16	37	0	NA	0.001	0.001	reported value matched reporting limit in all cases
Hexavalent Chromium	no results	NA	NA	NA	NA	NA	NA	
Cyanide	114	1/1/93 - 7/11/16	25	0	NA	0.01	0.01	reported value matched reporting limit in all cases
Iron	161	3/21/77 - 7/12/16	39	4	0.74 - 3.07	0.1	0.1	reported value matched reporting limit in all cases
Vinyl Chloride	116	2/29/88 - 7/11/16	0	0	NA	0.0005	0.0005	reported value matched reporting limit in all cases
Soil-Only COCs								
Benzene	116	2/29/88 - 7/11/16	0	0	NA	0.0005	0.0005	reported value matched reporting limit in all cases
Benzo(a)pyrene	30	12/18/95 - 4/14/09	0	0	NA	0.00004	0.00004	reported value matched reporting limit in all cases
Benzo(b)floranthene	30	12/18/95 - 4/14/09	0	0	NA	0.0002	0.0002	reported value matched reporting limit in all cases
Chrysene	30	12/18/95 - 4/14/09	0	0	NA	0.0002	0.0002	reported value matched reporting limit in all cases
Diesel	no results	NA	NA	NA	NA	NA	NA	
Gasoline	no results	NA	NA	NA	NA	NA	NA	
Lube Oil	no results	NA	NA	NA	NA	NA	NA	

TABLE 3

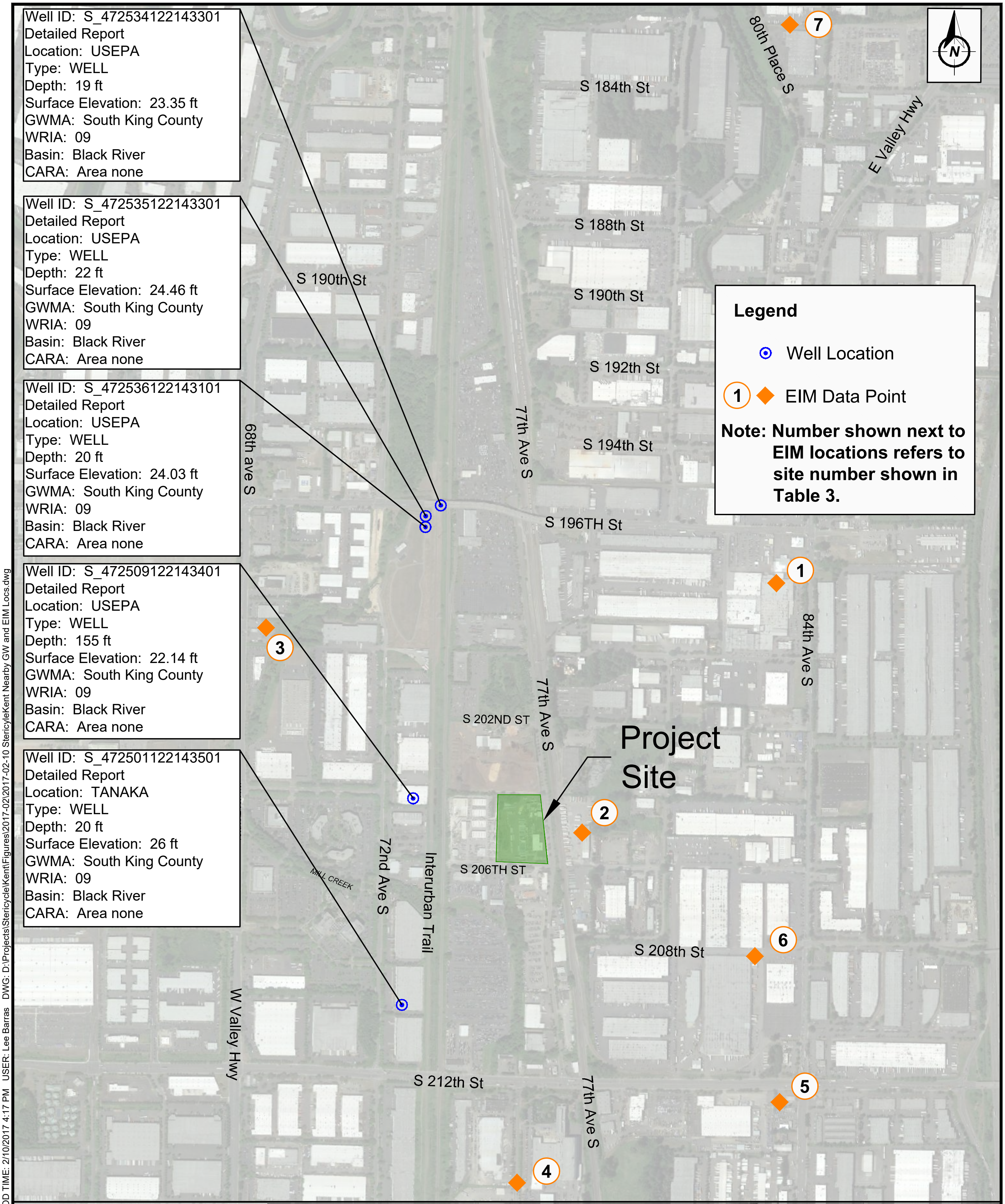
Ecology Environmental Information System Groundwater Data Summary

Stericycle Kent Facility
Kent, Washington

Township, Range, Section	Site Number[1]	Site Name	Address	Stericycle COCs Tested	Highest Detection (ug/L)	Year
T22N R4E S1	1	Hexcel Kent Facility	19819 84th Avenue South	Benzene	0.1	2015
				Vinyl Chloride	290	2015
	2	Former Colonial Cedar	7800 and 7830 South 206th Street	Benzene	12	2010
				Diesel	ND	2015
				Lube Oil	ND	2015
				Gasoline	1,900	2005
	3	Arco 5544, Kent	19918 68th AVENUE SOUTH	Benzene	52,500	2004
				Gasoline	513,000	2004
T22N R4E S2		None				
T22N R4E S12	4	Taylor Edwards	not provided - Latitude 47.4094, Longitude 122.2386	Benzene	4,100	2006
				Gasoline	7,200	2007
	5	Former Exxon Station 73383	8315 South 212th Street	Benzene	438	2012
				Benzo(a)pyrene	ND	2013
				Benzo(b)fluoranthene	ND	2013
				Chrysene	ND	2013
				Diesel	316	2011
				Gasoline	3,040	2012
				Lube Oil	ND	2013
	6	Olympic Steamship Company	not provided - Latitude 47.4153, Longitude 122.2298	Benzene	ND	2010
				Diesel	340	2009
				Gasoline	280	2008
				Lube Oil	ND	2010
T23N R4E S36	7	Former Tally Printer	18220 80th Place South	Vinyl Chloride	5.6	2006
T23 R4E S35		None				

Notes

1. Site number refers to Figure 1, which shows the location of each site, denoted by this Site Number.



Well ID: S_472534122143301
Detailed Report
Location: USEPA
Type: WELL
Depth: 19 ft
Surface Elevation: 23.35 ft
GWMA: South King County
WRIA: 09
Basin: Black River
CARA: Area none

Well ID: S_472535122143301
Detailed Report
Location: USEPA
Type: WELL
Depth: 22 ft
Surface Elevation: 24.46 ft
GWMA: South King County
WRIA: 09
Basin: Black River
CARA: Area none

Well ID: S_472536122143101
Detailed Report
Location: USEPA
Type: WELL
Depth: 20 ft
Surface Elevation: 24.03 ft
GWMA: South King County
WRIA: 09
Basin: Black River
CARA: Area none

Well ID: S_472509122143401
Detailed Report
Location: USEPA
Type: WELL
Depth: 155 ft
Surface Elevation: 22.14 ft
GWMA: South King County
WRIA: 09
Basin: Black River
CARA: Area none

Well ID: S_472501122143501
Detailed Report
Location: TANAKA
Type: WELL
Depth: 20 ft
Surface Elevation: 26 ft
GWMA: South King County
WRIA: 09
Basin: Black River
CARA: Area none

Legend

⊙ Well Location

① ◆ EIM Data Point

Note: Number shown next to EIM locations refers to site number shown in Table 3.

PLOT TIME: 2/10/2017 4:18 PM MOD TIME: 2/10/2017 4:17 PM USER: Lee Barras DWG: D:\Projects\Stericycle\Kent\Figures\2017-02\2017-02-10 StericycleKent Nearby GW and EIM Locs.dwg

0 400 800 1200

Scale in Feet

Stericycle - Kent Facility
Kent, Washington
Feasibility Study

Nearby Groundwater Wells and EIM Groundwater Data Locations

DOF DALTON OLMSTED FUGLEVAND

FIGURE 1

February 10, 2017

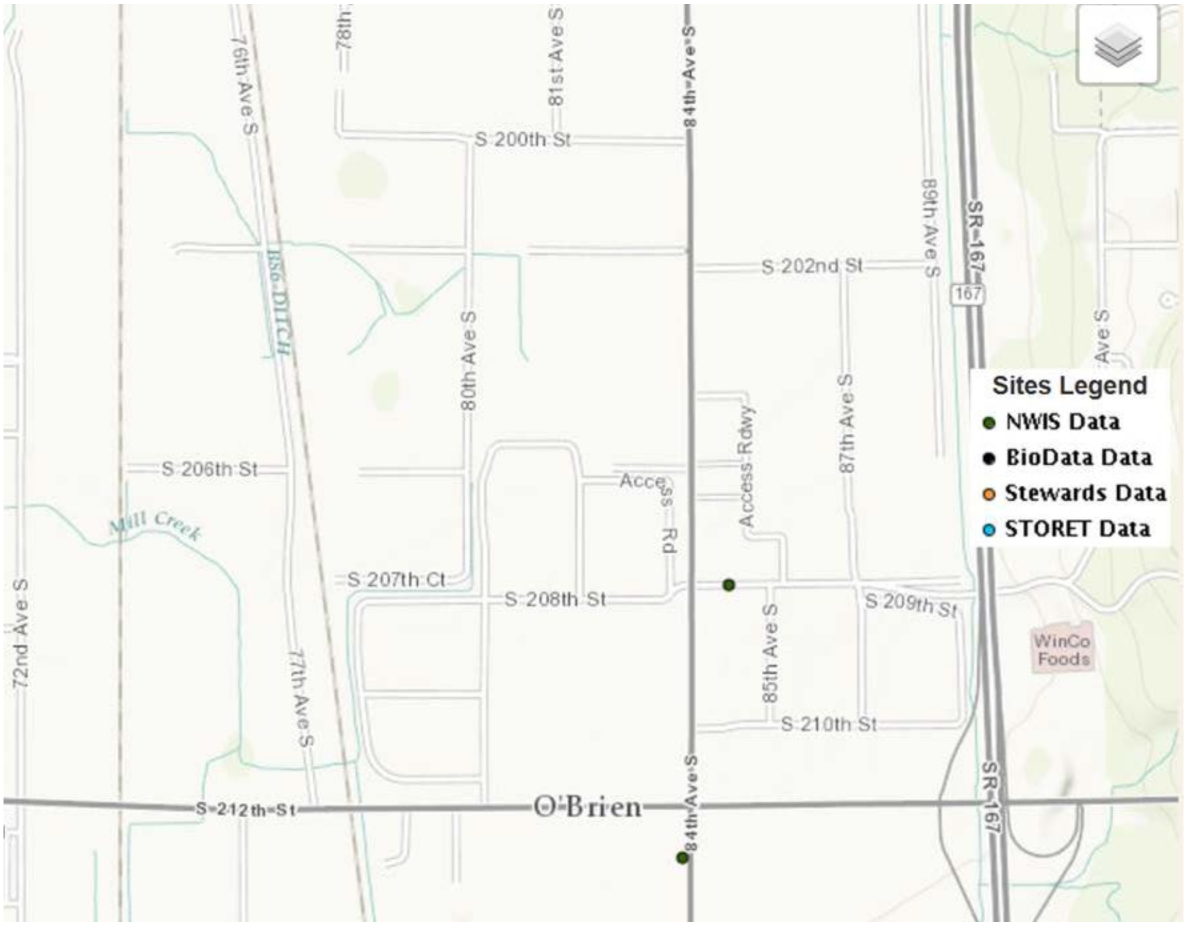
From:	Hines, Neal (ECY)
To:	Beck, William; Natasya Gray
Cc:	Fujita, Hideo (ECY)
Subject:	WQ data search Stericycle Kent
Date:	Monday, March 06, 2017 11:34:00 AM
Attachments:	USGS_WAwells.xlsx

Hi Bill & Tasya: Thanks for the supplemental info (dated 2/13/2017) on nearby wells for the Stericycle Kent facility. I appreciate casting the net wide. I searched one additional source that yielded some water quality data (2 wells). This was through the USGS Water Science Center, at:
https://waterdata.usgs.gov/wa/nwis/current/?type=qwsearch
I suspect these two USGS wells (see map below) are a part of their well network, and although the data are historic ('88 and late 60's-70's), it would be useful to document for the record. I have a question in to their office regarding the purpose of these wells (e.g. were they tied to an event like a spill or a pt. source, are they considered background). It also looks like they are deep wells, but the screened depth (depth that water would have been pulled from) was not clear to me.

The data retrieval was arcane but I was able to save the text to a spreadsheet (attached) for the two wells below & added some meta data. I suspect that the wells from EIM and King Co. GW Protection Program from your search are tied to a local source. A conf. call in a week or so would be useful to go over these details together and, also, to outline a schedule forward.

Let me know if these two wells came across in your search, and if not, please check the work for accuracy in downloading. I'll let you know what I find from USGS re. a response on the wells' purposes.

Thanks,
Neal



Upper Dot:

Station ID:	USGS-472503122132701
Name:	22N/05E-06N01
Type:	Well
HUC 8:	17110013
Org ID:	USGS-WA
Org Name:	USGS Washington Water Science Center

Lower Dot:

Station ID:	USGS-472435122133601
Name:	22N/04E-12H01
Type:	Well
HUC 8:	17110013
Org ID:	USGS-WA
Org Name:	USGS Washington Water Science Center

From:	Hines, Neal (ECY)
To:	Beck, William; Natasya Gray
Cc:	Fujita, Hideo (ECY)
Subject:	FW: East King COunty
Date:	Friday, March 10, 2017 9:34:00 AM
Attachments:	report.pdf doe.request.xlsx

A response came in from USGS regarding the two wells I mentioned. No specific point source tied to these wells, so I think they'd be a useful addendum to the supplemental info letter. The WQ report was new to me, also (attached). We can discuss at the conf. call in a few weeks.
-Neal

Neal A. Hines P.E. Ph.D. | WA State Department of Ecology | Hazardous Waste Toxics Reduction Program | 3190 – 160th AV SE , Bellevue, WA 98008-5452 | 425-649-7181 phone | 425-649-7218 fax | neal.hines@ecy.wa.gov email

From: Jones, Joseph [mailto:jljones@usgs.gov]
Sent: Friday, March 10, 2017 9:22 AM
To: GS-W-WA NWISWeb Data Inquiries <gs-w-wa_NWISWeb_Data_Inquiries@usgs.gov>; GS Archive Ask <archive_ask@usgs.gov>; Hines, Neal (ECY) <nhin461@ECY.WA.GOV>
Subject: Fwd: East King COunty

Hi Neil,

This is what our water quality types came up with. The wells were recon only, not associated with any known point source.

I hope this helps,
Joseph

---------- Forwarded message ----------
From: **Huffman, Raegan** <rhuffman@usgs.gov>
Date: Fri, Mar 10, 2017 at 8:43 AM
Subject: Fwd: East King COunty
To: Joseph Jones <jljones@usgs.gov>

Joseph-

Well 22N/04E-12H01 was part of the East King County project, see attached report. Framework well.

Well 22N/05E-06N01 was sampled in 1962, the 1963 sample has no results, notice the 1962 and 1963 sample dates are teh same, I suspect the 1963 date was a typo in login. The well was sampled in 1962 and 1971. Based on the analytes sampled, it was all reconnasance sampling. (NOT point source).

I'm attaching what I pulled from NWIS as well, hole depth is depth drilled, well depth is obviously what it says. Screened interval or top of water bearing unit would be what DOE would be wanting. This can be retrieved from NWIS web, my retrieval from the QWDATA database, has the water bearing unit populated for one well but not the other, so a site file retrieval of well information from the web would give the water bearing unit, or the information is most likely in the attached pdf of the report.

---------- Forwarded message ----------
From: **Cox, Stephen** <secox@usgs.gov>
Date: Thu, Mar 9, 2017 at 12:33 PM
Subject: East King COunty
To: "Huffman, Raegan" <rhuffman@usgs.gov>

this may be what your looking for. See attached

--
Stephen E Cox
Hydrologist
U.S. Geological Survey
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secox@usgs.gov
Phone: 253-552-1623
Fax: (253) 552-1581

--
Raegan Huffman
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--
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Geohydrology and Ground-Water Quality of East King County, Washington

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U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94-4082

Prepared in cooperation with
SEATTLE-KING COUNTY
DEPARTMENT OF PUBLIC HEALTH

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

Geohydrology and Ground-Water Quality of East King County, Washington

By G. L. Turney, S. C. Kahle, and N. P. Dion

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MARCH 3, 1849

Tacoma, Washington
1995

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For additional information write to:

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U.S. Geological Survey
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Denver, CO 80225

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	4,047	square meter
gallon (gal)	0.003785	cubic meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Temperature: Air temperatures are given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation:

$$°C = 5/9\ (°F-32)$$

Following convention, water temperatures are given in degrees Celsius, which can be converted to degrees Fahrenheit by the following equation:

$$°F = 1.8\ (°C) + 32$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Geohydrology And Ground-Water Quality of East King County, Washington

By G. L. Turney, S. C. Kahle, and N. P. Dion

ABSTRACT

East King County is a rapidly growing 250-square-mile area east of Seattle in western Washington. Because of the rapid growth, the demand for good-quality ground water is increasing. The major source of ground water is a sequence of unconsolidated deposits of both glacial and nonglacial origin that is as much as 1,200 feet thick and blankets Tertiary bedrock. A map of surficial exposures of those deposits and 12 geohydrologic sections were constructed from existing maps and from information on more than 600 inventoried wells and springs. Ten geohydrologic units were delineated, 4 of which are the major aquifers in the study area: the Quaternary alluvium, the Vashon recessional outwash, the Vashon advance outwash, and the upper coarse-grained unit.

Precipitation averages an estimated 57 inches per year over the study area, of which 31 inches, or 413,000 acre-feet, enters the ground-water system as recharge. Ground water generally flows to the Snoqualmie River, then northward along the Snoqualmie River Valley, which bisects the study area from south to north. Some ground water flows to Lake Sammamish, which forms part of the western boundary of the study area. An estimated 98,500 acre-feet of ground water discharges to the Snoqualmie River or Lake Sammamish each year. Another 9,540 acre-feet discharges to springs, and 4,270 acre-feet is withdrawn from wells. Most of the remaining 300,700 acre-feet of recharge flows as ground water to the north or west, out of the study area.

A total of 9,560 acre-feet of water from wells and springs was put to beneficial use during the year 1990. Approximately 4,460 acre-feet was used for public supplies, and 3,010 acre-feet was used for aquaculture (fish farming). Much of the remainder was used for domestic supplies, crop irrigation, and dairy cattle.

The chemical quality of the ground water was typical for western Washington, based on samples collected from 124 wells and springs. All of these samples were analyzed for concentrations of common ions and trace elements. The median dissolved-solids concentration was 115 milligrams per liter, and 95 percent of the water samples were classified as soft or moderately hard. The median nitrate concentration was 0.07 milligram per liter, and no widespread contribution from agriculture or septic tanks was apparent.

Water-quality problems in east King County, when present, were commonly due to natural causes. Iron and manganese concentrations were as large as 14,000 and 920 micrograms per liter (μg/L), respectively, but this is typical of western Washington ground waters. Arsenic was present in 64 percent of the samples, and 15 percent had concentrations of 20 μg/L or greater. Also, radon was present at levels exceeding the proposed maximum contaminant level of 300 picocuries per liter in 29 percent of the 17 samples analyzed for radon.

Samples from selected wells were analyzed for concentrations of pesticides and volatile organic compounds. The pesticide dicamba was present at a concentration of 0.01 μg/L in samples from 3 of 12 selected wells, and the pesticide 2,4-D was present at a concentration of

0.02 µg/L in one sample from a fourth well. No volatile organic compounds were detected in any samples collected from 11 selected wells.

INTRODUCTION

The demand for water in east King County has steadily increased over the past 20 years because of rapid growth in population and residential development. In one part of the study area, the Sammamish Plateau, the population increased by more than 150 percent from 1980 to 1990. Nevertheless, much of east King County remains undeveloped, and projected population growth rates are high. Also, the area is often considered for sources of water to supply other areas of the county. The demand for water in the area is, therefore, likely to increase in the future. Ground-water resources in east King County are already relied upon for most public supply, domestic, and agricultural uses, and undoubtedly will be developed further to help meet this future demand. Surface water is used for some industrial and agricultural purposes, but many surface-water bodies are closed to further appropriations.

The importance of ground water in east King County has led State and local officials to recognize the need for ground-water resource management that addresses several concerns:

(1) The potential for further ground-water development;

(2) the degree, if any, of existing ground-water contamination;

(3) the potential for future ground-water contamination; and

(4) the effects of ground-water development on ground-water and surface-water resources.

Accordingly, the Seattle-King County Department of Public Health (SKCHD) designated a 250-mi^2 area of east King County as a Ground-Water Management Area (GWMA) under the State GWMA program. The GWMA program, which is administered by the Washington State Department of Ecology (Ecology), calls for a description of the physical and chemical characteristics of the ground-water system (Washington State Department of Ecology, 1988). To address this need, in 1990 the U.S. Geological Survey (USGS) entered into a cooperative agreement with the SKCHD to conduct a 2-year study of the ground-water system in east King County. The study had the following objectives:

(1) Describe and quantify the ground-water system to the extent allowed using available and readily collectable data;

(2) describe the general water chemistry of the major geohydrologic units and any regional patterns of contamination;

(3) evaluate the potential for ground-water development on the basis of aquifer characteristics, ground-water interaction with surface water, and ground-water recharge; and

(4) determine what additional data are needed to further quantify ground-water availability.

Purpose and Scope

The purpose of this report is to summarize the findings of the study described above. The report includes descriptions of the areal geometry of the aquifers, ground-water flow system, water use, ground-water level fluctuations, and water-quality characteristics of the principal geohydrologic units.

The area actually studied comprises 259 mi^2, which is slightly larger than the designated GWMA (figs. 1 and 2). This is because data from a few wells outside the GWMA boundary were used in constructing some of the geohydrologic and water-table maps. Except where noted, results presented and mapped in this report are for the study area and may be considered the same for the GWMA. The most significant exceptions are some components of the water budget calculations, specifically rainfall, recharge, and water use, which are area-dependent and were calculated for the GWMA alone. Population figures are also for only the GWMA, except where noted.

Description of the Study Area

The study area and GWMA are referred to as east King County, but they are actually located in north-central King County. This reference is traditional and stems from the study area's location east of the Seattle-Bellevue urban area (fig. 1). The study-area boundary follows the King County-Snohomish County line (figs. 1 and 2) on the north. On the west, it roughly follows the Snoqualmie River drainage divide, then turns westward to the east shore of Lake Sammamish. The boundary follows the east shore of the lake then turns eastward to and continues along the Snoqualmie River drainage divide, which

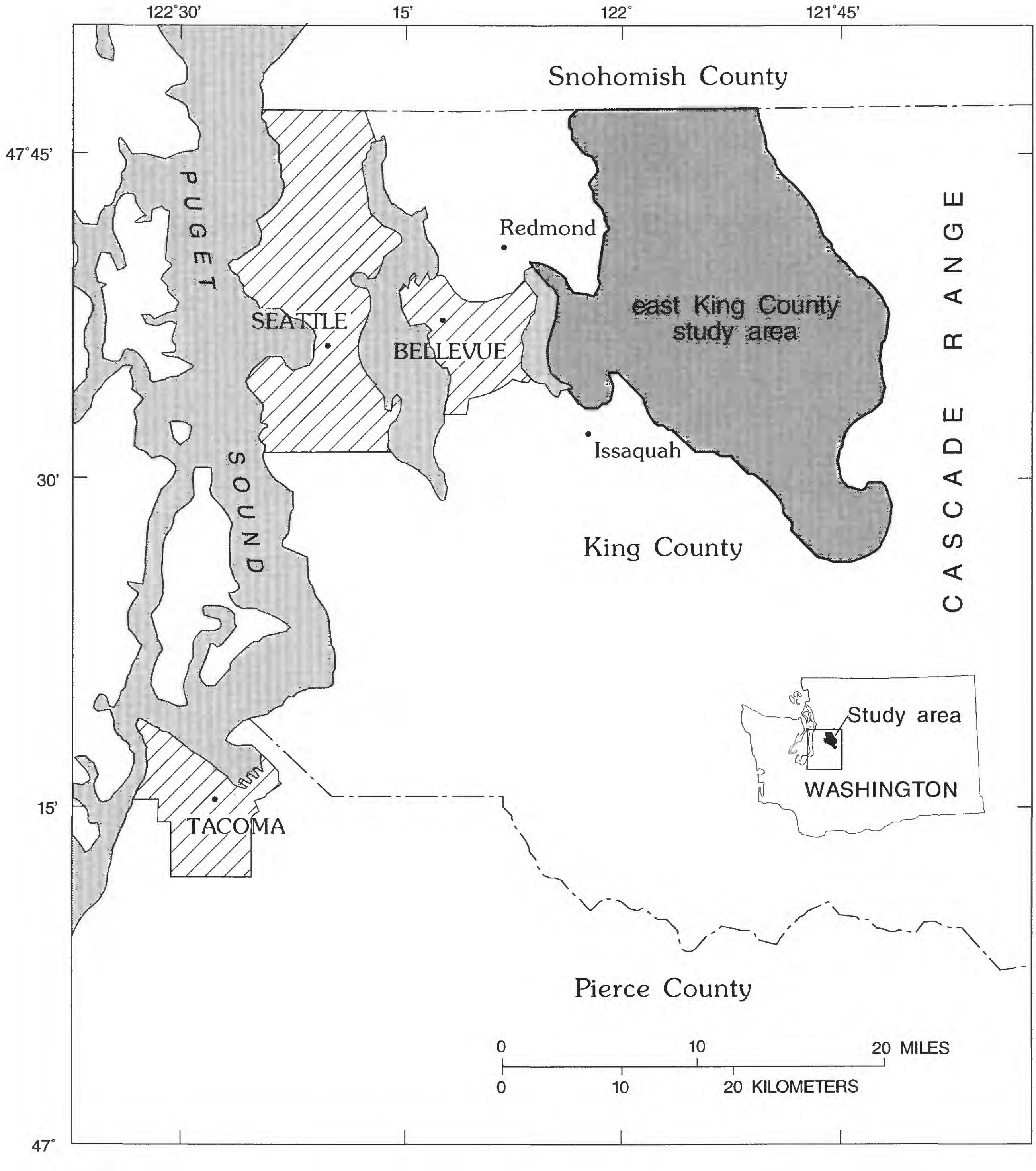


Figure 1.--Location of the east King County study area.

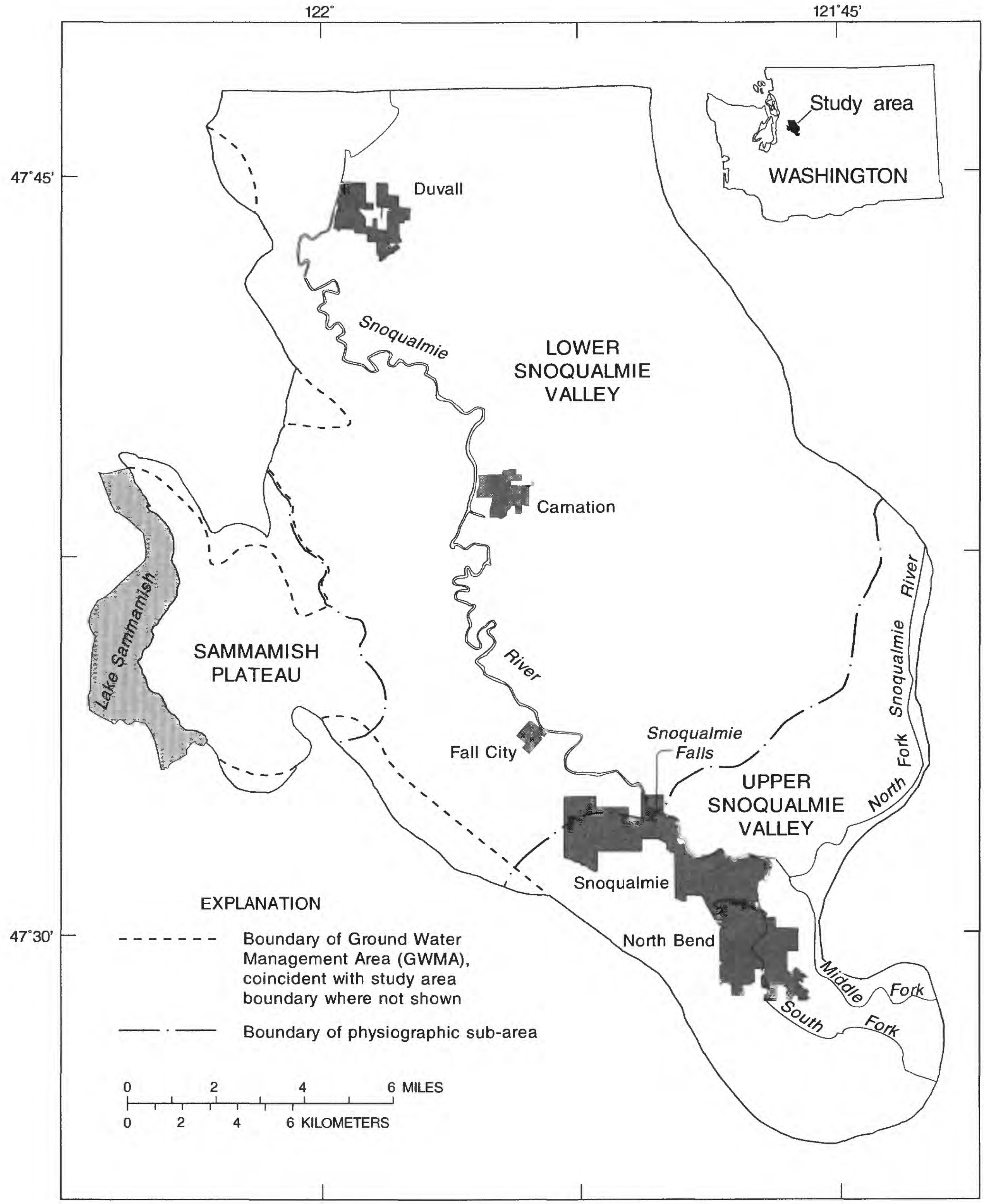


Figure 2.--East King County study area and three physiographic sub-areas.

defines the southwestern study boundary. The eastern boundary follows the base of the foothills of the Cascade Range.

The topographic surface of the study area resulted from erosion and deposition during and since the last glaciation (approximately 15,000 years ago). The Snoqualmie River flows generally from south to north, creating an alluvial valley approximately 1 mile wide that bisects the study area (fig. 2). About one third of the way into the study area from the south, the river drops some 270 feet over Snoqualmie Falls. Above the falls the altitude of the valley floor ranges from 400 to 600 feet and below the falls it ranges from 30 to 130 feet. West of the river is a glacial-drift-covered plateau that has moderate relief and ranges from 200 to 400 feet in altitude. Southwest and east of the river valley are hills of consolidated bedrock thinly mantled with glacial drift; these hills have considerably more relief than the rest of the study area. Some of this relief is due in part to incisions from tributaries to the Snoqualmie River, and the altitudes of the hills generally range from 500 to more than 1,000 ft.

Physiographically, the study area is divided into three sub-areas (fig. 2). The Sammamish Plateau consists of the western drift-covered plateau. The upper Snoqualmie Valley is the part of the study area generally upstream (south) of Snoqualmie Falls. The lower Snoqualmie Valley is the area downstream of the falls, less the Sammamish Plateau.

All of the study area except the Sammamish Plateau is drained by the Snoqualmie River. Three separate tributaries, the North, Middle, and South Forks of the Snoqualmie River, converge about 3 miles upstream of Snoqualmie Falls to form the main stem of the river. The Tolt and Raging Rivers also are tributaries to the Snoqualmie River, along with several smaller streams including Cherry, Harris, Griffin, and Patterson Creeks (plate 1). The Sammamish Plateau drains to Lake Sammamish by several small unnamed creeks. The major lakes in the study area include Ames, Beaver, Joy, Langlois, Margaret, and Pine (plate 1) and are described by Bortleson and others (1976).

The climate of the study area is characterized by warm, dry summers and cool, wet winters. Moist air masses reaching the area originate over the Pacific Ocean, and this maritime air moderates temperatures in both winter and summer (Phillips, 1960). Prevailing winds are from the south or southwest in fall and winter, gradually shifting to the northwest or north in late spring and summer.

The mean annual air temperature at the National Weather Service station at Snoqualmie Falls is 50°F, and July is usually the warmest month (mean monthly temperature of 63°F) and January the coldest (mean monthly temperature of 38°F) (fig. 3). Afternoon temperatures are usually in the 70's in summer and from the upper 30's to lower 40's in winter (National Oceanic and Atmospheric Administration, 1982).

During the wet season (winter), rainfall is usually of light to moderate intensity and continuous over an extended period of time. The mean annual precipitation for the study area is about 57 in., but ranges from less than 45 in. in the northwestern part of the study area to more than 90 in. in the southeastern part of the study area (fig. 3). The areas of greater precipitation result from the lifting and cooling of moist maritime air by relatively high landforms. The mean annual precipitation at Snoqualmie Falls is just over 61 in. (National Oceanic and Atmospheric Administration, 1982). In an average year, July has the least precipitation (1.4 in.) at Snoqualmie Falls and December has the greatest (9.5 in.). Seventy-two percent of the precipitation at Snoqualmie Falls falls in the 6-month period October to March. Most of the winter precipitation is rain. Total rainfall for the three driest months (June, July, and August) is 10 percent of the annual total. Precipitation at Snoqualmie Falls in 1990 was 81 in. (much larger than normal) and in 1991 it was 58 in. (slightly below normal). The monthly variability is apparent in figure 3.

The type of native vegetation varies according to soil type. Poorly drained fine-grained soils support mostly firs, cedars, alders, and maples. Beneath these trees is an understory of huckleberry, Oregon grape, salal, and ferns. On well-drained soils, underlain by coarse-grained outwash or alluvium, the vegetation usually consists of wild grasses, Scotch broom, and isolated patches of firs and oaks.

The estimated 1990 population of the GWMA, which encompasses the incorporated cities of Duvall, Carnation, Snoqualmie, and North Bend, was about 56,500 (King County Parks, Planning, and Resources Department, 1991). However, only about 14 percent of the population resided within the boundaries of those four cities. The population of King County's East Sammamish and Snoqualmie Valley Planning Areas, which have approximately the same boundary as the study area, more than tripled from 1970 to 1990 and is projected to double from 1990 to 2020 (fig. 4, King County Parks, Planning, and Resources Department, 1991). Most of the growth is in the East Sammamish Planning Area, where the

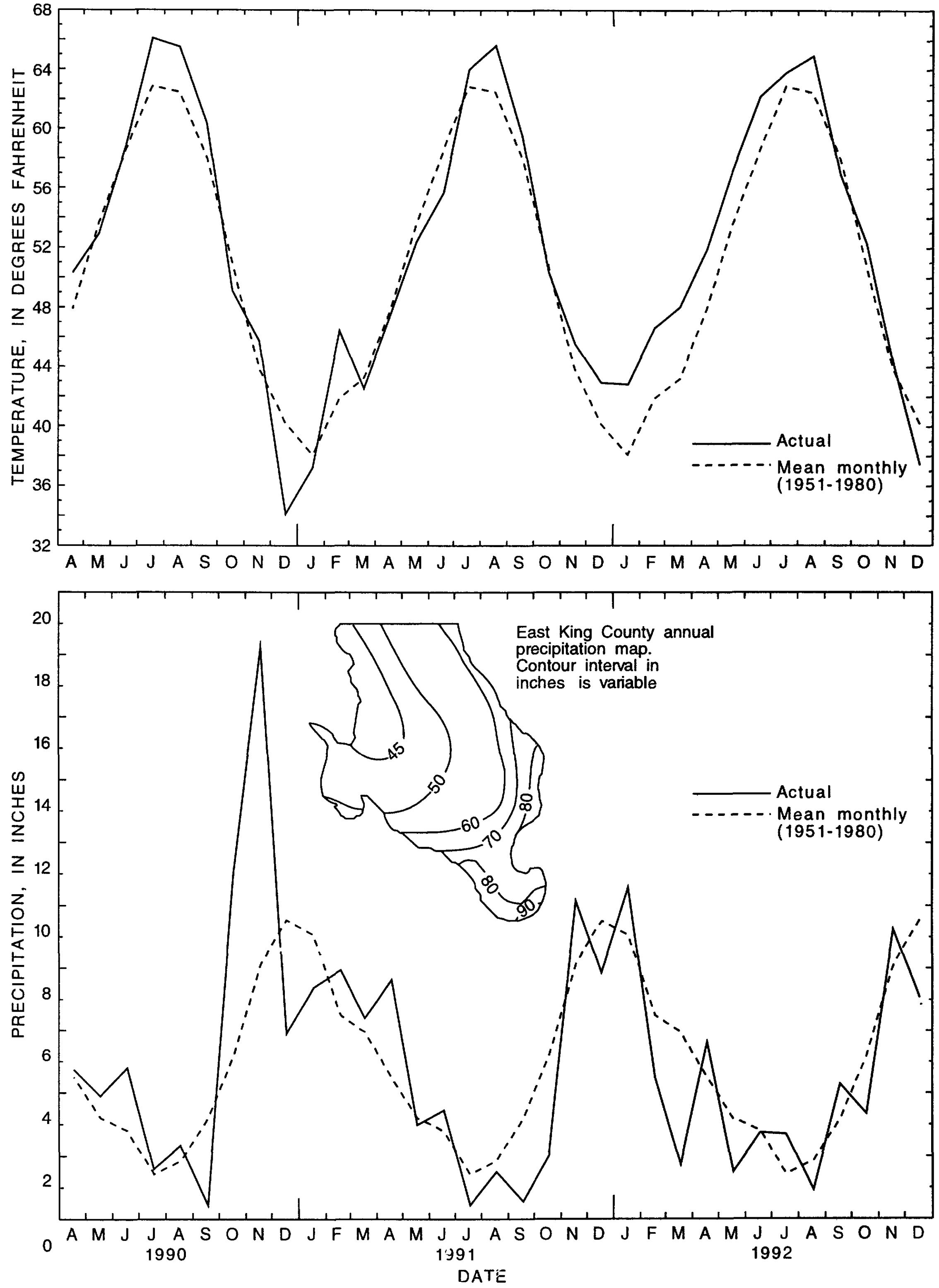


Figure 3.--Observed and mean monthly climatic conditions at Snoqualmie Falls, and precipitation map of east King County. (Observed values are from National Weather Service records; mean monthly values are from National Atmospheric and Oceanic Administration, 1982.)

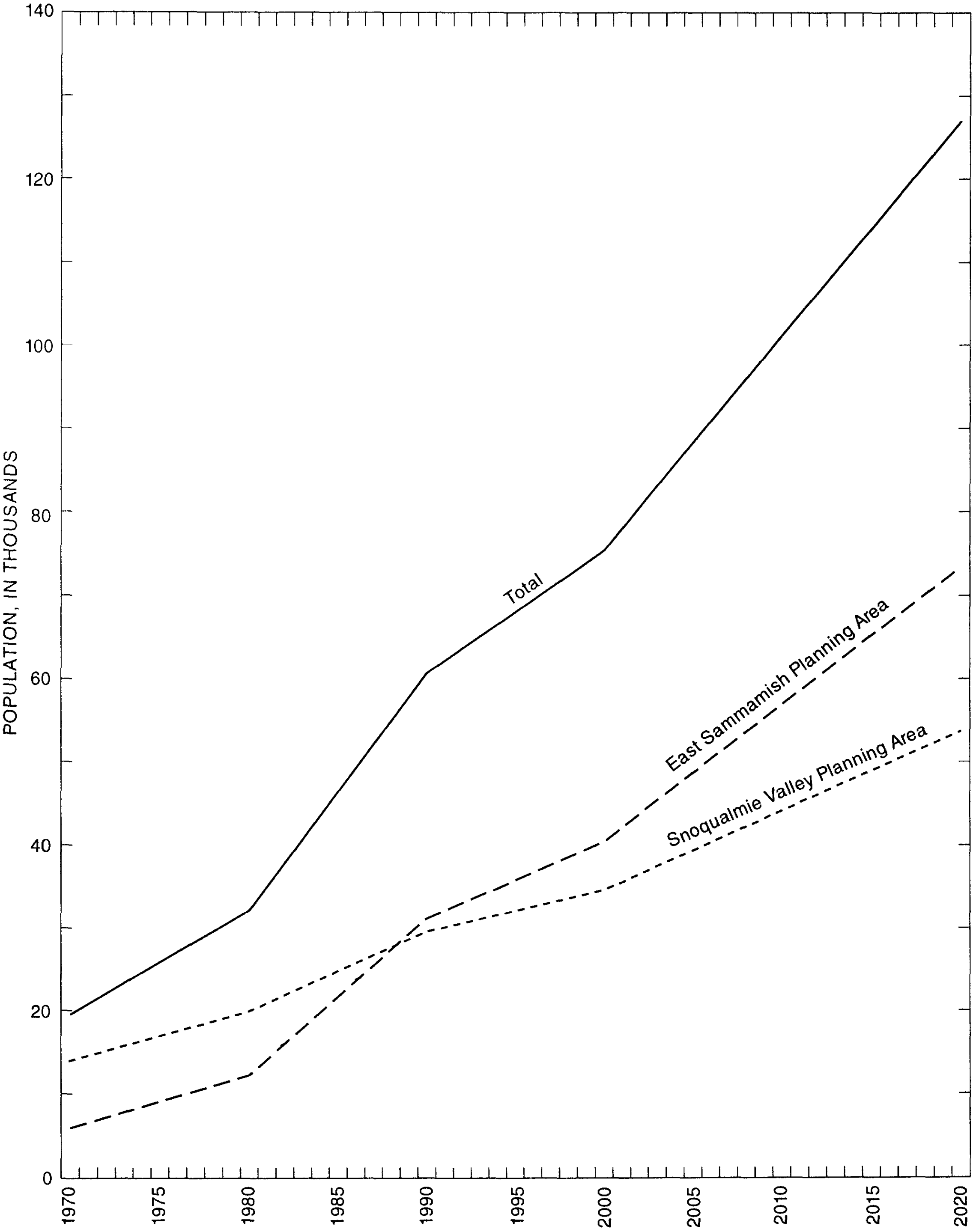


Figure 4.--Population trends for East Sammamish and Snoqualmie Valley Planning Areas. (Data from King County Parks, Planning, and Resource Department, 1991).

population increased over 150 percent from 1980 to 1990. As a result, the Sammamish Plateau is more suburban in nature than is the rest of the study area.

Much of the population, especially in the Sammamish Plateau, is employed in Redmond, Issaquah, or in the Seattle-Bellevue metropolitan area to the west (fig. 1). There is also commercial employment throughout the study area. In the Snoqualmie River Valley, there are some agricultural activities, the largest of which is dairy farming. Other agricultural activities include berry farms, nurseries, tree farms, and a few crops. Timber production and processing was historically a major employer and it is still significant in some communities.

Well-Numbering System

In Washington, wells are assigned numbers that identify their location within a township, range, section, and 40-acre tract. For example, well number 25N/06E-12H02 (fig. 5) indicates that the well is in township 25 North (25N) and range 6 East (6E) of the Willamette base line and meridian. The numbers immediately following the hyphen indicate the section (12) within the township; the letter following the section gives the 40-acre tract of the section, according to the schematic shown on figure 5. The two digit sequence number (02) following the letter indicates that the well was the second one inventoried by

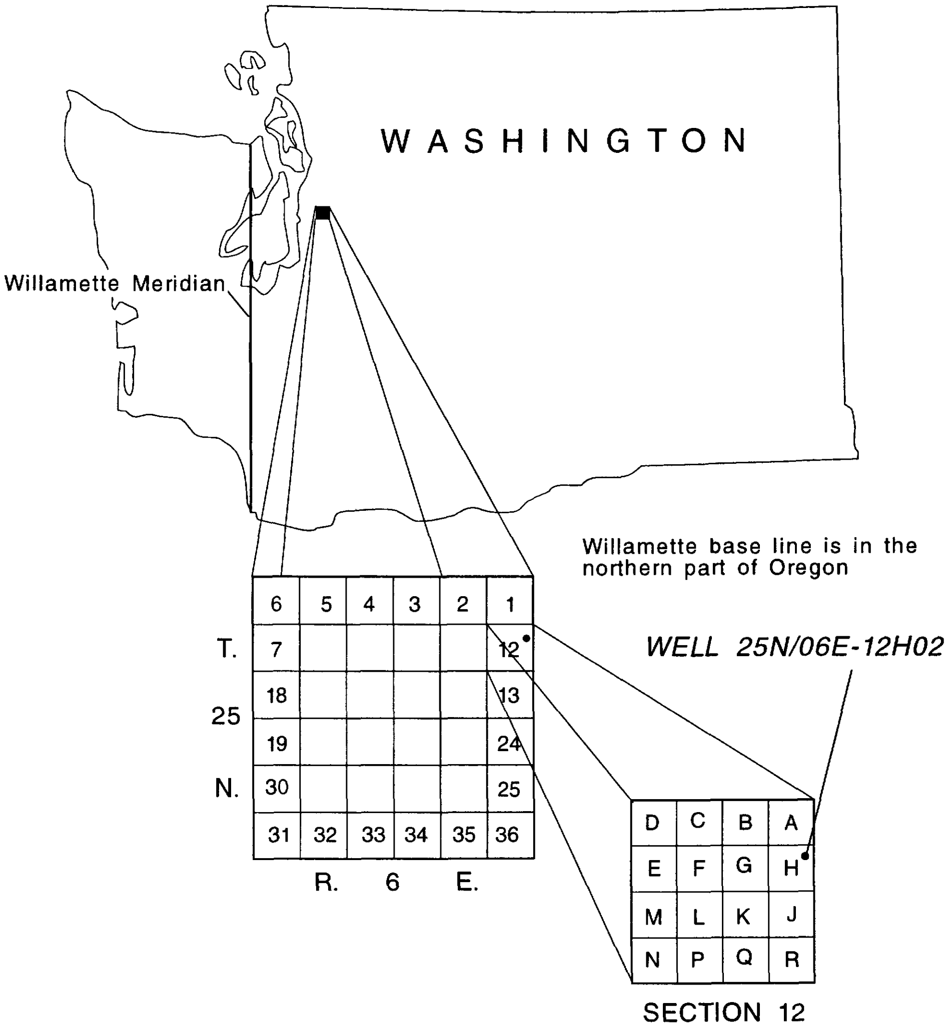


FIGURE 5.--The well-numbering system in the State of Washington.

USGS personnel in that 40-acre tract. In some plates of this report, wells are identified individually by only the section and 40-acre tract, such as 12H02, and township and range are shown as a grid. Well numbers with a P1 or P2 following the sequence number designate a piezometer, or monitoring well, and those with a D1 (or D2) following the sequence number indicate the well has been deepened once (or twice). An S following the sequence number indicates the site is a spring, rather than a well.

Acknowledgments

The authors acknowledge the cooperation of the many well owners and tenants who supplied information and allowed access to their wells and land during the field work, and the owners and managers of various water systems and companies who supplied well and water-use data. Two drillers, T. L. Cannon and H. O. Meyer, were also of assistance in providing and clarifying well logs and records.

STUDY METHODS

The approach and study methods used to describe the ground-water system in east King County are discussed in this section. The data collected and the rationale for collecting the data are also discussed. Assumptions made in collecting and interpreting the data are presented as necessary.

Approach

The following steps were taken to achieve the study objectives.

1. A surficial geology map of exposures of the geologic units was made for the study area.
2. Geohydrologic sections showing the altitude and thickness of the identified lithologies were constructed along selected lines throughout the study area.
3. The surficial geology map and the geohydrologic sections were used to identify and describe the major geohydrologic units in the Quaternary sediments.
4. The areal extent and the altitude of the top of each major geohydrologic unit was mapped.
5. The range of hydraulic conductivities of each geohydrologic unit was estimated.
6. The quantity of ground-water recharge derived from precipitation was estimated and mapped.
7. The ground-water flow system was described on maps showing the configuration of the potentiometric surface and the implied horizontal direction of water movement in each major aquifer.
8. The annual quantity of ground water withdrawn was estimated and its use described.
9. A comprehensive water budget was estimated.
10. The overall significant chemical characteristics of the ground water were described and mapped.
11. Areas or points of detected water-quality problems were identified.
12. Deficiencies in the existing data were identified and possible sampling programs to obtain the necessary data were briefly described.

Only data either readily available or collectable were used--that is, no test drilling or borehole geophysical logging was conducted for this study. Also, because of the size of the study area and the heterogeneity of the subsurface deposits, a regional perspective was used to characterize and describe the individual geohydrologic units and the water movement and quality in each unit.

Geohydrologic Methods

The bulk of the data used in this study came from information on a total of 604 wells (plate 1) that were inventoried in the field during 1990 and 1991. An attempt was made to inventory an average of three wells per section (1 square mile) or a total of approximately 750 wells. Because the eastern part of the study area contains no wells, the total number of wells inventoried (604) falls short of this planned number (750). However, the well density in the rest of the study area is approximately three per section.

The wells to be inventoried were selected on the basis of several criteria. First, only wells having a Washington State Water Well Report, or equivalent, were selected. The report contains information on the owner, construction, lithology, and testing of the well, and in most cases is the only way the USGS and other agencies are aware of the well's existence. Second, wells were selected to provide an even areal coverage of the study area. Also, wells of various depths and lithologies were selected. Where possible, wells with detailed well logs and smaller screened intervals were selected. Finally, ease of access was considered. In many instances, only one or two wells in a given section were available to inventory. However, where several wells were available, field personnel were given the option to inventory the most readily available well. As a result, one well may have been inventoried instead of another because of something as simple as the owner being at home. The 604 inventoried wells represent only about 20 percent of the total number of wells estimated to be in the study area at the time of the inventory.

Six springs were inventoried (plate 1) to help estimate ground-water discharge. The primary criterion for inventorying a spring was that it was present on USGS topographic maps, and all of these were inventoried. Other springs were also inventoried if they were identified in the field or during discussions with water purveyors. It should be recognized that there are hundreds of small springs and seeps in the study area, most of which would be difficult to locate and measure.

The well and spring inventory process began with locating the site in the field. Latitude, longitude, and land-surface altitude of the site were then determined from 1:24,000 scale topographic quadrangle maps. Finally, the water level was measured where possible. The information obtained during the inventory, along with information from the water well report, was then entered into the USGS National Water Information System (NWIS) data base. Data pertaining to the inventoried wells and springs are presented in Appendix A.

Information used to map the surficial geology of the study area was obtained from maps published by Tabor and others, 1982; Frizzell and others, 1984; Minard, 1985; Minard and Booth, 1988; Booth, 1990; and Booth and Minard, 1992. Field observations by project personnel at road and stream cuts provided additional information concerning geomorphic features and shallow geologic conditions.

The surficial geology map and subsurface lithologic information from water well reports were used to construct geohydrologic sections and maps of the geohydrologic units. Twelve sections were constructed using data from 120 wells. The sections were oriented both east-west and north-south across the study area, and were correlated to define the major geohydrologic units. After the sections were correlated, the data from the sections were extrapolated and used in conjunction with the data from the remaining wells to construct maps showing the areal extent and the altitude of the tops of the upper six units. Few wells were deep enough to extend into the deeper geohydrologic units, so those units were not mapped. All wells determined to be completed in a single geohydrologic unit were assigned a unit designation.

The estimates of recharge to the ground-water system from precipitation were based on the results of precipitation-runoff studies in King County. Because the methods used in making the estimates are complex and involve much interpretation, they are described in greater detail in the section on recharge (p. 27).

The ground-water flow system is depicted in part on maps showing the potentiometric surfaces of four major aquifers. The maps were based on water levels measured in more than 340 wells at the time of inventory. (Water levels were measured in more than 475 inventoried wells, but only 340 were completed in the four major aquifers.) An additional 40 water levels reported by drillers of inventoried wells were used as needed to corroborate or refine the contours. The number and distribution of water-level measurements in the major aquifers were considered adequate to map and contour the respective potentiometric surfaces. The number of water-level measurements in other, less-widely used units was more limited, and thus the potentiometric surfaces for those units could not be mapped. Vertical flow directions were determined by comparing water levels in closely spaced wells finished at significantly different altitudes, and by comparing the maps of the potentiometric surfaces for the major aquifers.

For a network of 42 wells, water levels were measured monthly from May 1991 to December 1992 in order to track seasonal water-level variations. The 42 wells were selected from the inventoried wells, taking care to preserve the areal and vertical distribution. In some cases, wells relatively close to each other but with different depths were selected. The selected wells were then reviewed to verify that all of the major geohydrologic units were represented. If continued access to a well was thought to be a potential problem, it was replaced by another well with similar characteristics prior to beginning the monthly measurements.

Estimates of the horizontal hydraulic conductivity for each aquifer were based on specific-capacity data. Only data from wells with complete specific-capacity information (discharge rate, time, draw-down, well-construction data, and geologic log) were used. Two different sets of equations were used, depending on how the well was finished. For wells that had a screened, perforated, or open-hole interval (a section of a well in bedrock with no casing or screen), the modified Theis equation (Ferris and others, 1962) was used to first estimate transmissivity values. This equation is

$$T = \frac{Q}{4\pi s} \ln \frac{2.25Tt}{r^2 S} \qquad (1)$$

where

T = transmissivity of the geohydrologic unit, in ft^2/day;

Q = discharge, or pumping rate, of the well, in ft^3/day;

s = drawdown in the well, in feet;

t = length of time the well was pumped, in days;

r = radius of the well, in feet; and

S = storage coefficient, a dimensionless decimal.

The equation was solved for transmissivity using Newton's iterative method (Carnahan and others, 1969). The transmissivity was then used in the following equation to calculate horizontal hydraulic conductivity:

$$K_h = T/b \qquad (2)$$

where

K_h = horizontal hydraulic conductivity of the geohydrologic unit, in ft/day;

T = transmissivity, as calculated above; and

b = thickness of the geohydrologic unit, in feet, approximated by the length of the open interval as described in the water well report.

The use of the open interval to approximate the aquifer thickness assumes that the wells are open through the entire thickness of the aquifer, which was almost never the case. Nevertheless, this assumption is necessary because the equations as derived assume only horizontal flow (vertical flow is nonexistent, or at least insignificant) and in a homogeneous aquifer, horizontal flow alone can be measured only if a well penetrates the entire aquifer thickness. However, in heterogeneous glacial aquifers, such as those in east King County, vertical flow is likely to be insignificant compared to horizontal flow because the layering of the aquifer materials leads to horizontal hydraulic conductivities that are generally much larger than vertical hydraulic conductivities. Thus, although the wells are rarely open through the entire aquifer thickness, the assumption that they are is reasonable for glacial aquifers.

A third equation was used to estimate hydraulic conductivities for wells having only an open end, and thus no vertical dimension to the opening. Bear (1979) provides an equation for hemispherical flow to an open-ended well just penetrating an aquifer. When modified for spherical flow to an open-ended well within an aquifer, the equation becomes

$$K_h = \frac{Q}{4\pi sr} \qquad (3)$$

where

K_h = horizontal hydraulic conductivity of the geohydrologic unit, in ft/day;

Q = discharge, or pumping rate of the well, in ft^3/day;

s = drawdown in the well, in feet; and

r = radius of the well, in feet.

Equation 3 is based on the assumption that ground water can flow equally in all directions, and specifically that horizontal and vertical hydraulic conductivities are equal. As discussed above, this is not likely to be true for glacial aquifers. However, the errors associated with violating this assumption are likely to be less than those resulting from using equations 1 and 2 for open-ended wells. In fact, hydraulic conductivities were calculated with both methods for open-ended wells, and the values calculated with equation 3 more closely resembled the hydraulic conductivities calculated for the screened wells in a given geohydrologic unit.

Water-use data estimated for this study were for the year 1990. Most of the data were obtained by telephone canvassing of the major water users in the study area. Data also were collected from Ecology, Washington Department of Health (WDOH), USGS, and reports from utilities and other agencies.

At the time of the water-use canvass, public water systems in Washington were divided into four classes (Washington State Department of Social and Health Services, 1983).

Class 1 systems had 100 or more permanent services (a physical connection designed to serve a single family) or served a transitory population of 1,000 or more people on any one day;

Class 2 systems had 10 to 99 permanent services or served a transitory population of 300 to 999 people on any one day;

Class 3 systems served a transitory population of 25 to 299 people on any one day; and

Class 4 systems had 2 to 9 permanent services or served a transitory population of less than 25 people per day.

Data for Class 1 and 2 systems were obtained by direct contact, either by telephone or letter, with each system manager or representative. Withdrawals for most Class 1 and some Class 2 systems were metered, and in those cases actual pumpage data were used. For systems that were not metered, estimates of withdrawals were made with the following formula:

$$W = CPU \times 365 \qquad (4)$$

where

W = annual system withdrawal;
C = number of connections;
P = average number of persons per connection; and
U = daily water use per person.

For unmetered systems, system managers knew the number of connections and could usually provide estimates of the other two figures (P and U). If the managers could not estimate these numbers, values of 2.5 persons per connection and 110 gal of daily water use per person were used. These numbers are based on typical averages for public supply systems in Washington (R. C. Lane, U.S. Geological Survey, written commun., 1992). For purposes of this study, persons served by the dozens of Class 3 and 4 systems were considered to be supplied by privately owned wells.

Annual ground-water withdrawals from privately owned wells for domestic use were calculated by first determining the population of the study area whose homes were supplied water by Class 1 or 2 public water systems (48,100) and subtracting that number from the total population of the area (56,500). The difference (8,400) was then multiplied by a per capita rate of 110 gal/day and by 365 days.

Ground-water withdrawals for agricultural activities were based on the operators' estimates. If estimates were unknown or uncertain, withdrawals were calculated by one of the following methods. For crop irrigation, one of two methods was used: (1) The pumping capacity of the irrigation well was multiplied by the owner's estimate of the duration of pumping; or (2) a uniform application rate of 1.5 acre-ft of water per acre per year (irrigation season) was multiplied by the estimate of irrigated acreage. To determine livestock consumption, the number of head in a herd was multiplied by the estimated daily consumption per head and the number of days of consumption. For example, dairy cattle (the livestock using the most water) were each estimated to consume 30 gallons of water per day, or about 11,000 gal/yr. Information about irrigated acreage and herd size was obtained by telephone and personal contact with farmers identified either by USGS personnel during the well-inventory process or by personnel of the U.S. Department of Agriculture Soil Conservation Service.

Ground-water withdrawals from private wells for commercial, industrial, and institutional purposes are referred to as self-supplied. They were estimated on the basis of telephone canvassing of water users identified during the well inventory, by SKCHD personnel, and by publications such as the telephone directory. Because of the large number of small commercial businesses in the study area, the canvass of this category is most likely incomplete, but the omissions are likely insignificant.

Water-Quality Methods

The sampling and analytical methods used in the water-quality phase of this study follow guidelines presented in various U.S. Geological Survey Techniques of Water-Resources Investigations (Wood, 1981; Friedman and Erdmann, 1982; Wershaw and others, 1987; Britton and Greeson, 1988; and Fishman and Friedman, 1989) and where applicable, guidelines for GWMA studies as presented by Carey (1986). This section presents an overview of selected methods.

Water samples were collected from 121 wells and 3 springs (plate 2) during July and August 1991. All samples were analyzed for concentrations of major ions, alkalinity, silica, nitrate, iron, manganese, and selected trace elements. The trace-element analytes were arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, silver, and zinc. In addition, field measurements of temperature, specific conductance, pH, and dissolved-oxygen concentration were made at all sites. Samples from all but three wells also were analyzed for concentrations of fecal-coliform and fecal-streptococci bacteria. A subset of 11 samples, taken mostly from wells situated in more populated areas, was analyzed for concentrations of volatile organic compounds. Another subset of 12 samples collected from wells in agricultural areas was analyzed for concentrations of selected pesticides. The volatile organic compound and pesticide analytes are presented later in this report. A subset of 19 samples from wells in areas without sewers was analyzed for concentrations of boron, dissolved organic carbon (DOC), and methylene blue active substances (MBAS, or detergents). Finally, samples from 17 randomly selected wells were analyzed for concentrations of radon. All water-quality data that resulted from this study are presented in Appendix B.

All the wells sampled in this study had been inventoried and field-located, as previously described, prior to sampling. Most of the wells selected for sampling were used for domestic or, to a lesser extent, municipal purposes; a few were used for agricultural, industrial, or commercial purposes. The sampled wells were selected to provide a broad geographic coverage and a representation of the major geohydrologic units. The number of wells selected for sampling within each of the geohydrologic units was approximately proportional to the total number of wells inventoried in each unit. Wells open to more than one geohydrologic unit were not sampled. If a selected well could not be sampled for any reason, a substitute well was selected using the same criteria; care was taken to preserve the original well distribution, both areally and geohydrologically. Areas of potential ground-water-quality problems, such as elevated nitrate concentrations or the presence of pesticides, were also considered in the well-selection process. Although an effort was made to sample wells that might be representative of widespread water-quality problems, because of the regional nature of this study no attempt was made to sample wells affected by known small-scale or point-source problems. Wells from which samples were analyzed for concentrations of volatile organic compounds, pesticides, and septage-related compounds were selected mostly on the basis of the predominant land use in the general vicinity of each well. A map of potential sources of water-quality problems, including land fills, dairy farms, berry farms, and underground storage tanks, was also used to guide the well selection by identifying areas where point-source problems may be dense enough to result in regional problems.

Water samples usually were collected from a hose bib in the well distribution system as close to the wellhead as possible. All samples were collected at a point ahead of any water treatment, such as chlorination, fluoridation, or softening. Where feasible, samples were collected upstream of any holding tank. Sample water was directed from the hose bib through nylon tubing to a flow-directing stainless-steel manifold mounted in a mobile water-quality laboratory; a diagram of the system is shown on figure 6. At a flow chamber, temperature, pH, specific conductance, and dissolved-oxygen concentration were monitored continuously. Once these readings were constant for 10 minutes (indicating that the water was being drawn from the aquifer), raw and filtered samples were collected from the appropriate manifold outlet. Raw samples to be analyzed for concentrations of organic compounds and bacteria were collected last, directly from the hose bib.

After collection, samples were treated and preserved according to standard USGS procedures (Pritt and Jones, 1989). Samples requiring laboratory analysis were sent to the laboratory by first-class mail on the next work day. All sampling equipment was rinsed and cleaned as appropriate before subsequent samples were collected.

Field determinations of temperature, pH, and specific conductance were made on-site with meters, using methods outlined by Wood (1981). Dissolved-oxygen concentrations also were determined onsite with a meter, but concentrations of 1.0 mg/L (milligram per liter) or less were verified onsite with a Rhodazine-D colorimetric method (White and others, 1990) developed by Chemetrics, Inc. Alkalinity was determined in the field for samples with a dissolved-oxygen concentration of 1.0 mg/L or less and an iron concentration of 800 μg/L (micrograms per liter) or greater. The iron concentration was estimated in the field with a colorimetric method developed by Chemetrics. Only eight samples met the criteria for determining a field alkalinity, but the differences between the laboratory and field alkalinity determinations did not affect the statistical analyses or interpretations of alkalinity. The field alkalinity results are therefore presented only in Appendix B and are not discussed in the text. A detailed comparison of the laboratory and field alkalinity determinations is discussed in Appendix C. Samples were also analyzed in the field for concentrations of fecal-coliform and fecal-streptococci bacteria by membrane filtration methods outlined by Britton and Greeson (1988).

Laboratory analyses were done by the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo. Dissolved concentrations were determined for all inorganic constituents and total concentrations were determined for all organic compounds except dissolved organic carbon and the triazine herbicides. The triazine herbicide concentrations were reported as dissolved because the

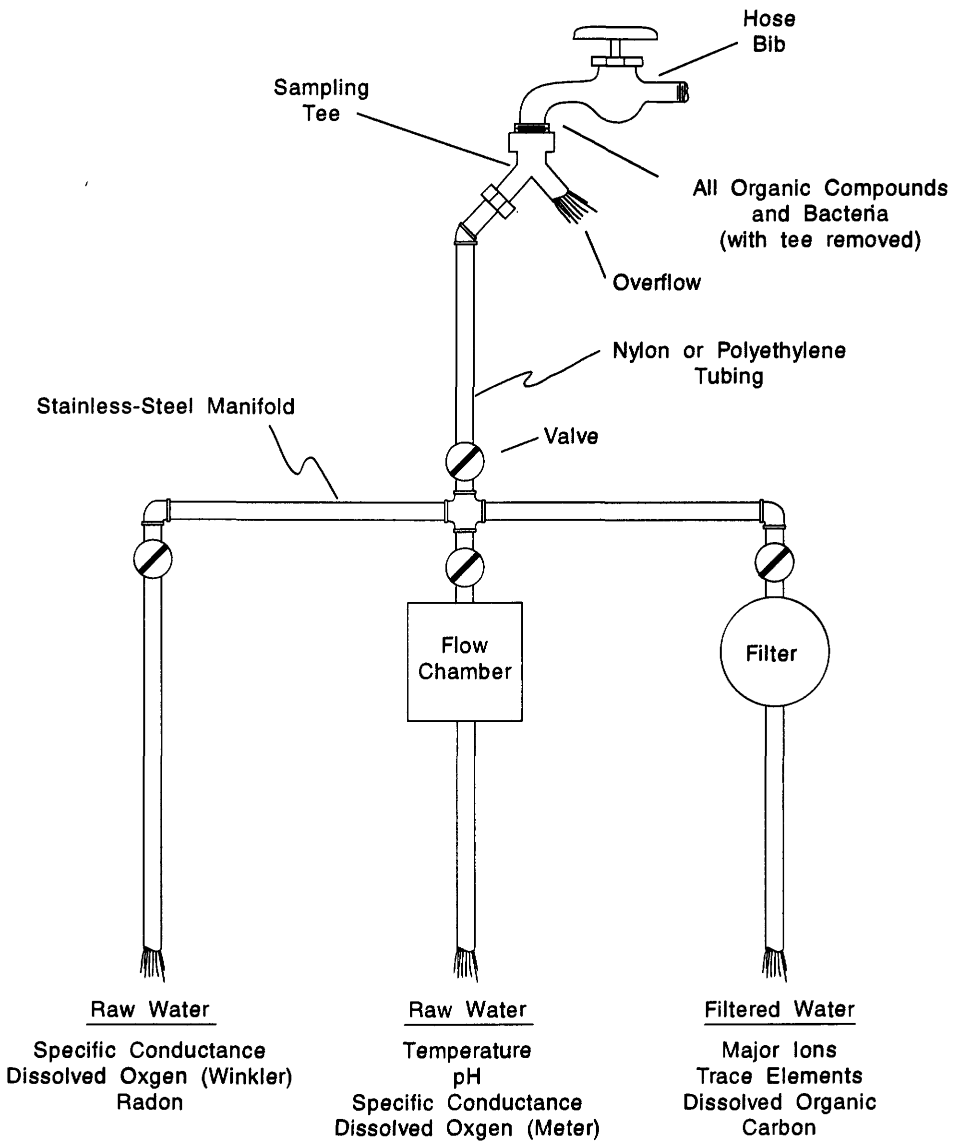


Figure 6.--Ground-water sampling system.

analytical procedure called for filtering the samples in the laboratory. Analytical procedures used at the NWQL are described by Fishman and Friedman (1989) and Wershaw and others (1987).

As part of the study's quality-assurance program, the accuracy of field measurements of pH and specific conductance was ensured by daily calibration of meters with known standards. Dissolved-oxygen meters were also calibrated daily using the water-saturated air technique. Field analyses of bacteria concentrations were performed in duplicate for 1 in every 15 wells sampled.

Samples for analysis by the NWQL were collected in duplicate on a random basis. One duplicate sample was collected for every 15 wells sampled for major ion and trace element analysis, and 1 duplicate sample was collected for every 10 wells sampled for volatile organic compound or pesticide analysis. Blank samples of deionized water were prepared at the same frequencies. Duplicates and blanks were processed in the same manner as ordinary ground-water samples and were submitted to the laboratory disguised as ordinary ground-water samples.

Because standards for most inorganic constituents are inserted routinely as blind samples into the sample stream at the NWQL, no standards or spiked samples were submitted from the field to the laboratory. At the NWQL appropriate standards were spiked into each sample for organic analysis to determine the percentage of constituent recovered.

Standard quality-assurance procedures were used at the NWQL. The resulting data were reviewed by laboratory personnel, then released to the local USGS district office in Tacoma, Wash., by electronic data transfer. The laboratory data were reviewed further by district and project personnel in consideration of the geohydrologic setting. Computer programs and statistical techniques were used to assist in all stages of the reviews. Additional details of laboratory quality-assurance procedures and data review are discussed in the project quality-assurance plan by G. L. Turney (U.S. Geological Survey, written commun., 1991) and in a general plan by Friedman and Erdmann (1982). The quality-assurance data for this project are assessed in Appendix C of this report.

GEOHYDROLOGY

The basic principles of ground-water occurrence are described in this section, followed by descriptions of the geology and ground-water flow system in east King County. The quantity of ground water used for beneficial purposes, a water budget, and water-level fluctuations are also discussed. Most of the material that follows applies specifically to east King County, but the reader is referred to Freeze and Cherry (1979) or Heath (1983) for more comprehensive discussions of general ground-water occurrence.

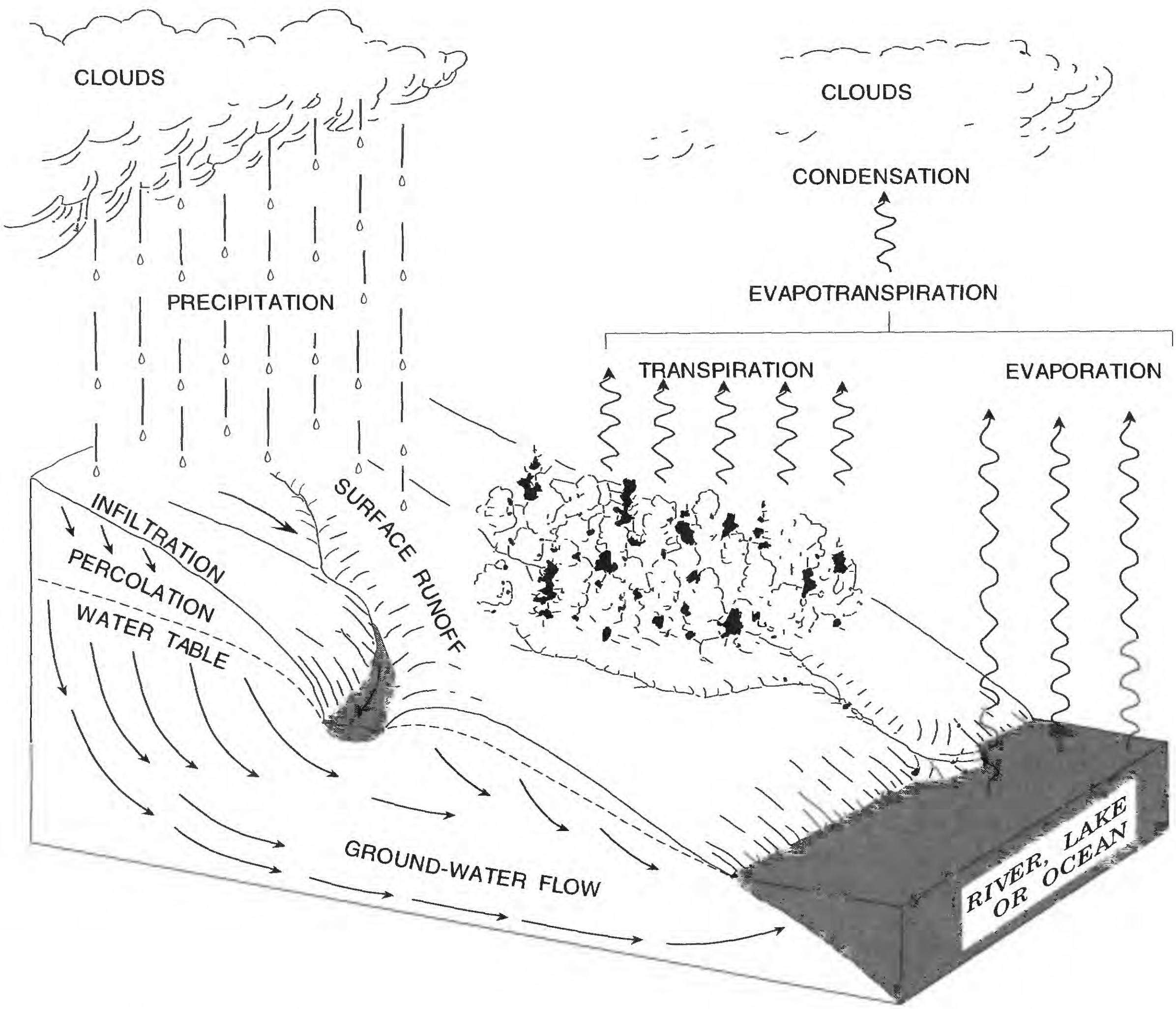


Figure 7.--The hydrologic cycle.

The Hydrologic Cycle

Water circulates continually between the ocean, the atmosphere, and the Earth's surface in a process known as the hydrologic cycle (fig. 7, see page 15). Precipitation, as rain or snow, is the source of all fresh ground water. Once on the land surface, some of the precipitation runs off to streams and lakes, some infiltrates the ground, and some is evaporated back to the atmosphere from the soil and from freewater surfaces such as ponds and lakes. Some of the water entering the soil is drawn up by plant roots and returns to the atmosphere by transpiration from leaves; the combination of evaporation and transpiration is called evapotranspiration. Most of the remaining water that enters the ground continues to percolate downward to the water table, becoming recharge to the ground water. Some of this ground water eventually returns to the land surface by seepage to springs, lakes, and streams, and some discharges directly to the sea. From the sea and other surface-water bodies, water is evaporated back to the atmosphere, where it forms clouds and, eventually, precipitation.

Ground-Water Occurrence

The occurrence of ground water varies greatly, and is largely dependent on a geohydrologic unit's permeability, or its ability to transmit water. In unconsolidated materials, such as clay, sand, or gravel, water moves through pore spaces separating the individual particles. Because these pore spaces are for the most part interconnected, there is relatively free movement of water within the deposits. Water moves more easily, however, through the larger pore spaces within deposits of well-sorted coarse sand and gravel than through the smaller pore spaces in clay, silt, and poorly sorted till. Therefore, sands and gravels are more permeable than clays, silts, and tills. In consolidated material such as granite or basalt, the principal movement of water is through interconnected joints, fractures, and faults, and permeability is highly variable.

Water-saturated geologic units can be classified either as aquifers or as confining (or semiconfining) beds. An aquifer is a geologic unit that is at least partly saturated and is sufficiently permeable to yield water in significant

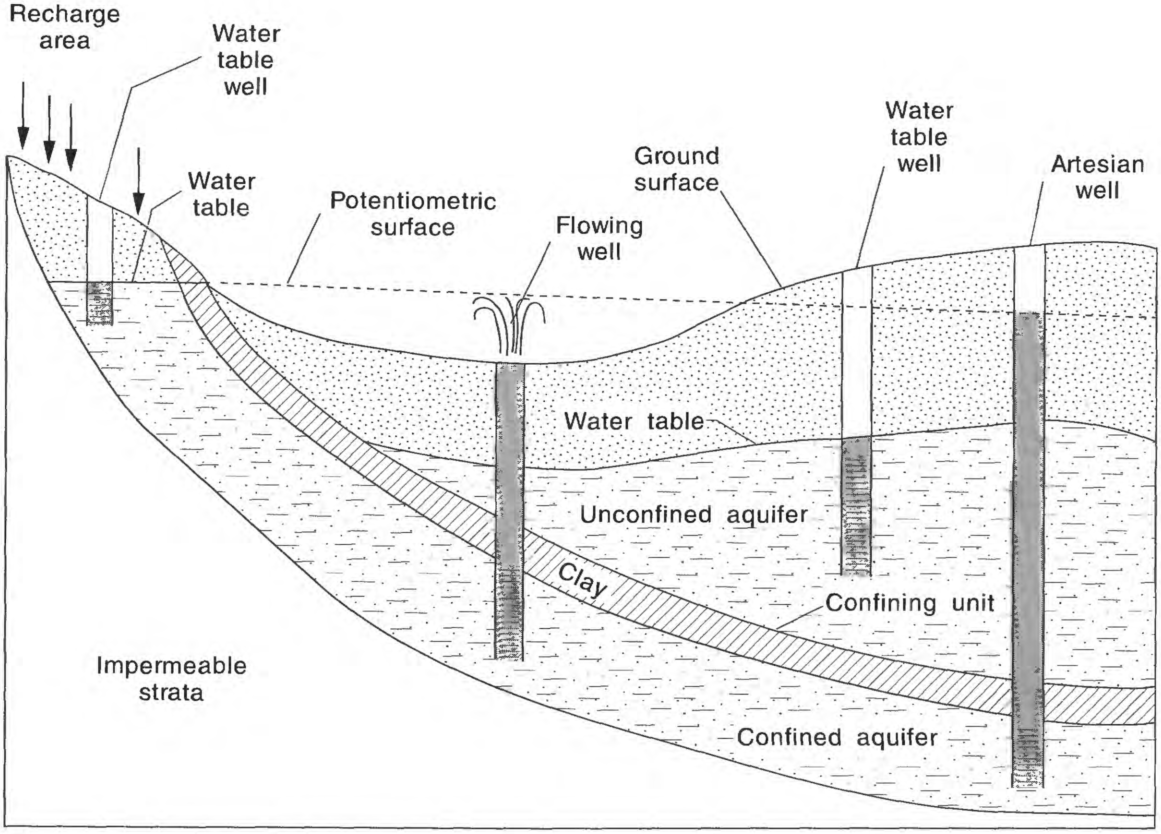


Figure 8.--Features of unconfined and confined ground-water systems. (Modified from Todd, 1980.)

quantities to a well or spring (Freeze and Cherry, 1979). A confining bed is a geologic unit having a much lower permeability than that of adjacent aquifers, thus restricting the movement of ground water into, or out of, those aquifers.

Ground water in aquifers can be present under two different conditions. Where water only partly fills an aquifer (fig. 8), the water table (the upper surface of the saturated zone) is free to rise and fall with changes in recharge and discharge. The position of the water table is determined by measuring water levels in shallow wells. In this situation, the ground water is considered to be unconfined or under "water table" conditions. Where water completely fills an aquifer that is overlain and underlain by a confining bed, ground water is considered to be confined or "artesian". In wells that tap a confined aquifer (fig. 8), water rises to a height corresponding to the hydraulic head of the confined ground water at that point. If the head is sufficient to raise the water above land surface, the well will flow and is called a flowing artesian well. A map of the heads in a confined aquifer defines the potentiometric surface, which is analogous to the water table in an unconfined aquifer. Unlike a water table, the potentiometric surface is higher in elevation than the top of the aquifer. The potentiometric surface does, however, fluctuate in response to changing recharge-discharge relations.

Flowing wells can also be constructed in aquifers without confining layers. The idealized ground-water flow pattern beneath an area of uniformly permeable material, as modified from Hubbert (1940), is shown on figure 9. In the figure, the approximate flow paths of water are shown by dashed lines with arrows; the dotted lines, which intersect the flow lines, are lines of equal potential or head. Deeper cased wells finished in recharge areas, where ground water generally moves downward, receive water under lower head than do shallower wells at the same location. Conversely, deeper cased wells located in discharge areas, where ground

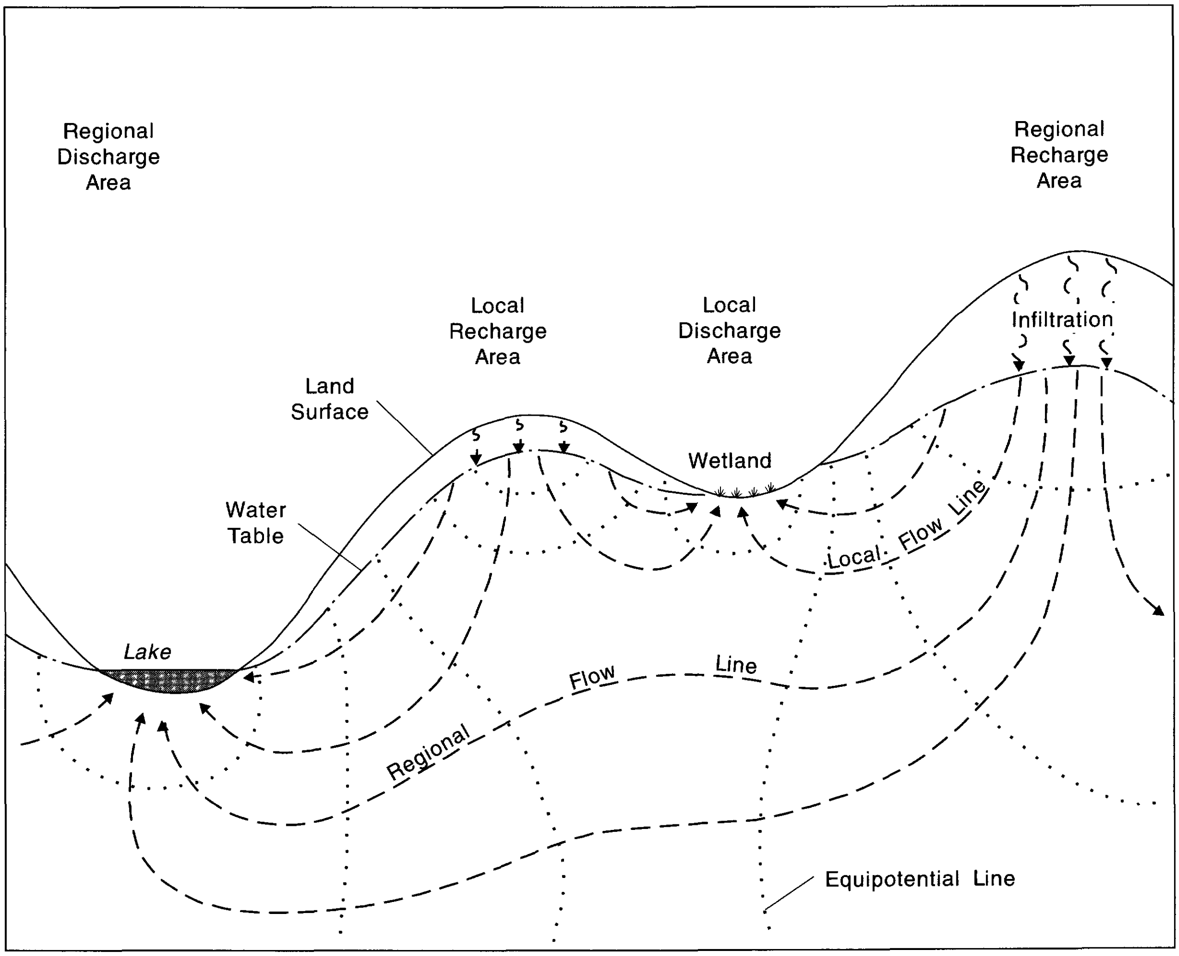


Figure 9.--Idealized ground-water flow beneath an area of uniformly permeable material. (Modified from Hubbert, 1940.)

water generally moves upward, receive water under higher head than do shallower wells at the same location. If the heads are sufficiently high, the wells will flow. The primary control on the occurrence of flowing wells is not structure or stratigraphy, but topography (Freeze and Cherry, 1979).

Ground-water flow systems are commonly divided into local and regional systems (Tóth, 1963; Freeze and Cherry, 1979). Local flow systems (fig. 9) have short flow paths, involve shallow aquifers, and are controlled chiefly by local topography. In contrast, regional flow systems have long flow paths, involve deep aquifers, and are controlled chiefly by large-scale topographic features. A third kind of flow system, termed intermediate, commonly exists between the two extremes. In reality, the three flow systems are continuous rather than discrete.

The occurrence of ground water is also important in defining geohydrologic units. Geohydrologic units are identified by considering the hydrologic properties of the initially defined geologic units. Thus, geologic units are categorized as aquifers or confining units and become geohydrologic units. Although geologic and geohydrologic units are often the same, differences arise when two geologic units directly above one another have similar hydrologic properties and are combined to form one geohydrologic unit, or when one geologic unit varies greatly in hydrologic properties (usually from top to bottom) and is split into two or more geohydrologic units. An example is the combining of glacial outwash units and overlying alluvial units into one geohydrologic unit. Identifying the distinctions between geologic and geohydrologic units is useful in the study of east King County.

Geologic Framework

Many studies have contributed to our current understanding of the geologic framework of the study area. Detailed descriptions of geologic conditions in the study area, and the Puget Sound Lowland in general, are provided in Willis (1898), Bretz (1913), Mackin (1941), Liesch and others (1963), Crandell and others (1958, 1965), Crandell, 1965, Richardson and others (1968), Livingston (1971), Hall and Othberg (1974), Thorson (1980), Gower and others (1985), Blunt and others (1987), and Booth (1990). The summary that follows is taken from the work of Liesch and others (1963) and Booth (1990); the reader is referred to those two publications for additional information concerning the geology of east King County.

Continental glacial ice originating in British Columbia invaded the Puget Sound Lowland, within which the study area lies, several times during the Pleistocene Epoch (10,000 to 1,600,000 years before present). Referred to as the Puget Lobe, this ice was part of the Cordilleran ice sheet of northwestern North America. The extent of the ice was limited geographically by the mountains and hills that surround the lowland. Within the study area the Cascade Range foothills limited the easternmost extent of the Puget Lobe. Repeated episodes of ice advance and retreat, called glaciations, resulted in thick accumulations of glacial and interglacial deposits throughout the region. These deposits consist of unconsolidated gravel, sand, silt, clay, and peat. The identification of deposits of successive glaciations in the Puget Sound region is difficult because each glaciation eroded and disturbed the deposits from previous glaciations. Therefore our knowledge of all but the last major glaciation is limited.

This most recent glaciation, referred to as the Vashon Stade of the Fraser Glaciation, began about 15,000 years ago when the ice slowly advanced southward, blanketing the entire Puget Sound Lowland. Evidence of this glaciation is apparent throughout the lowland in the form of topographic features as well as deposits called glacial drift. Although valley glaciers extended westward from the Cascade Range foothills at the same time as the continental ice, those in the study area did not extend down the valleys far enough to merge with the continental ice during this last glaciation.

As the Vashon Glacier advanced southward, rivers such as the Snoqualmie River that originally flowed northward were either diverted southward or dammed. Blocked drainages often resulted in extensive lakes fed by the rivers and the advancing glacier itself. Such lakes eventually breeched or overtopped their enclosing basins. The Vashon Glacier remained at its maximum extent for a relatively short period. As the climate warmed, beginning about 13,500 years ago, the glacier began to melt faster than it advanced, beginning the process of retreating. As the glacier retreated northward, the drainage to the north across the Puget Sound Lowland to the Strait of Juan de Fuca eventually was re-established. The Snoqualmie River, having regained its northerly course, subsequently formed a valley-wide floodplain graded to present-day sea level.

As a result of the Vashon and previous glaciations, much of the study area is covered by unconsolidated deposits that are of both glacial and nonglacial origin. These deposits tend to be heterogeneous and may be discontinuous in places. The variable topographic relief of the study area further contributes to the complexity of the deposits. Beneath these unconsolidated deposits, which are as much as 1,200 feet thick, are Tertiary and pre-Tertiary consolidated rocks, which are referred to in this report as bedrock. The various types of bedrock were not differentiated in this study. The surficial extent of the geologic units is shown on plate 1.

The youngest geologic units in the study area are Qb, bog deposits, and Qal, alluvium. The bog deposits, which cover less than 1 percent of the study area (plate 1), consist of alluvium and peat that have accumulated in poorly drained depressions on the present-day land surface. Because Qb has such small exposures, it is considered geohydrologically insignificant for this study. Qal consists mostly of the extensive deposits of the Snoqualmie River and its tributary streams and covers about 19 percent of the study area. Smaller amounts of alluvial fan deposits and landslide material are included in the unit. The Snoqualmie River alluvium consists of sand, silt, and clay downstream from Snoqualmie Falls, and sand and gravel upstream from the falls. Alluvium in tributary streams generally consists of sand, gravel, and silt.

The youngest glacial unit in the study area is Qvr, the Vashon recessional outwash. About 22 percent of the study area is covered with Qvr. Qvr consists of moderately to well-sorted sand and gravel laid down by streams emanating from the receding Vashon Glacier. Included in this unit are ice-contact deposits that accumulated along the margin of the ice in the eastern part of the study area. Associated with the recessional outwash but mapped as a separate unit is Qvrl, a fine-grained deposit of ice-dammed lakes. Qvrl covers about 1 percent of the study area and is found in limited exposures along the margins of the Snoqualmie River and Patterson Creek Valleys. Lithologically, Qvrl contains much more silt and clay than does Qvr.

Glacial till, often referred to as hardpan or boulder clay, consists of a compact, unsorted mixture of sand, gravel, and boulders in a matrix of silt and clay. Vashon till, designated Qvt, owes its compact nature to the fact that it was laid down beneath the heavy mass of the advancing Vashon Glacier. Vashon till is exposed at land surface over about 40 percent of the study area (see plate 1).

As the Vashon Glacier advanced southward, large quantities of stratified sand and gravel were deposited by meltwaters at the front and sides of the ice mass. These deposits, the Vashon advance outwash, are designated Qva and typically consist of well-bedded gravelly sand to fine-grained sand. The unit is exposed in the bluffs along the margins of the Snoqualmie River and tributary valleys (plate 1). These surficial exposures cover only 3 percent of the study area.

Beneath Qva is an extensive fine-grained assemblage of laminated clayey silt to clay with minor lenses of sand, gravel, peat, and wood. This unit, referred to as the transitional beds (Qtb), was deposited in standing water ponded by the advancing Vashon Glacier. Surficial exposures of the unit, located mostly on the walls of the Snoqualmie Valley west of Duvall and Snoqualmie, cover about 1 percent of the study area.

The oldest unconsolidated deposits mapped in the study area are referred to as pre-Fraser deposits (Qpf). These include any unconsolidated material, regardless of origin, that was deposited prior to the Fraser Glaciation. Surficial exposures of this unit are limited to less than 1 percent of the study area, and consist of either interglacial sand and gravel deposited by rivers between ice advances, or clay-rich till from earlier ice advances.

Most of the consolidated rocks that make up the bedrock (Br) consist of andesite with minor amounts of basalt and diorite. However, sandstone, siltstone, and conglomerate are predominant southwest of the Snoqualmie River. Bedrock is exposed in about 13 percent of the study area, mostly in the east and southwest (plate 1). Drillers' logs indicate that the bedrock surface forms a southeast-to-northwest-trending structural trough beneath the low-lying areas occupied by the Snoqualmie River Valley. The bedrock outcrop at Snoqualmie Falls represents a structural high that interrupts the otherwise continuous trough.

Principal Geohydrologic Units

The geologic units described previously were differentiated into aquifers and confining beds based on lithologic and well-yield data from the 604 wells inventoried in the study (Appendix A). The aquifers and confining beds thus defined are referred to as geohydrologic units because the differentiation takes into account both the geologic and hydrologic characteristics of the unit. However, the heterogeneity of the units can result in local variations in hydrologic characteristics. For example, a glacial aquifer may be composed predominantly of sand and (or) gravel, but on a small scale it also may contain relatively thin and discontinuous lenses of clay or silt. Conversely, a confining layer, composed predominantly of silt and (or) clay, also may contain local lenses of sand or gravel. As a consequence, the general occurrence and movement of ground water may be influenced locally by these small-scale variations in lithology.

The geohydrologic units defined in the subsurface were related to the surficial geologic map (plate 1) in order to place the subsurface units in their proper stratigraphic position. An examination of the geohydrologic sections (plate 1) indicates that there is a great deal of variation in the thickness of individual units, and that not all units are necessarily present at any one location.

Ten geohydrologic units were identified, as shown in figure 10, and they are listed here, in order of increasing geologic age:

(1) Alluvium (Qal);

(2) Vashon recessional outwash (Qvr);

(3) Vashon till (Qvt);

(4) Vashon advance outwash (Qva);

(5) Upper fine-grained unit (Q(A)f);

(6) Upper coarse-grained unit (Q(A)c);

(7) Lower fine-grained unit (Q(B)f);

(8) Lower coarse-grained unit (Q(B)c);

(9) Deepest unconsolidated and undifferentiated deposits (Q(C)); and

(10) Bedrock (Br).

Previously accepted and published nomenclature associated with the alluvium and Vashon Drift was used for the upper four geohydrologic units--Qal, Qvr, Qvt, and Qva. These geohydrologic units also correlated identically with the geologic units identified in the previous sections. Names that refer to grain size and relative stratigraphic position were used to refer to older unconsolidated geohydrologic units that are, in effect, subdivisions of the previously discussed geologic units. For example, Q(A)c is the upper (A) coarse-grained (c) geohydrologic unit in the Quaternary (Q) geologic units. The extent and altitude of the tops of the youngest six of these units are shown on plate 2. The remaining units are not shown because of a lack of data. The limited surficial extent of bog deposits precluded them from being recognized as a separate geohydrologic unit. However, the bog deposits can perch or confine ground water locally.

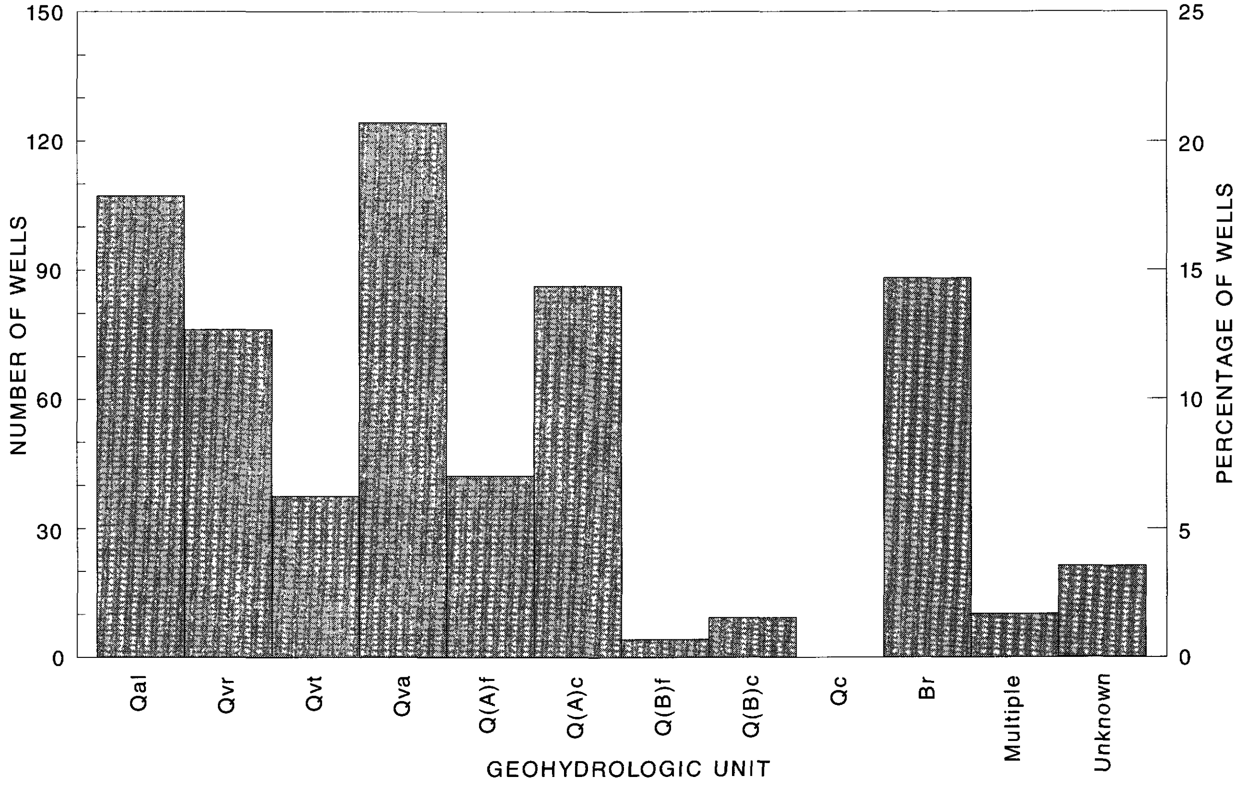
The relative importance of each of the geohydrologic units as a source of ground water can be determined from a graph of the number of study wells finished in each of them (fig. 11). The resulting information indicates that Qal, Qvr, Qva, Q(A)c, and Br are the principal sources of water for existing wells in east King County, but that usable quantities of ground water also can be obtained from Qvt, Q(A)f, Q(B)f, and Q(B)c. Qvt, Q(A)f, and Q(B)f generally act as confining beds, but some wells in these otherwise poorly permeable deposits produce water from thin, local lenses of sand or gravel. Because none of the study wells is finished in unit Q(C), the potential of the unit as a source of ground water is unknown. Although Q(C) is deep and probably of limited extent, it could provide usable quantities of water given the coarse nature of the deposits.

The Quaternary alluvium, Qal, is present mostly in the floor of the Snoqualmie River Valley and its tributaries (plate 2). An average thickness of 100 feet and a maximum thickness of 250 feet in the upper Snoqualmie River Valley is shown on the geohydrologic sections (plate 1). However, the thickness of the Qal is difficult to determine because most wells do not penetrate the entire unit. Furthermore, Qal commonly overlies older but lithologically similar deposits. The altitude of the top of the unit ranges from less than 40 feet near the King County-Snohomish County boundary to 800 feet in the uppermost reaches of the Snoqualmie River tributaries (plate 2). Qal is a highly productive aquifer, especially upstream of Snoqualmie Falls in and around the town of North Bend. Most of the 107 inventoried wells that tap this unit are located in this upper valley, where the North, Middle, and South Forks of the Snoqualmie River converge. Wells that tap Qal either downstream from the falls, in landslide deposits, or in alluvial fans have yields that tend to be smaller and somewhat less predictable than the wells in the upper valley. Wells that are on the lower valley floor are also subject to periodic flooding of the Snoqualmie River, so there are far fewer of them.

Qvr, the Vashon recessional outwash, is present in a large part of the study area (plate 2). However, Qvr is noticeably absent beneath the Snoqualmie Valley floor. A typical thickness of the unit is 60 ft, but as shown on the geohydrologic sections (plate 1), the unit can vary from a veneer overlying till to an accumulation greater than 300 ft. The altitude of the top of the unit varies from slightly less than 100 feet along the flanks of the Snoqualmie River Valley downstream from Snoqualmie Falls to 1,200 feet in the upper Snoqualmie River Valley. This coarse-grained unit can be a productive aquifer in places where relatively thick sequences of sand and gravel

Period	Epoch	Geohydrologic unit		Geohydro-logic unit label	Typical thickness (feet)	Lithologic characteristics	Hydrologic characterisics
Quaternary	Holocene	Alluvium		Qal	100	Unit consists primarily of Snoqualmie River alluvium; sand and gravel upstream of Snoqualmie Falls; sand, silt, and clay downstream. Unit includes tributary stream, landslide, and alluvial fan deposits.	Highly productive unconfined aquifer upstream of Snoqualmie Falls. Unit becomes less permeable and apparently less productive downstream.
	Pleistocene	Vashon Drift of the Fraser Glaciation	Recessional outwash, ice-contact deposits, and ice-dammed lake deposits	Qvr	60	Moderately to well-sorted sand and gravel. Unit includes poorly sorted ice-contact deposits and fine-grained ice-dammed lake deposits.	An aquifer where saturated. Ground water is mostly unconfined. Perched conditions occur locally.
			Till	Qvt	70	Compact, unsorted sand, gravel, and boulders in a matrix of silt and clay. Some lenses of sand and gravel.	Confining bed, but can yield usable quantities of water.
			Advance outwash	Qva	200	Well-bedded gravelly sand to fine-grained sand.	Principal aquifer in terms of use. Ground water mostly confined.
		Upper fine-grained unit including transitional beds and minor till		Q(A)f	250	Laminated clayey silt to clay with minor lenses of sand, gravel, peat, and wood. Local occurrences of till at base of unit.	Confining bed, but can yield usable quantities of water.
		Upper coarse-grained unit consisting of intraglacial deposits		Q(A)c	140	Strongly oxidized sand and gravel.	Principal aquifer in terms of use. Ground water is confined.
		Lower fine-grained unit		Q(B)f	Unknown	Clay, silt, and till with some sand and gravel.	Confining bed, but can yield usable quantities of water. Tapped by few wells.
		Lower coarse-grained unit		Q(B)c	Unknown	Sand and gravel with minor clay and silt.	An aquifer where saturated. Ground water is probably confined. Tapped by few wells.
		Deepest unconsolidated and undifferentiated deposits		Q(C)	Unknown	Unconsolidated deposits of largely unknown lithology.	Unit encountered in few wells; tapped by none. Ground water, if available, is probably confined.
Tertiary	Eocene	Bedrock		Br	Unknown	Andesite with minor amounts of basalt and diorite, and some sandstone, siltstone, and conglomerate.	Locally an aquifer, but often unreliable. Water contained in fractures and joints. Well yields relatively small.

Figure 10.--Lithologic and hydrologic chracteristics of geohydrologic units in east King County.



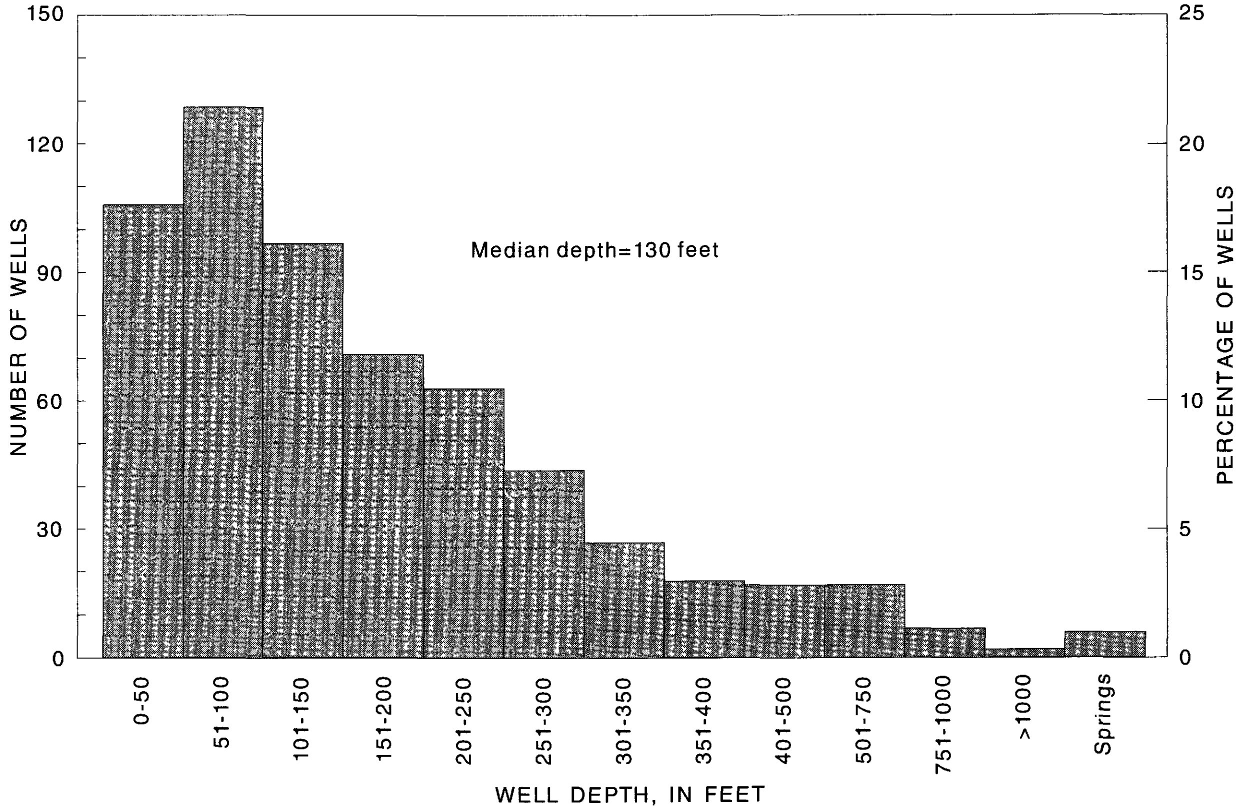


Figure 11.--Frequency distributions of geohydrologic units tapped and of well depths.

are saturated. In some areas east of the Snoqualmie River and along the edges of the Sammamish Plateau, however, little water is available from the unit because it is thin or lies above the water table. Most of the 76 inventoried wells that tap Qvr are either east of Fall City, northeast of Snoqualmie, or on the Sammamish Plateau where ground water within Qvr is under water-table (unconfined) conditions, and the wells produce moderate yields for domestic purposes (plate 2).

The Vashon till, Qvt, is broadly distributed throughout a large part of the study area, but it is thin or absent in some areas where thick deposits of Qvr are present (plate 2). This implies that the till was probably eroded within the fluvial environment during the deposition of the Qvr. Like Qvr, it is also absent beneath the Snoqualmie Valley floor. Although the unit can be as much as 200 feet thick, a more typical thickness is 70 ft. The altitude of the top of the unit ranges from 100 to 1,400 feet above sea level. Qvt generally produces low yields of water and is considered a confining bed. However, 37 inventoried wells tap thin layers of relatively clean sand and (or) gravel within the unit. In many places the upper part of the Vashon till is more permeable than the lower part. Therefore, the upper part can contain perched water bodies that will yield usable short-term quantities of water to shallow wells (Liesch and others, 1963). Because Qvt is typically dense and unsorted, well yields from it are variable.

The Vashon advance outwash, Qva, is present throughout much of the study area, mostly in the subsurface (plate 2). Like Qvr and Qvt, it too is absent beneath the Snoqualmie River Valley floor and its extent east of the valley cannot be readily defined at this time due to a lack of data. A typical thickness of the unit is 200 ft. The top of the unit varies from slightly below sea level (plate 2) to 900 ft. Qva is tapped by 124 of the inventoried wells and is one of the major aquifers of east King County. Ground water in this aquifer is usually confined by the overlying Qvt and the underlying Q(A)f.

The upper fine-grained unit, Q(A)f, consists primarily of all of the transitional beds (Qtb) and local occurrences of pre-Fraser till from Qpf. It is present at depth throughout nearly all of the study area (plate 2). It is the youngest continuous unit beneath the Qal of the Snoqualmie River Valley. The top of the unit ranges from 100 feet below to 800 feet above sea level. Q(A)f has a typical thickness of 250 feet but can be as thick as 550 ft; it is the thickest unconsolidated unit in the study area. Q(A)f is not made up completely of fine-grained materials; 42 inventoried wells tap local, thin lenses of sand or gravel that yield relatively small quantities of water suitable for domestic use. Q(A)f generally acts as a confining bed between the coarse-grained deposits above and below it. Because of this, Q(A)f retards the percolation of ground water into Q(A)c and causes vertical head gradients between Qva and Q(A)c in places.

The upper coarse-grained unit, Q(A)c, consists of interglacial sand and gravel from Qpf and is extensive throughout the study area (plate 2). The average thickness of the unit is approximately 140 feet (plate 1). The top of the unit varies from 300 feet below to 700 feet above sea level in the north-central part of the study area (plate 2). This unit may be present at even higher altitudes in the easternmost part of the study area where small exposures of pre-Fraser deposits have been mapped. Because of the lack of wells in that area, however, the hydrologic characteristics of the deposits are unknown and including them with Q(A)c is not warranted. Q(A)c is a major aquifer in the study area. Eighty-six inventoried wells tap this mostly confined unit.

The three deepest unconsolidated units in the study area are the lower fine-grained unit Q(B)f, the lower coarse-grained unit Q(B)c, and the deepest unconsolidated and undifferentiated deposits Q(C), all from geologic unit Qpf. Estimated thicknesses and depths of these units, where they are known to exist, are shown on the geohydrologic sections (plate 1). On the basis of the few available drilling records, Q(B)f is a mostly fine-grained confining bed. There is little information about the productivity and extent of Q(B)c and Q(C). Four inventoried wells are completed in Q(B)f and nine are completed in Q(B)c. No inventoried wells are completed in Q(C).

The consolidated Tertiary and pre-Tertiary rocks that constitute the bedrock, Br, contain small quantities of water in fractures and joints that are probably more numerous near the top of the unit. In general, however, the bedrock is an unreliable source of ground water, and many wells drilled into that unit yield insufficient or poor-quality water. Most of the 88 inventoried wells that tap bedrock are located in the southwestern and northeastern parts of the study area, and the wells supply water for domestic use. In these areas, bedrock is either exposed at land surface or is covered by a thin, unproductive layer of unconsolidated deposits. Because bedrock is the only source of water in these areas, water supplies in these areas are often tenuous at best. In some areas northeast of Duvall, for example, wells in bedrock typically go dry in summer. Where the bedrock is exposed at land surface, the ground water is likely under water-table conditions; where the bedrock is covered by a significant thickness of unconsolidated deposits, especially clays and silts, the ground water is likely to be confined.

Hydraulic Conductivity

Estimates of the horizontal hydraulic conductivity of the geohydrologic units were used to help understand the availability and movement of ground water. Hydraulic conductivity is a measure of a geohydrologic unit's ability to transmit water. It is defined as the volume of water that will move in unit time through a unit cross-sectional area under a unit hydraulic gradient. For unconsolidated materials, hydraulic conductivity depends on the size, shape, and arrangement of the particles. Because these physical characteristics vary greatly within the glacial deposits of the study area, hydraulic conductivity values are also highly variable. Hydraulic conductivity data were statistically summarized so that differences between aquifers could be determined. A summary by geohydrologic unit is presented in table 1. Individual values of hydraulic conductivity can be found in Appendix A.

The median hydraulic conductivities are reasonable for all units except Qvt. The median hydraulic conductivities for the coarser grained units, Qal, Qvr, Qva, Q(A)c, and Q(B)c range from 34 to 130 ft/day and are the larger values observed (table 1). The median hydraulic conductivity of 130 ft/day for Qal is the largest of any unit. The median hydraulic conductivity of 51 ft/day for Qvt is somewhat anomalous because Qvt is relatively fine grained, and its hydraulic conductivity is larger than those determined for the coarse-grained Qva and Q(A)c. The median hydraulic conductivities for Q(A)f and Q(B)f are 9 ft/day and 15 ft/day, respectively, and are consistent with the fine-grained deposits present in those units. However, the median hydraulic conductivity for Q(B)f is based on only two samples. The lowest median hydraulic conductivity (0.88 ft/day) was for the Br unit. Because ground water in bedrock is present primarily in the fractures, a low median hydraulic conductivity suggests that the Br unit generally is not fractured enough to produce large quantities of water. This low hydraulic conductivity is the primary reason the bedrock is generally a poor source of water.

Table 1.--Summary of hydraulic conductivity values, by geohydrologic unit
[--, not determined]

		Hydraulic conductivity (feet per day)				
Geohydrologic unit	Number of wells	Minimum	25th percentile	Median	75th percentile	Maximum
Qal	59	0.64	37	130	310	1,800
Qvr	39	.43	18	61	200	670
Qvt	24	.04	19	51	120	1,900
Qva	94	.13	14	35	150	6,100
Q(A)f	24	.03	2.3	9.0	22	37
Q(A)c	51	.38	18	37	78	1,700
Q(B)f	2	6.0	--	15	--	24
Q(B)c	6	1.4	8.6	34	97	1,100
Total	299	.03	14	39	150	6,100
Br[1]	53	.00	.12	.88	8.1	430

[1] Hydraulic conductivities for Br were not included in the totals because the Br unit is lithologically quite different from the other units. The Br unit consists of consolidated material and all of the other units consist of unconsolidated material.

The relatively large median hydraulic conductivity of Qvt is likely a reflection of the presence of more permeable zones, as described in the Principal Geohydrologic Units section. It is likely that most wells in this unit have been completed in sand and gravel lenses or in the upper part of the unit. Wells completed in the less-permeable zones either have been abandoned or may not have produced enough water for a pump test to be practical. As a result, the data are biased toward the more productive zones in the unit and are not representative of Qvt as a whole. This bias is unavoidable when relying upon production well data; the bias probably exists for all of the units to various degrees, depending upon the heterogeneity of the unit. As a result, all of the median hydraulic conductivity values may be biased high. Because Qvt is probably the most heterogeneous of the units, the bias for it is probably the largest. The minimum hydraulic conductivities for the geohydrologic units illustrate that there are poorly producing wells in each unit. Also, the range of hydraulic conductivities is at least three orders of magnitude for most units, indicating a substantial amount of heterogeneity.

No data were available to estimate the vertical hydraulic conductivity of aquifers or of confining layers between aquifers. Estimates made as part of other studies indicate that in glacial materials vertical hydraulic conductivity is commonly several orders of magnitude less than horizontal hydraulic conductivity.

Conceptual Model of the Ground-Water System

A generalized conceptual model of the ground-water system beneath east King County is shown in figure 12. Four coarse-grained major aquifers (Qal, Qvr, Qva, and Q(A)c) and two fine-grained confining layers (Qvt and Q(A)f) were identified. Beneath this assemblage and above the relatively impermeable bedrock are the older unconsolidated deposits (Q(B)f, Q(B)c, and Q(c)) that could contain significant quantities of water, but for which little data exist. The bedrock (Br) is not considered a principal source of water because it has relatively poor yields, as discussed previously. The resulting ground-water flow system described for east King County is local to intermediate in scale and is controlled mostly by the relief between the upland foothills of the Cascade Range and the Snoqualmie River Valley.

Part of the precipitation that falls on and around the study area recharges the ground-water system. Ground water in upland areas (such as the Sammamish Plateau and Cascade Range foothills) moves vertically downward and laterally to discharge points (such as Lake Sammamish and the Snoqualmie River). The general directions of ground-water movement in the system are indicated with arrows on figure 12. The amount of time required for an individual molecule of water to travel through the system is roughly proportional to the length of the arrow. Water molecules along a relatively short travel path from recharge point to discharge point may be in the ground-water system for only a few months; molecules along relatively long flow paths may be in the system for years or centuries. Also, water may be withdrawn from any point in the system, creating an artificial discharge point.

Flow into and out of the study area can be qualitatively assessed by evaluating the ground-water conditions along the study boundaries. Ground water flows out of the study area along the northern boundary. Along the eastern boundary, including the Snoqualmie River upstream of North Bend, ground water flows into the study area. Except for the western boundary along Lake Sammamish, all of the southwestern and western boundaries are along surface-water drainage divides; shallow ground water likely flows neither into nor out of the study area along the divides. However, along the Lake Sammamish boundary, ground water flows out of the study area to the west and in some areas deeper ground-water flow may be to the west also.

More-detailed descriptions of the recharge, movement, and discharge of water in the ground-water system of east King County are presented in the following sections of the report.

Recharge

The bulk of the recharge to the ground-water system of the study area comes from precipitation. Recharge is present everywhere, with the possible exceptions of (1) areas of ground-water discharge, such as along the Snoqualmie River, and (2) those areas covered by impermeable, man-made materials such as asphalt and concrete. Impermeable materials at land surface may only delay and redistribute the recharge water; precipitation that runs off of impermeable surfaces may seep into the ground as soon as it encounters natural permeable materials. Where runoff from impermeable surfaces is channeled into sewer systems, recharge is lessened. However, the total area covered with impermeable material is negligible in east King County. The quantity of recharge in the study area is probably largest from October to March, when precipitation is greatest.

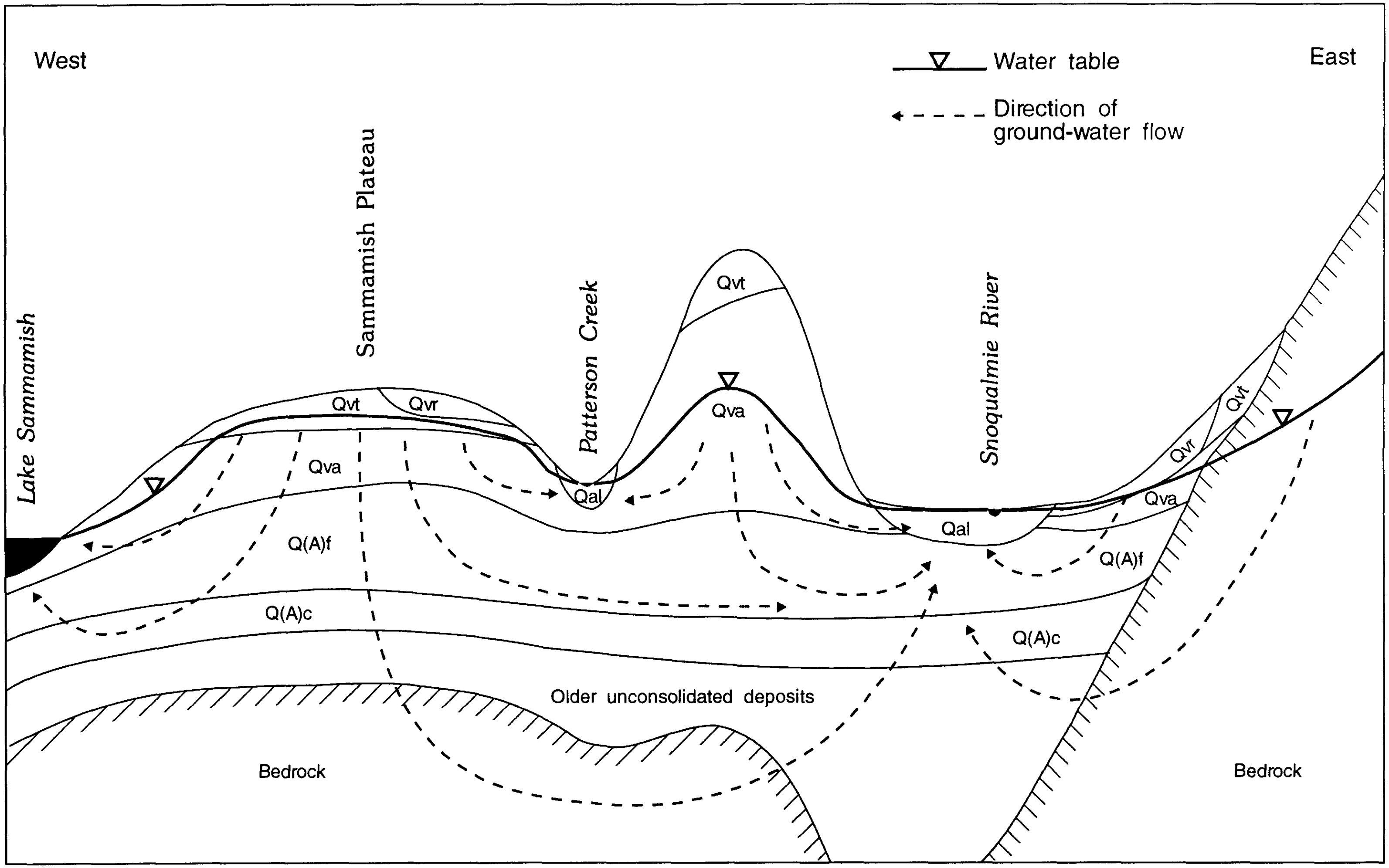


Figure 12.--Conceptual model of the ground-water system in east King County. (See Figure 10 for a description of the geohydrologic units.)

The quantity of recharge to the ground-water system of east King County was estimated using precipitation/recharge relations derived from a study of southwest King County (Woodward and others, in press). These relations are based on the application of a deep-percolation recharge model developed by Bauer and Vaccaro (1987). Regression equations determined from the southwest King County data showed that precipitation and surficial geology were the most significant independent variables in determining recharge. For the two predominant types of surficial geology in east King County, outwash (Qvr and Qva) and till (Qvt), curves were drawn relating precipitation to recharge based on the data from southwest King County (fig. 13). These curves were applied to east King County because the geohydrologic units, climate, and vegetation in both areas are similar.

Given the derivation of the curves in figure 13, some observations and assumptions needed to be made regarding their use. First, the percentage of precipitation becoming recharge increases with increasing precipitation. This is likely due to evapotranspiration, which decreases proportionally with increasing precipitation because of increased cloud cover. Second, data from southwest King County included only annual precipitation up to approximately 60 in., whereas some areas of east King County

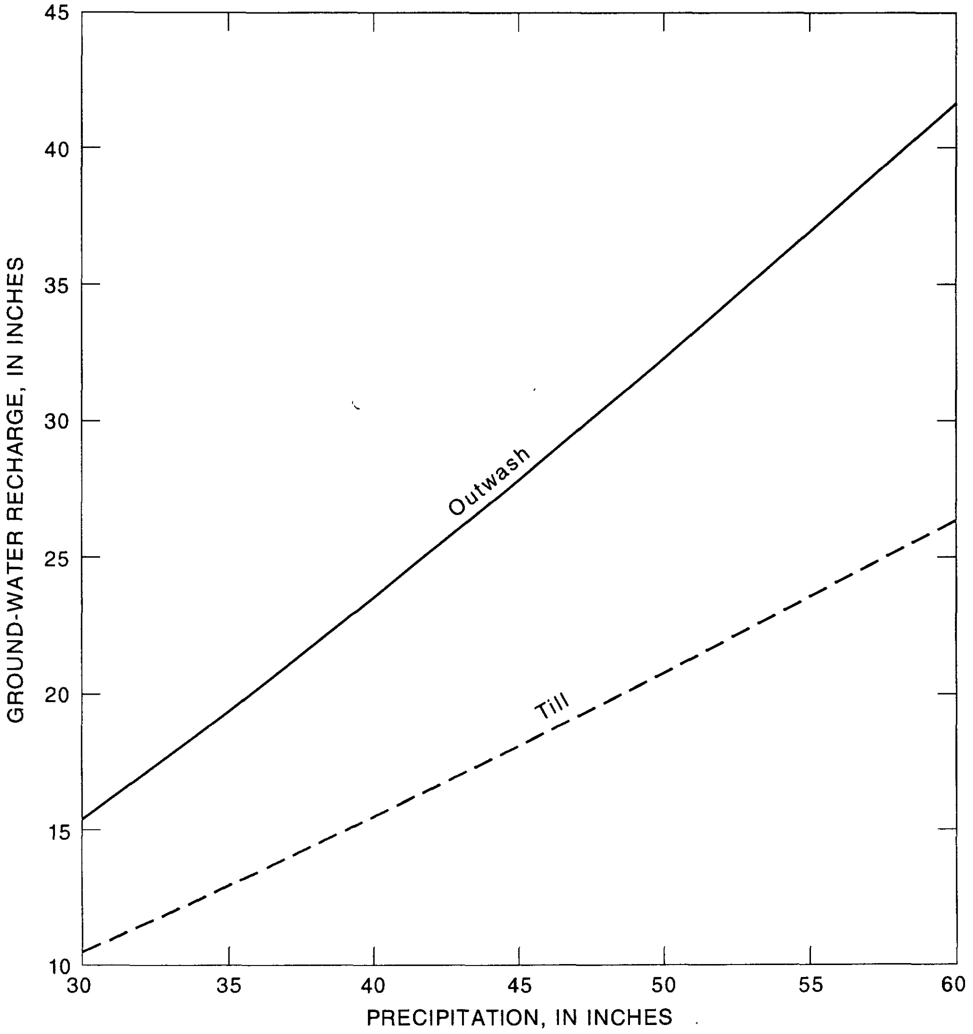


Figure 13.--Precipitation-recharge relations used in the estimation of recharge in east King County.

receive almost 100 in. To estimate recharge for areas receiving between 60 and 100 in. of annual precipitation, the percentage of precipitation that goes to recharge at 60 in. was assumed to be constant above 60 in. Therefore, for precipitation values greater than 60 in., recharge was calculated as 69 percent of precipitation for outwash, and 44 percent of precipitation for till. Because, as noted above, the effects of evapotranspiration decrease with increased precipitation, this was considered a somewhat conservative approach. Also, at 100 in. of precipitation, evapotranspiration is estimated to be 20 to 25 in. based on published values for the area (U.S. Department of Agriculture, 1973), leaving 75 to 80 in. for recharge and runoff. Because the calculated recharge for outwash is 69 in. for 100 in. of precipitation, one must assume in this method that there is negligible runoff on outwash in the higher precipitation areas. Outwash is generally quite permeable, and these high-precipitation areas tend to be densely vegetated, both of which are factors that contribute to the land's ability to absorb precipitation as recharge, so runoff is indeed likely to be minimal. Finally, because data existed only for outwash and till, estimates needed to be made for other surficially exposed geohydrologic units. The alluvium (Qal) was assumed to have lithologic and hydrologic characteristics similar to the outwash, so the outwash curve was used for Qal as well. Similarly, recharge into bedrock (Br) was estimated with the till curve, because exposed bedrock in the study area usually is weathered and is assumed to be less permeable than outwash and approximately equivalent to till. Units other than alluvium, till, outwash, and bedrock are not surficially exposed over a large enough area in east King County to affect the recharge estimates. These other units are the bog deposits (Qb), which were aggregated into whichever unit surrounded a given Qb exposure, and the transition beds (Qtb) and pre-Fraser deposits (Qpf), for which the till curve was used.

To determine the distribution of recharge, a detailed contour map of long-term precipitation rates was overlaid on the map of the surficial geologic units (plate 1). Geographic information system techniques were used to combine like units and calculate recharge based on the relations shown in figure 13. The resulting map (plate 3) shows higher recharge rates in the eastern and southeastern parts of the study area, where precipitation is highest. There are large areas where recharge is 20 to 30 in/yr because of the aggregation of high-precipitation areas on till with lower-precipitation areas on outwash or alluvium. As a whole, the ground-water system of the study area (GWMA only) receives 413,000 acre-ft, or about 31 in., of recharge in a typical year, based on an area-weighted average of the recharge polygons on plate 3. This figure must be considered in light of the assumptions made, and may contain some degree of unquantifiable error.

No attempt was made to determine the fate of the recharge water in quantitative terms once it becomes part of the ground-water system. Some of the recharge may immediately discharge to nearby streams, while some may enter the deeper regional flow system and not be discharged for many years. Such determinations would require a three-dimensional ground-water flow model.

Movement

After the geohydrologic units were delineated and wells were assigned to one or more of the units, water-level maps were made for the major aquifers. These maps were used to describe and interpret the horizontal and vertical components of the ground-water flow system.

Water-level maps were drawn for Qal, Qvr, Qva, and Q(A)c, the four major aquifers of east King County for which adequate data are available. For the purposes of showing ground-water flow, Qal and Qvr were combined on one map because these two units are primarily surficial units and they have common boundaries. Lateral flow directions of ground water within all of the aquifers are shown with arrows on plate 3. Flow is from areas of higher to lower hydraulic head, and is generally perpendicular to the contours of equal head. Because the units are heterogeneous and complex, the mapped heads are considered regional in nature; local conditions may vary. Flow directions are also subject to the same conditions.

Ground water in the combined Qal-Qvr unit generally moves toward the Snoqualmie River, then northward along the Snoqualmie River Valley (plate 3). The gradient is nearly flat in the lower valley; in some places it is 5 ft/mi or less. In the upper valley, the gradient is somewhat steeper: at least 10 ft/mi. In contrast, in the vicinity of Snoqualmie Falls, local gradients may exceed an estimated 1,000 ft/mi over short distances. Flow from the uplands to the valley is significant in areas north and east of Carnation and north of Snoqualmie. Driven by local topography, the gradient in these areas is relatively steep. Flow within this unit on the Sammamish Plateau is not well defined because of a lack of data points and because much of the unit is completely unsaturated there. Similarly, a lack of data points in the Cascade Range foothills and in the Cherry Creek Valley precludes any contouring in these areas.

Ground-water flow in Qva is discontinuous because the unit is divided by Qal of the Snoqualmie River Valley (plate 3). Flow follows the general surface topography into the Snoqualmie River Valley. Ground water also flows toward Patterson Creek from the eastern Sammamish Plateau and Ames Lake areas. Flow from the western Sammamish Plateau is toward Lake Sammamish. The flatter gradients are less than 100 ft/mi in areas such as the Sammamish Plateau and southeast of Duvall. Steeper gradients in excess of 500 ft/mi are present along the slopes to the Snoqualmie River Valley and near Patterson Creek.

In Q(A)c, ground-water flow is also generally to the Snoqualmie River Valley, then northward down the valley (plate 3). There is a ground-water divide in the Sammamish Plateau, with ground water in the western part flowing to Lake Sammamish and ground water in the eastern part flowing ultimately toward the Snoqualmie River. Gradients are generally more gradual in this unit; some of the steeper gradients (200 to 300 ft/mi) are found between Snoqualmie Falls and Fall City. Gradients in the river valley and east of the Sammamish Plateau are less than 50 ft/mi in some places.

Vertical flow directions are difficult to ascertain because (1) the Qal-Qvr and Qva are discontinuous, and (2) in some areas the heads are similar from one unit to the next. In general, vertical flow is downward in upland areas. This is apparently the case in the Sammamish Plateau, where heads in Qva are generally larger than those in the underlying Q(A)c. Water-level altitudes in a set of five piezometers on the plateau decreased with piezometer depth, also indicating downward flow. The data are for wells 24N/06E-09A11 through 09A15, and are listed in table 2. The best evidence for upward vertical flow is in about 30 flowing wells located in lowlands and along valley floors near the base of uplands. Several such flowing wells are listed in Appendix A. The water-level altitude maps also show that heads in the lower Snoqualmie River Valley are less than 100 feet above sea level in Q(A)c, and heads in the overlying Qal-Qvr are less than 60 feet in some places. Although this difference does not confirm upward flow in the entire valley, it suggests that the upward flow is likely; the difference is also consistent with the existence of the flowing wells along the valley floors.

The presence of downward vertical flows indicates that some water may be moving into the deeper regional geohydrologic system, possibly even the bedrock. Although this water would probably tend to flow north and west also, it would flow within the deeper geohydrologic units not mapped, such as Q(B)c, Qc, and possibly Br. The ground water in these units could easily flow beneath surface waters such as Lake Sammamish and the Snoqualmie River, and ultimately flow to surface-water bodies well outside the study area.

Discharge

Ground water in east King County discharges as seepage to lakes and streams, spring flow, transpiration by plants, seepage to valley walls, ground-water flow out of the study area, and withdrawals from wells. Only a small

Table 2.--Water-level altitudes in five wells on the Sammamish Plateau, east King County

Local well number	Geohydro-logic unit	Depth of well (in feet below land surface)	Water level (in feet below land surface)	Water-level altitude (in feet above sea level)
24N/06E-09A12	Qva	125	72.81	328.89
24N/06E-09A15	Qva	170	85.34	316.17
24N/06E-09A14	Qva	203	86.16	315.53
24N/06E-09A13	Q(A)f	231	87.96	313.91
24N/06E-09A11	Q(B)f	424	158.77	242.91

[1] Water levels were measured on July 6, 1990, except for 24N/06E-09A15, which was measured July 9, 1990. Any difference due to temporal changes apparently does not affect the relative water altitudes because in almost 10 years of monthly record, the relative water altitudes were always in the order shown.

part of discharge was quantified during this study: specifically, the quantity of water discharged to streams and springs and the quantity withdrawn from wells.

Ground water discharges to certain reaches of some of the rivers and streams and augments streamflow to produce what is usually referred to as a gaining reach. Ground-water discharge also sustains the late summer flow of numerous streams in the study area, especially those not fed by glacial meltwater. Conversely, some river reaches may discharge water to the ground-water system to produce a losing reach. The results of a seepage study conducted in September 1991 showed that the Snoqualmie River system generally gains ground water within the study area (table 3, fig. 14). The Snoqualmie River itself appeared to gain water along its entire length except for the reach from Carnation to Monroe. The two largest tributaries, the Raging River and Tolt River, lose water to the ground-water system. The total net discharge of ground water to the river system was 133 ft^3/sec. An estimated 3.3 ft^3/sec discharges from the Sammamish Plateau to Lake Sammamish. The total ground-water discharge to surface water bodies within the study area is therefore an estimated 136 ft^3/sec or 98,500 acre-ft/yr. This should be considered a minimum value, however, because these discharges were determined during the dry summer period of low river flow. During wetter periods, larger quantities of ground water likely flow to the river because regional water levels are usually higher, increasing water-level gradients. Also, interflow, which is water that enters the shallow water table and seeps directly and quickly to adjacent streams, can be large during wetter periods. Finally, many small streams were not measured, but they may collectively receive a significant quantity of ground-water discharge.

The principal known springs in east King County are listed in table 4; there are, in addition, probably hundreds of smaller springs scattered throughout the study area. The City of North Bend spring (24N/08E-35N01S) has by far the largest discharge of any spring in the study area, averaging 9.0 ft^3/s. The total spring discharge accounted for in this study is about 13.2 ft^3/sec, or 9,540 acre-ft/yr, but this quantity is probably low because of unaccounted springs. As noted in table 4, three of the major springs were not inventoried, and as such are not listed in Appendix A. The three springs are not shown on USGS maps and their size was not apparent until the water-use figures were compiled, after the inventory was completed.

Ground-water withdrawals from wells in the study area (GWMA only) in 1990 were an estimated 4,270 acre-ft of water. This quantity represents gross withdrawals and does not reflect the quantity of water returned to the ground-water system through septic tanks or excessive irrigation. The withdrawals from wells are categorized by water-use category in detail in the next section of this report.

The quantity of ground water that discharges through plant transpiration, as seepage to valley walls, or as ground-water flow out of the study area, is unknown at this time, but probably constitutes the bulk of the discharge from the ground-water system. The combined quantity was estimated, however, in a preliminary water-budget analysis that is addressed in greater detail in a later section of this report.

Table 3.--Summary of seepage run data collected in September 1991
[--, not determined]

	Discharge (cubic feet per second)		
Surface-water body	at site	total upstream	gain (loss)
Boxley Creek near mouth	34.3	--	--
South Fork Snoqualmie River at Edgewick Road	66.3	--	--
South Fork Snoqualmie River at North Bend	132	101	31
Middle Fork Snoqualmie River near mouth	210	--	--
North Fork Snoqualmie River near mouth	104	--	--
Snoqualmie River below Snoqualmie Falls	534	446	88
Tokul Creek at mouth	27.6	--	--
Raging River (upstream)	14.9	--	--
Raging River at mouth	11.8	14.9	(3.1)
Snoqualmie River at Fall City	581	573	8
Patterson Creek near mouth	9.8	--	--
Tolt River (upstream - below South Fork/North Fork confluence)	136	--	--
Tolt River near mouth	114	136	(22)
Snoqualmie River at Carnation	798	705	93
Snoqualmie River near Monroe	736	798	(62)
Total gain on the Snoqualmie River system from North Bend to Monroe			133
Issaquah Creek near mouth	27.2	--	--
Pine Lake drainage near mouth	.15	--	--
Sammamish River at Lake Sammamish outlet	35.6	27.4	8.2
Gain to Lake Sammamish corrected for percentage of shoreline that drains the study area (approximately 40 percent)			3.3

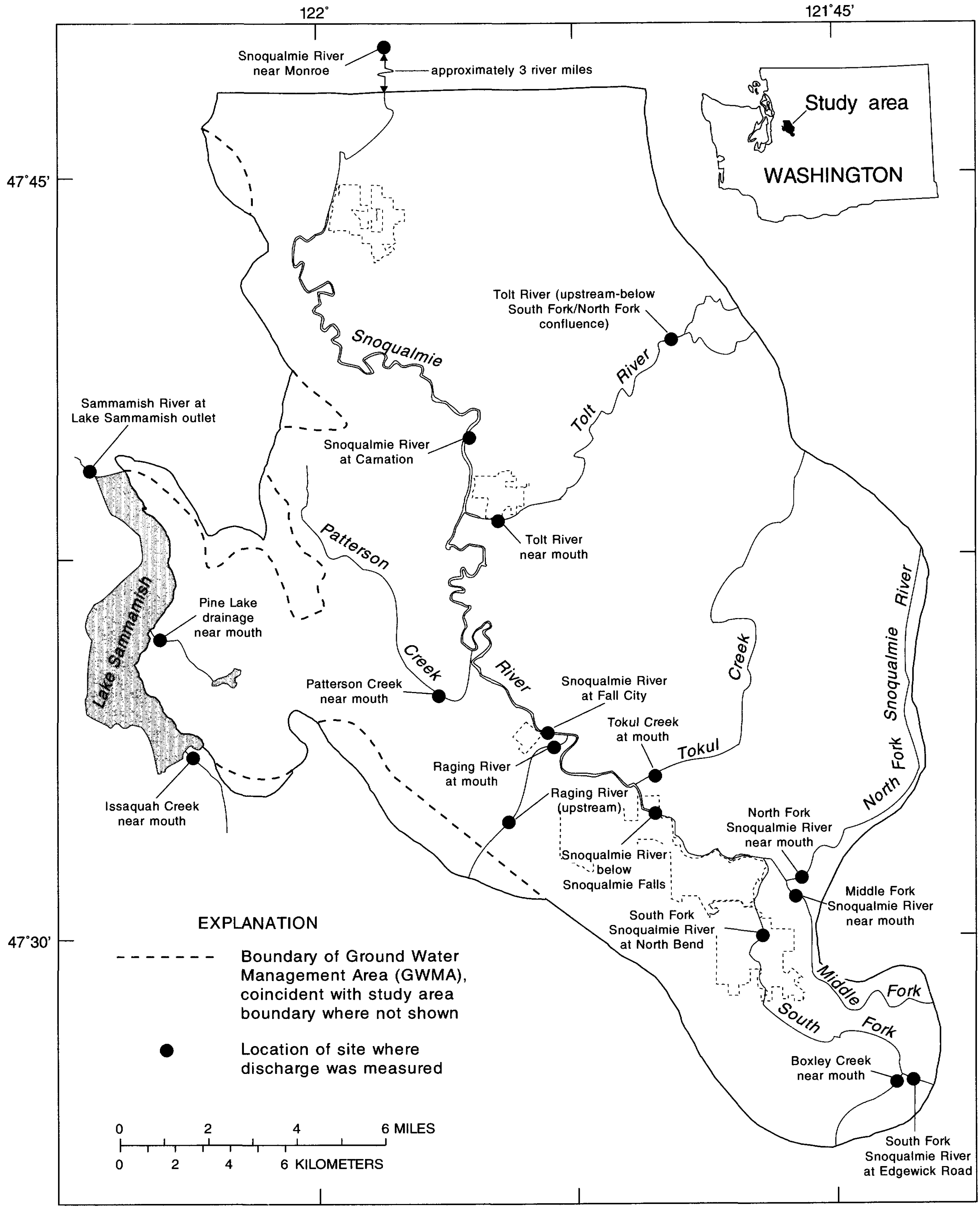


Figure 14.--Locations of stream sites where discharge was measured to determine ground-water seepage.

Table 4.--Principal springs in east King County
[P, public supply; Q, aquaculture (fish farms); I, irrigation; U, unused; --, not determined]

Local number	Owner	Land surface elevation (feet)	Use	Discharge (cubic feet per second)
24N/07E-11L01S	Fall City	330	U	--
24N/08E-18G__S[1]	Tokul Creek Community	--	P	0.25
24N/08E-19D__S[1]	Tokul Fish Hatchery	--	Q	.89
24N/08E-24Q01S	City of Snoqualmie	680	P	1.9
24N/08E-35N01S	City of North Bend	425	P,Q	9.0
25N/07E-21L__S[1]	Private owner	--	I	.36
25N/07E-23E01S	Unknown	290	U	--
25N/07E-23Q01S	City of Carnation	450	P	.78
25N/07E-26F01S	Private owner	380	I	--

[1] These springs were not inventoried and are not listed in Appendix A; locations are approximate.

Ground-Water Withdrawals

A summary of ground-water withdrawals from the study area (GWMA only) in 1990, compiled by water-use category, source (well or spring), and physiographic sub-area, is presented in table 5. As shown, approximately 4,270 acre-ft of water was withdrawn from wells. Another 5,290 acre-ft of the water that discharges naturally through springs was put to beneficial use, for a total use of 9,560 acre-ft. The use of spring water is not a true withdrawal of the ground-water resource because the spring would discharge anyway, regardless of the use. Nevertheless, water drawn from springs is discussed because it does represent a significant use of ground water. About 4,460 acre-ft (47 percent) of the total quantity was used for public supply, and another 3,010 acre-ft (31 percent) was used for aquaculture.

Of the estimated 56,500 people that resided in the study area in 1990, 48,100 (85 percent) obtained household water from Class I or Class II public supply systems. A total of 2,490 acre-ft of water was withdrawn from wells, and 1,970 acre-ft was drawn from springs to furnish these Class I and II public supply systems. The relatively large percentage (44 percent) drawn from springs reflects the fact that the Cities of North Bend, Snoqualmie, and Carnation use springs emanating from the Cascade Range foothills as their primary water supplies. More than 98 percent, or 1,110 acre-ft, of the total ground-water withdrawals in the Sammamish Plateau went to public supply systems, reflecting the suburban nature of that sub-area. Another 2,280 acre-ft, not shown in table 5, was imported for public supply systems from water systems outside the study area. For example, the City of Duvall imports its entire water supply from the City of Seattle system. Although most of the water withdrawn for public supply is used for individual households, undetermined quantities are used for commercial, institutional, industrial, or municipal purposes and for some dairies. Also, a significant quantity of water can be lost through leakage from distribution systems. There is a marked seasonal variation in the demand for, and therefore withdrawal of, water for public supply purposes. The greatest demand is in summer, when temperatures are high, precipitation is at a minimum, and ground-water levels are relatively low.

The remaining 15 percent of the population (8,400 people) relied on either privately owned wells or Class IV systems that supply nine or fewer households. An estimated 1,040 acre-ft of ground water was withdrawn from wells for domestic purposes. Most domestic withdrawals (958 acre-ft) were from the lower Snoqualmie Valley sub-area.

Irrigation water use totalled an estimated 679 acre-ft in 1990. Because not all irrigators could be contacted, this is probably a minimum value. About 529 acre-ft was used for irrigation of crops on truck farms, tree farms, nurseries, and pastures, all in the lower Snoqualmie Valley. About half of the crop irrigation water was drawn from springs.

Table 5.--Summary of ground-water withdrawals in 1990 by water-use category, source, and sub-area. Data are for the Ground-Water Management Area (250 mi^2), not the entire study area (259 mi^2)
[nr, no withdrawals reported]

Water use category	Withdrawals (acre-feet per year)			
	Sub-area			
	Sammamish Plateau	Upper Snoqualmie Valley	Lower Snoqualmie Valley	Total
Public supply				
Wells	1,110	745	635	2,490
Springs	nr	1,540	433	1,970
Domestic				
Wells	16	63	958	1,040
Springs	nr	nr	nr	nr
Crop irrigation				
Wells	nr	nr	267	267
Springs	nr	nr	262	262
Non-crop irrigation				
Wells	4.5	86	48	138
Springs	nr	nr	12	12
Dairy livestock				
Wells	nr	nr	243	243
Springs	nr	nr	31	31
Other livestock				
Wells	nr	.3	8.1	8
Springs	nr	nr	4.0	4
Aquaculture				
Wells	nr	nr	nr	nr
Springs	nr	2,350	659	3,010
Industrial				
Wells	nr	82	1.3	83
Springs	nr	nr	nr	nr
Subtotal				
Wells	1,130	976	2,160	4,270
Springs	nr	3,890	1,400	5,290
Total	1,130	4,870	3,560	9,560

The remaining irrigation withdrawals, 150 acre-ft, were used for non-crop purposes, such as watering golf courses and school grounds. The quantity of water used to water residential lawns was accounted for in the domestic water category.

Most of the water withdrawn for livestock usage went to dairies, all located in the lower Snoqualmie Valley. About 274 acre-ft of water was withdrawn for these dairies, almost all from wells. A few dairies are in the upper Snoqualmie Valley, but their water comes from public supplies. The quantity of water withdrawn for other livestock is negligible.

Of the 3,010 acre-ft of water used for aquaculture, or fish hatcheries, 2,350 acre-ft was used by a single hatchery in the upper Snoqualmie Valley. The source of the water is the City of North Bend spring (24N/08E-35N01S) and the water is taken from the excess not used by the city. The remaining 659 acre-ft was used in the lower Snoqualmie Valley, and of this, 645 acre-ft was used by a State fish hatchery near Tokul Creek. All of the aquaculture water is from springs and, as mentioned previously, does not constitute a real withdrawal from the ground-water system. In addition, the use of spring water for fish propagation is nonconsumptive, although the quality of the water is probably altered slightly as a result.

One industrial operation, a sand and gravel quarry located about a mile east of Snoqualmie Falls, accounted for the 82 acre-ft of ground water used for industrial purposes in the upper Snoqualmie Valley. This use also represents almost all of the industrial withdrawals in the study area. However, as mentioned previously, ground water is provided to some minor industrial concerns by public supply systems.

The documentation of long-term trends in ground-water withdrawal is difficult because of a lack of readily available data. One can assume, however, that withdrawals have increased over time, at least with respect to public and domestic water supplies, because of the relatively steady growth in population in the study area (see fig. 4).

Water Budget of the Study Area

On a long-term basis, a hydrologic system is usually in a state of dynamic equilibrium; that is, inflow to the system is equal to outflow from the system and there is little or no change in the quantity of water stored within the system. An approximate water budget, or distribution of precipitation, for an average year in the study area (GWMA only) is presented in table 6. The total recharge to the system (31 in.) is from the recharge calculations described earlier. The value for evapotranspiration (23 in.) was calculated by averaging values reported for selected sites in and around the study area (U.S. Department of Agriculture, 1973). The value for runoff (3 in.) is a residual; that is, it represents the quantity that remains after recharge (31 in.) and evapotranspiration (23 in.) are subtracted from precipitation (57 in.). Similarly, the value of 22.6 in. for ground-water flow out of the study area also is a residual; it represents the remainder when the quantities known to be withdrawn by wells (0.3 in.), discharged to springs (0.7 in.), and discharged to rivers and lakes (7.4 in.), are subtracted from recharge (31 in.).

The water budget in table 6 indicates that more than half of the precipitation (54 percent) falling on the study area becomes ground-water recharge. Of this recharge, only 1 percent is withdrawn from wells for use. The spring discharge represents another 2 percent of recharge, but only about half of this (5,290 acre-ft of 9,540 acre-ft, or 55 percent; see table 5) is put to beneficial use. The ground water used from the study area is, therefore, a small quantity of the total water present in the system.

It would seem, then, that additional ground water may be withdrawn with little effect on the system. Certainly the water budget shows that 300,700 acre-ft, or 73 percent of the total recharge, simply flows as ground water north and west out of the study area and part could be available for additional withdrawal. This may not be the case, however.

First, less than 300,700 acre-ft/yr is present as ground-water flow, because this quantity includes unaccounted discharge to springs, rivers, and lakes, which may be significant. Second, any additional withdrawals from the ground-water system may reduce flows to other discharge points. As pointed out by Bredehoeft and others (1982), any additional withdrawal or discharge superimposed on a previously stable system must be balanced by an increase in recharge, a decrease in the discharge, a loss of storage within the aquifer (reflected by lower water levels), or by a combination of these factors. Considering the ground-water system of east King County in particular, the possibility of increased natural recharge on a long-term basis appears remote. In fact, the trend of increased residential development and construction of central storm sewers will most likely result in decreased recharge. Additional withdrawals, therefore, would result in a loss of storage (with an attendant decline in water levels) or a decrease in discharge to springs, rivers, or lakes, or a

Table 6.--*Water budget of the east King County study area*

Water budget component	Quantity Inches[1] per year	Quantity Acre-feet[1] per year	Percent
Precipitation	57	760,000	100
Fate of precipitation			
Runoff	3	40,000	6
Evapotranspiration	23	307,000	40
Recharge	31	413,000	54
Total	57	760,000	100
Recharge	31	413,000	100
Fate of recharge			
Withdrawal from wells	.3	4,270	1
Discharge to springs[2]	.7	9,540	2
Discharge to rivers and lakes[2]	7.4	98,500	24
Ground-water flow out of study area[3]	22.6	300,700	73
Total	31	413,000	100

[1] Values are for the Ground Water Management Area (250 mi^2), not the entire study area (259 mi^2).

[2] These are likely minimum figures, due to unaccounted discharge to springs, rivers, and lakes.

[3] Also includes deep flow to the regional ground-water system and any unaccounted discharge to springs, rivers, or lakes.

decrease in ground-water flow out of the study area. Discharged water used either directly or indirectly for streamflow maintenance, fish propagation, waste dilution, or supply would decrease also. The magnitude of potential ground-water development, therefore, depends on the decrease in discharge that can be tolerated. Because it can take many years for a new equilibrium to become established, the effects of additional ground-water development may not be immediately apparent.

Bredehoeft and others (1982) also point out that the effects of additional development are independent of the magnitude of the original recharge and discharge and depend solely on how much of the original discharge can be diverted, or captured, without unwanted effects. Therefore, a water budget alone is of limited use in determining the magnitude of ground water available for development. Of much greater significance are the geometric boundaries and hydraulic properties of the aquifer system and the present uses of the discharged water that would be affected by pumping.

Water-Level Fluctuations and Trends

The configuration of the water table or potentiometric surface of an aquifer is determined by (1) the overall geometry of the ground-water system; (2) the hydraulic properties of the aquifer; and (3) the areal and temporal distribution of recharge and discharge. Where recharge exceeds discharge, the quantity of water stored will increase and water levels will rise; where discharge exceeds recharge, the quantity of water stored will decrease and water levels will fall.

As stated previously, most of the recharge in east King County is from the infiltration of precipitation during the months of October through March (fig. 3). Previous studies in western Washington have shown that, in years of typical precipitation, ground-water levels in shallow wells generally rise from October through March and fall from April through September. Water levels in deep wells generally respond more slowly, and usually with less change, than water levels in shallow wells. This happens because deeper wells are usually farther from the source of recharge, and any variability in recharge is dampened. Along rivers or lakes, water-level fluctuations also are influenced by river or lake level changes; these fluctuations due to these surface-water bodies are superimposed on the seasonal and long-term changes that are related to changing recharge-discharge relations.

Water-level fluctuations varied considerably throughout the study area but generally followed the patterns described above. Hydrographs of water levels in six selected observation wells are shown in figure 15 for the period May 1991 through December 1992. The water levels in well 23N/08E-03L03 probably exhibited the most month-to-month variability, but this well is in Qal less than a half mile from the Snoqualmie River, and the water levels closely reflect the discharge of the river (fig. 16). Likewise, the water levels in 24N/06E-04K01 reflect a

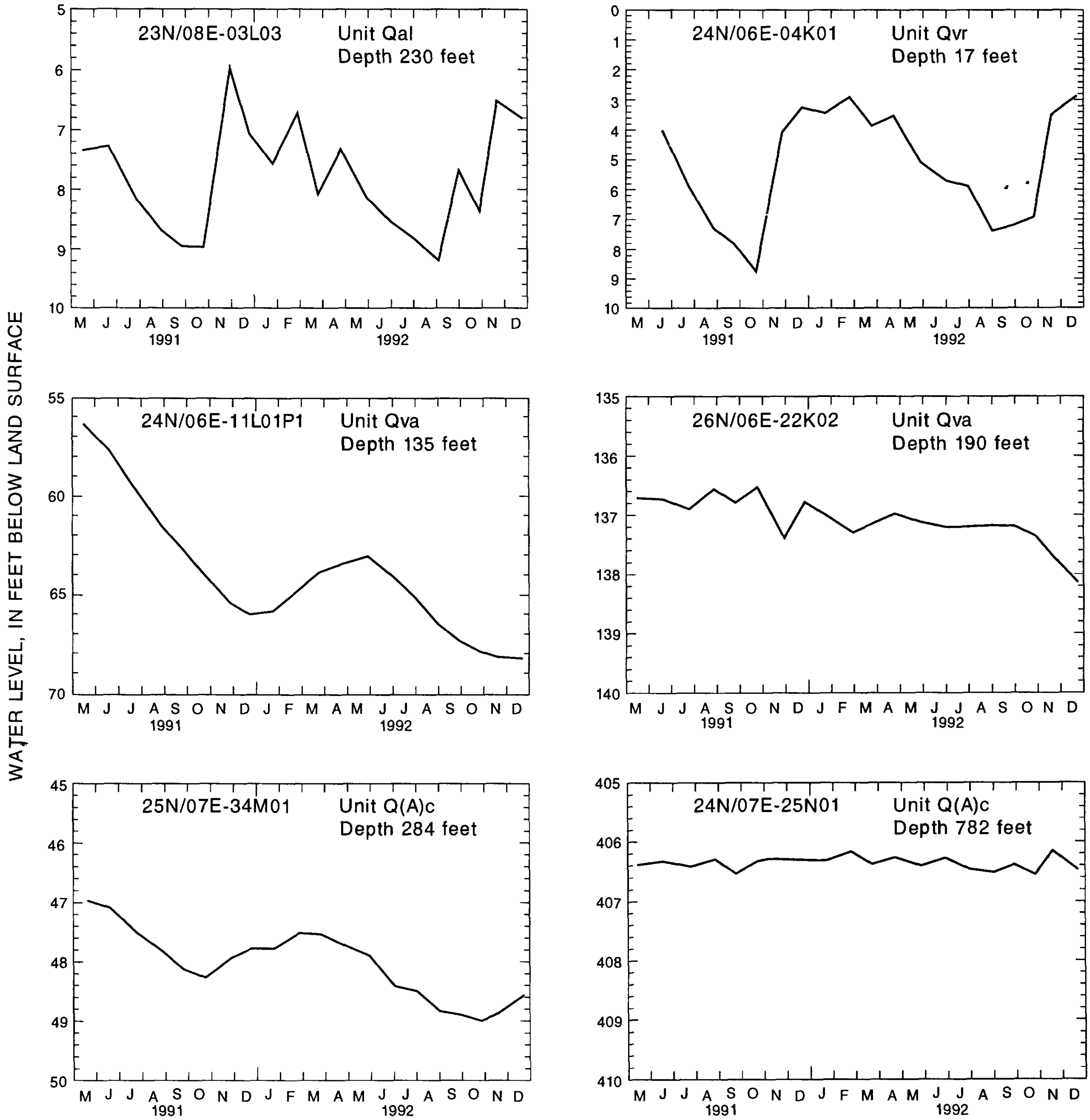


Figure 15.--Water levels in selected wells in east King County.

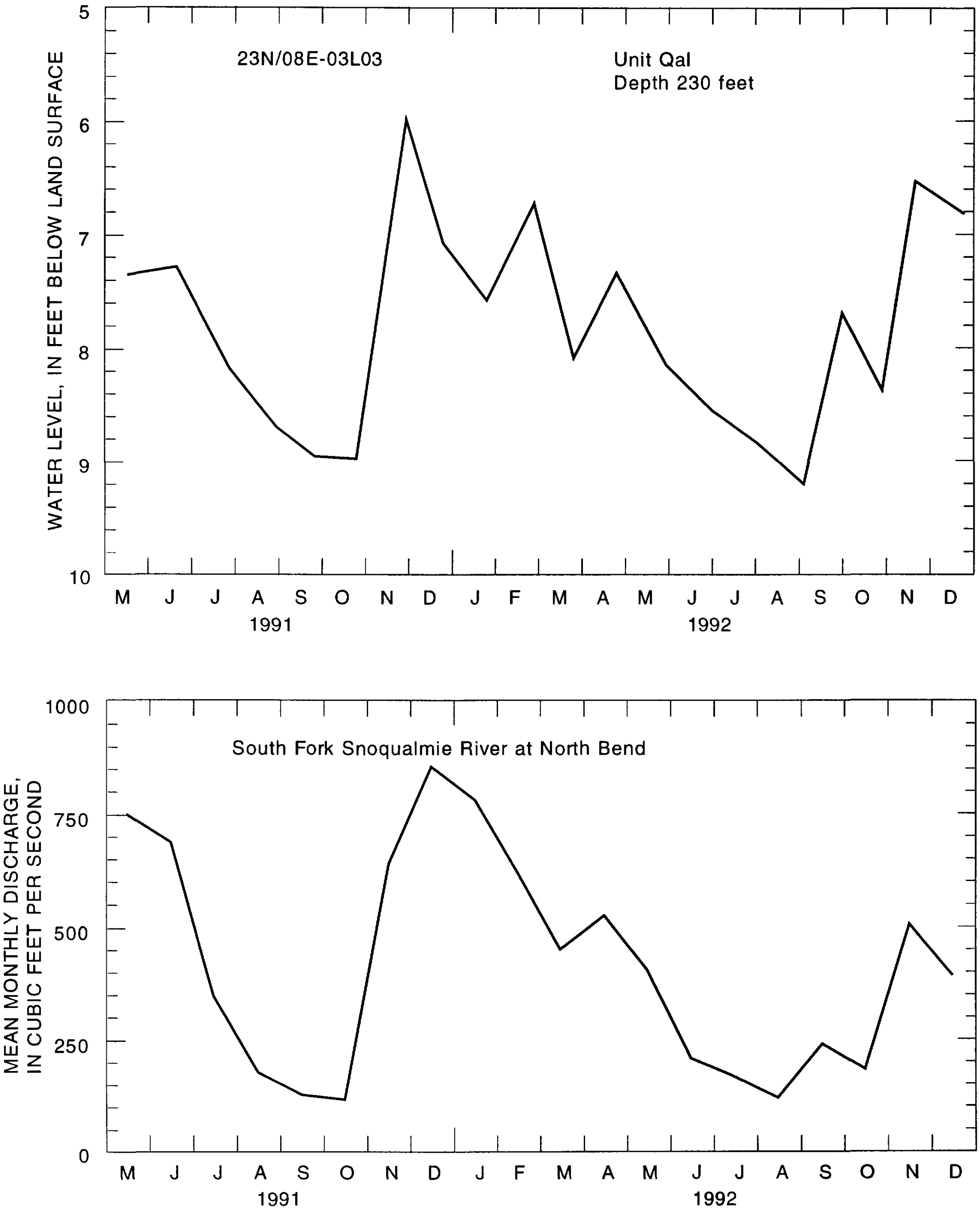


Figure 16.--Water levels in well 23N/08E-03L03 and mean monthly discharge of the South Fork Snoqualmie River at North Bend.

rapid response of the shallow ground water in the Qvr to variations in precipitation. When compared with figure 3, these water levels closely follow monthly precipitation. Hydrographs of water levels in wells 24N/06E-11L01P1 and 25N/07E-34M01 (fig. 15) are much smoother and the maximums and minimums take place several months after those for precipitation. This is typical of the response in deeper, confined systems. The total fluctuation in 24N/06E-11L01P1, which is in Qva, is more than 10 ft, and the total fluctuation in 25N/07E-34M01, which is in the lower Q(A)c, is only about 2 ft. Also, both hydrographs have a general downward trend, which is probably because annual precipitation in 1990 was 81 in., much larger than normal, and water levels were declining from the resulting higher-than-normal levels. This trend was common to several wells monitored throughout the study area. In contrast, the hydrographs of 26N/06E-22K02, in Qva, and 24N/07E-25N01, in Q(A)c (fig. 15), each exhibit about a foot of fluctuation, with no trend. The ground-water fluctuations observed in the course of this study are seasonal and are probably not typical of the long-term average conditions; rather, the fluctuations are a reflection of recharge-discharge relations over a relatively short period.

The detection of long-term trends in ground-water levels requires the plotting and analysis of water-level data for several years of record. These data are generally lacking for east King County. However, several wells on the Sammamish Plateau were monitored for water levels from 1979 to 1987 as part of a study of Pine Lake (Dion and others, 1983), and the wells were available for observation during this study. The water levels in one of the deep wells, 24N/06E-09A15, declined from 1982 to 1986 (fig. 17). Rainfall in 1982-84, 1986, 1988, and 1990 was above the long-term average, so the decline was not likely related to precipitation. Pumping may be a factor, as this well is located on the Sammamish Plateau where the population is rapidly increasing. In contrast, the shallow ground water in another well on the Sammamish Plateau, 24N/06E-04K01, showed little year-to-year variation (fig. 17).

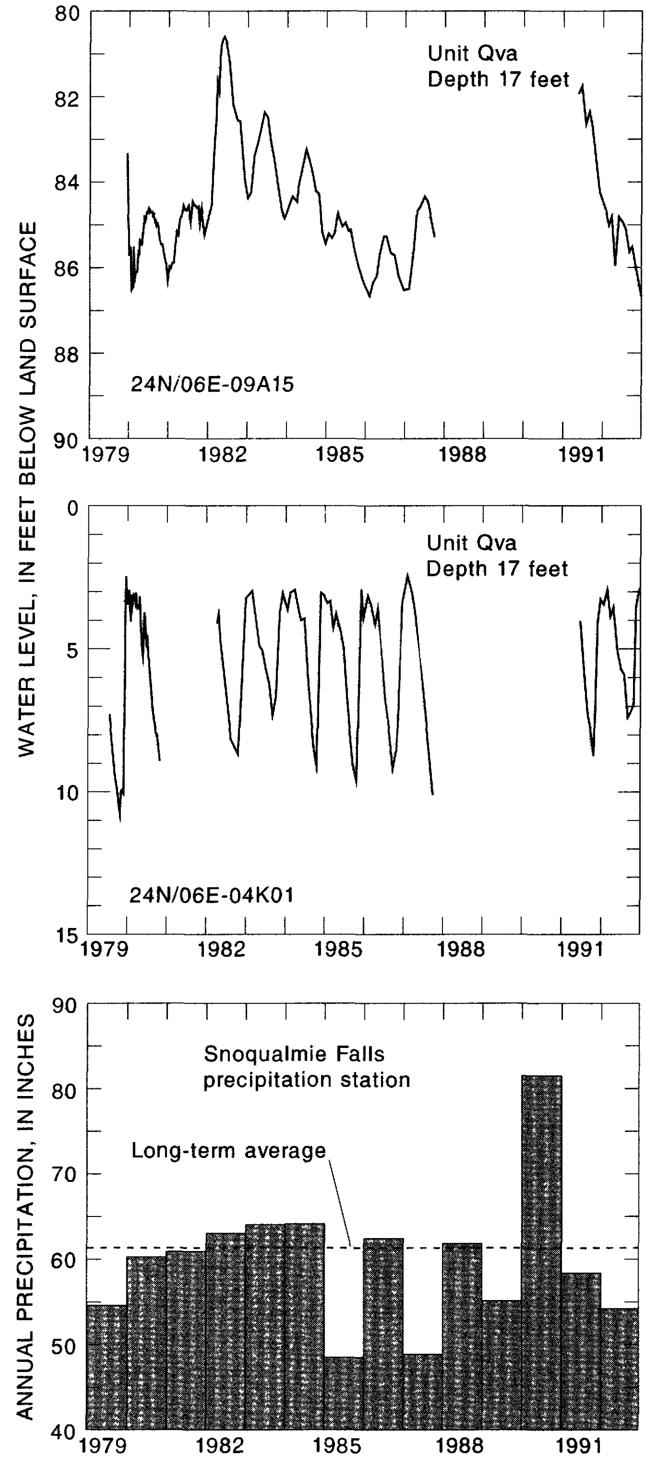


Figure 17.--Water levels in wells 24N/06E-09A15 and 24N/06E-04K01 and annual precipitation at Snoqualmie Falls.

GROUND-WATER QUALITY

In this section, the ground-water quality of the study area is described, based on the results of chemical analyses of water samples. Chemical concentrations and characteristics are discussed and related to geographic area and geohydrologic unit. Concentrations are compared with applicable U.S. Environmental Protection Agency (USEPA) drinking water regulations, and causes of widespread or common water-quality problems are identified.

Ground-Water Chemistry

Most of the data that describe the general chemistry of the ground water are presented statistically in summary tables. Table 7 presents the minimum, median, and maximum values of the common constituents determined; table 8 shows median values for each of the common constituents by geohydrologic unit. Similar summary tables are presented for other constituents and chemicals as needed for the discussion. The areal distributions of selected constituents are shown on plate 4. All supporting data are presented in Appendix B.

For many constituents, some concentrations are reported as less than (<) a given value, where the value given is the reporting limit of the analytical method. For example, the concentrations of many pesticides are reported as <0.05 µg/L, where the reporting limit is 0.05 µg/L. The correct interpretation of such concentrations is that the constituent was not detected at or above that particular concentration. The constituent could be present at a lower concentration, such as 0.01 µg/L, or it may not be present at all, but that is impossible to tell with certainty because of the reporting limit of the analytical method used.

Table 7.--*Summary of field measurements and concentrations of common constituents*

[Concentrations in milligrams per liter unless otherwise noted. All are dissolved concentrations. Values are for samples from 124 wells and springs unless noted; µS/cm, microsiemens per centimeter at 25 °Celsius; <, not detected at the given concentration; µg/L, micrograms per liter]

Constituent	Minimum	25th percentile	Median	75th percentile	Maximum
pH (standard units)	5.6	6.8	7.8	8.3	9.5
Dissolved oxygen[1]	.0	.1	.6	5.5	10.6
Specific conductance (µS/cm, field)	50	130	163	233	830
Hardness (as $CaCO_3$)	2	45	61	78	250
Calcium	.79	11	15	20	55
Magnesium	.03	3.4	5.0	7.7	27
Sodium	1.9	5.1	6.6	17	200
Percent sodium	4	15	18	30	99
Potassium	.1	.7	1.3	2.0	7.0
Alkalinity (as $CaCO_3$)	20	54	76	105	266
Sulfate	<.1	2.2	4.8	7.1	170
Chloride	.3	1.6	3.0	4.2	140
Fluoride	<.1	<.1	.1	.1	2.5
Silica	8.5	17	23	28	43
Dissolved solids	37	95	115	164	551
Nitrate (as nitrogen)	<.05	<.05	.07	.81	6.3
Iron (µg/L)	<3	8	24	106	14,000
Manganese (µg/L)	<1	2	17	60	920

[1] Based on 123 samples.

Table 8.--*Median values of field measurements and concentrations of common constituents by geohydrologic unit*

[Concentrations in milligrams per liter unless otherwise noted. All are dissolved concentrations; µS/cm, microsiemens per centimeter at 25 °Celsius; <, not detected at the given concentration; µg/L, micrograms per liter]

	Geohydrologic unit (Number of samples)							
	Qal (20)	Qvr (15)	Qvt (8)	Qva (27)	Q(A)f (4)	Q(A)c (26)	Q(B)c (2)	Br (22)
pH (standard units)	6.9	7.0	6.7	7.6	8.4	8.2	7.8	8.4
Dissolved oxygen	3.0	3.9	6.7	2.1	.2	.1	.1	.9
Specific conductance (µS/cm)	124	156	158	148	200	193	176	226
Hardness (as $CaCO_3$)	49	59	62	64	62	73	74	34
Calcium	14	15	12	14	18	18	18	12
Magnesium	3.4	5.4	6.1	6.5	4.0	6.5	6.8	1.8
Sodium	3.9	5.9	7.2	5.7	26	11	8.0	26
Percent sodium	17	17	18	16	45	24	19	66
Potassium	.9	1.1	1.0	1.3	3.1	2.1	2.2	.5
Alkalinity (as $CaCO_3$)	52	58	68	66	109	94	85	97
Sulfate	4.3	5.8	4.1	5.0	2.5	4.0	4.4	5.4
Chloride	1.8	3.7	3.5	3.0	2.8	3.2	3.7	2.8
Fluoride	<.1	<.1	.1	.1	<.1	.1	.1	.1
Silica	16	24	28	23	24	26	26	21
Dissolved solids	89	106	116	103	145	141	121	152
Nitrate (as nitrogen)	.36	.71	1.2	.40	<.05	<.05	<.05	.06
Iron (µg/L)	30	13	14	33	52	39	372	15
Manganese (µg/L)	4	3	4	25	38	42	134	6
Arsenic (µg/L)	2	2	1	2	12	6	2	<1

pH, Dissolved Oxygen, and Specific Conductance

The acidity or basicity of water is measured by pH on a scale from 0 to 14. A pH of 7.0 is considered neutral; smaller values are acidic and larger values are basic. The scale is logarithmic; therefore, a pH of 6.0 indicates that a water is 10 times as acidic as water with a pH of 7.0.

The pH values of the samples collected as part of this study ranged from 5.6 to 9.5 (table 7), and the median was 7.8. The median pH by geohydrologic unit generally increased from 6.9 in Qal to 8.4 in Br (table 8). The variation in pH values is mostly natural, due to alterations of the water composition by chemical reactions with minerals in the geohydrologic unit. Some of these reactions and the effects they have on water chemistry will be discussed later, along with water types.

Dissolved-oxygen concentrations are used to help determine the types of chemical reactions that can take place in water. Small dissolved-oxygen concentrations indicate that a chemically reducing reaction can take place, and large concentrations indicate that a chemically oxidizing reaction can take place. In some instances, though, large dissolved-oxygen concentrations may have been caused by the introduction of air into plumbing systems by pumps, leaking tanks, or pipes. All attempts were made to avoid aeration of the samples, but sometimes it was unavoidable or undetectable.

Dissolved-oxygen concentrations ranged from 0.0 to 10.6 mg/L, and the overall median concentration was 0.6 mg/L. As shown in table 7, median concentrations varied considerably by unit with the largest in Qvt (6.7 mg/L) and the smallest in Q(A)f, Q(A)c, and Q(B)c (0.2, 0.1, and 0.1 mg/L, respectively). However, there was much variation within individual units in that the maximum value for each unit with eight or more samples was at least 8.0 mg/L, and the minimum value in each unit was either 0.0 or 0.1 mg/L. Much of this variation is natural and is due to reactions between the water and minerals or organic matter.

Specific conductance is a measure of the electrical conductance of the water (corrected for water temperature). Because specific conductance increases with the amount of dissolved minerals, it is a good indicator of the total concentration of those minerals, usually called dissolved solids. Dissolved-solids concentrations are discussed in detail in the next section; therefore, specific conductance data are presented in the tables for information only. The median specific conductance of the 124 samples was 163 μS/cm (microsiemens per centimeter at 25°C), and the values ranged from 50 to 830 μS/cm.

Dissolved Solids

The concentration of dissolved solids is the total concentration of all the minerals dissolved in the water. The major components of dissolved solids depend on many factors, but usually include calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, nitrate, and silica. Other constituents such as carbonate and fluoride, or metals such as iron and manganese, are also components but are rarely found in large enough concentrations to significantly affect dissolved solids concentrations.

Dissolved-solids concentrations ranged from 37 to 551 mg/L, with a median concentration of 115 mg/L (table 7). The concentrations tended to be larger in the deeper, older units (table 8). The median concentration in Qal was 89 mg/L, and there was a general increase down to the Br unit, where the median concentration was 152 mg/L. Some of this variation is because of different rock types in the units, as reported by Liesch and others (1963), but some variation is likely due to increased residence time of water in the lower units. Water that has been in the ground for a longer time generally has had the opportunity to dissolve more minerals than water with a shorter residence time.

A map of dissolved-solids concentrations (plate 4) shows some areal variation. Throughout most of the study area, concentrations were between 100 and 200 mg/L. Concentrations east of North Bend and east of Carnation tended to be less than 100 mg/L. Around North Bend, the relatively large quantity of precipitation, which has a small dissolved-solids concentration, would have a diluting effect on the ground-water system. Concentrations exceeding 200 mg/L were found in samples from wells along the Snoqualmie River and in the foothills east of the river. These large concentrations appear to be due to natural conditions, and most of the wells are finished in older units such as Q(A)c, Q(A)f, or Br.

Major Ions

Most of the major components of dissolved solids are ions, meaning they have an electrical charge. Cations are ions with a positive charge and include calcium, magnesium, sodium, potassium, and most metals. Anions are ions with a negative charge and include bicarbonate, sulfate, chloride, nitrate, carbonate, and fluoride. Silica has no charge and is the only major component that is not a cation or anion.

The median concentration of calcium (table 7) was 15 mg/L, the largest of any of the cations. Magnesium and sodium had median concentrations of 5.0 and 6.6 mg/L, respectively, and account for most of the remaining cations. Maximum concentrations of all these cations are at least five times larger than the median concentrations, and variability is such that in a given sample, any of these three cations may be the dominant cation. Concentrations of potassium, iron, and manganese were generally small compared with calcium, magnesium, or sodium.

Hardness is calculated from the concentrations of calcium and magnesium. The most familiar effect of increased hardness is a decreased production of lather from a given amount of soap introduced into the water. Hard water may also cause a scale deposit on the inside of plumbing pipes. Ninety-five percent of the samples were classified as soft or moderately hard, as defined by the following scheme (Hem, 1985).

Description	Hardness range (milligrams per liter of $CaCO_3$)	Number of samples	Percentage of samples
Soft	0-60	57	46
Moderately hard	61-120	61	49
Hard	121-180	4	3
Very hard	Greater than 180	2	2
		124	100

The dominant anion was bicarbonate, as indicated by the median alkalinity concentration of 76 mg/L (table 7). Alkalinity consists mainly of bicarbonate, carbonate, and hydroxide, but the concentrations of each are dependent on pH. At all pH values observed, bicarbonate is the major component of the alkalinity. The largest alkalinity concentration observed in the study area was 266 mg/L, in a sample from well 23N/08E-08K01, which is completed in Br. The median concentrations of sulfate, chloride, nitrate, and fluoride were small compared with alkalinity, and as such they are generally negligible as major components of the water. The maximum concentration of chloride, however, was 140 mg/L, and chloride was the dominant anion in some samples. The maximum concentration of sulfate was 170 mg/L. Nitrate is discussed in more detail in a separate section of the report because it is generally considered an indication of ground-water contamination.

Silica was also a major component of the dissolved solids, with a median concentration of 23 mg/L. The maximum silica concentration observed was 43 mg/L.

Comparisons of median concentrations of the major ions by geohydrologic unit indicate that sodium and alkalinity vary the most between units, and concentrations are largest in Br and Q(A)f (table 8). This suggests that these major ions are the main source of the variation in dissolved-solids concentrations observed between units. Variations in median concentrations of calcium, magnesium, potassium, sulfate, chloride, fluoride, and nitrate are not large enough to account for the variations in median dissolved-solids concentrations between units. In fact, median calcium, magnesium, and potassium concentrations were actually smallest in Br. Median chloride and fluoride concentrations were the same for all units. The variations in concentration for all of the major ions except nitrate are within natural limits and are probably due to natural causes.

Water Types

Another way to describe major ion data is by water type (dominant ion). First, concentrations of the major ions are converted from milligrams, which are based on mass, to milliequivalents, which are based on the number of molecules and electrical charge. A milliequivalent is the amount of a compound that either furnishes or reacts with a given amount of H^+ or OH^-. When expressed as milliequivalents, all cations or anions are equivalent for the purpose of balancing chemical equations. A milliequivalent of sulfate will balance a milliequivalent of calcium, as would a milliequivalent of chloride. The milliequivalents of all the cations and anions are added into cation and anion sums. Because water is electrically neutral, the cation and anion sums should be close in value. The contribution of each ion to its respective sum is then calculated as a percentage. The cation(s) and anion(s) that are the largest contributors to their respective sums define the water type. For example, the water type of seawater is sodium/chloride.

To make the determination of water type easier, the percentages of cations and anions for a given sample, as milliequivalents, are plotted on a trilinear (Piper) diagram, as shown on plate 5. The water type is then determined from the area of the diagram in which the sample is plotted. One plot defines the dominant cation, another the dominant anion. Combined water types, where more than one cation or anion dominate, are possible and are actually common. An inspection of the explanation diagram on plate 5 shows that to be defined as a sole dominant ion, (1) an ion must account for 60 percent or more of the cation or anion sum, and (2) the analysis will be plotted near one of the corners. On the other hand, an ion that accounts for less than 20 percent of the sum will not be part of the water type. An exception to the latter case is when two ions, such as chloride and nitrate, are summed and plotted together on a single axis of the plot. If both together contribute 20 percent, then the plot will show chloride as a dominant anion, although individually chloride and nitrate contributions may be less than 20 percent. For the study, the actual percentages were used to determine the water type, and if both were less than 20 percent neither was considered dominant. For a combined water type, the ions are listed in order of dominance. For example, a calcium-magnesium/bicarbonate type has more calcium than magnesium, and a magnesium-calcium/bicarbonate type has more magnesium than calcium, but both plot in the same section of the diagram. The diagram is based only on percentages and does not show actual concentrations or milliequivalents.

For the study, all of the samples from each geohydrologic unit were plotted on a single trilinear diagram for each unit (plate 5) so that trends and anomalies could be more easily discerned. Samples that plotted away from the majority of samples for the unit were considered anomalies. They are listed, along with comments, on plate 5.

Samples with calcium and magnesium as the dominant cations and bicarbonate as the dominant anion were the most common throughout the study area. For the most part, these water types were from wells finished in the unconsolidated units. Such water types are characteristic of the glacial deposits of western Washington (Van Denburgh and Santos, 1965; Turney, 1986a; Dion and others, 1994). Freeze and Cherry (1979) attribute these water types to the interaction of dilute, slightly acidic recharge water with alumino-silicate minerals. These minerals dissolve slowly, resulting in low concentrations of dissolved solids and pH values that commonly do not exceed 7.0. Ultimately, carbonate minerals such as calcite and dolomite are dissolved, resulting in the characteristic water type. Chloride and sulfate-containing minerals are rare, so these anions are usually present in small concentrations.

Sodium/bicarbonate and sodium-calcium/bicarbonate water types were most common in Br. The elevated sodium proportions result from a series of geochemical reactions of the ground water with andesite and basalt, which make up much of this unit. Initially, slightly acidic calcium/bicarbonate water from precipitation or the upper, younger units enters Br as a result of downward vertical flow. The water begins to dissolve the minerals in Br, which contains calcium, magnesium, and sodium. Hydrolysis is part of the dissolution mechanism and produces excessive hydroxyl ions (OH^-) that raise the ground-water pH. Solubilities for calcium carbonate and magnesium carbonate, which are pH-controlled, are exceeded, and these minerals precipitate. However, the solubilities of the sodium minerals are not exceeded as quickly, resulting in water enriched in sodium. The pH is also higher, as can be seen by the higher median pH in Br (table 8), leading to the conversion of some of the bicarbonate to carbonate. This process also causes Br rocks to weather geochemically into clays such as kaolinite or montmorillonite. These reactions have been described in more detail by Freeze and Cherry (1979) for general cases, and by Hearn and others (1985) and Steinkampf and others (1985) for basalts in eastern Washington.

Many of the anomalous water types listed on plate 5 were related to uncharacteristically large percentages of sodium in some samples from the unconsolidated units. The inherent heterogeneity of these deposits and the possible presence of sodium-rich clays are factors, as is the incongruous dissolution of the minerals present. In the deeper unconsolidated units, such as Q(A)f and Q(A)c, water is likely to be older and has had more time to be in contact with the formation minerals and to undergo sodium-enrichment reactions, which can take place in glacial deposits as well as bedrock. Another consideration is that sodium-rich water may be flowing upward from Br into these overlying unconsolidated units. However, none of these mechanisms can be proven without further study.

Two other anomalous water types are those with large proportions of either sulfate or chloride. The three samples with high sulfate all came from wells finished in Br (plate 5). Sulfur-bearing minerals, in the form of metallic sulfides, are commonly associated with igneous and sedimentary rocks such as those found in Br. When sulfide minerals undergo geochemical weathering in contact with aerated water, the sulfur is oxidized into sulfate ions that dissolve in the water (Hem, 1985). As with the unconsolidated deposits, Br can be chemically heterogeneous, so these high-sulfate water types may be present only in local instances. The high-chloride samples (two from Q(A)c and one from Br) are more difficult to explain because no chloride-containing minerals are known to be present in the study area. Marine deposits, another source of chloride, are also not common in the study area. However, one possible source of chloride is connate seawater, which is seawater trapped in a geohydrologic unit during the time of formation. Connate seawater may be locally present in Q(A)c or Br, or may be flowing out of nearby formations into these units. The Q(A)c wells are flowing, which indicates upward ground-water flow, so ground-water contamination from local sources is unlikely.

Nitrate

Although not a major component of most water samples, nitrate is of interest in east King County because of a few locally large concentrations and the associated implications of ground-water contamination. Nitrate concentrations ranged from <0.05 mg/L to 6.3 mg/L (table 7). The analysis used for nitrate actually results in a combined nitrate and nitrite concentration; however, nitrite concentrations in ground water are usually negligibly small (National Research Council, 1978). The concentrations determined in this study are therefore considered to be entirely nitrate. With a median value of 0.07 mg/L, the nitrate concentrations observed in east King County are generally smaller than those reported for other areas of western Washington. Median nitrate concentrations have been reported as 0.16 mg/L in Clark County (Turney, 1990), 0.33 mg/L in Thurston County (Dion and others, 1994), and 0.10 mg/L or greater for much of the Puget Sound area (Turney, 1986a).

Concentrations of nitrate were small throughout most of the study area (plate 4). About 80 percent of the samples analyzed had concentrations of 1.0 mg/L or less, a level above which some sort of contamination may be suspected. Two areas appeared to have nitrate concentrations generally exceeding 1.0 mg/L: west of Fall City and east of Duvall. However, no large areal sources of nitrate are present in these areas because they have fairly low population densities and no extensive agricultural activities. It is likely that these areas coincidentally had several wells with local sources of nitrate that are not related on a larger scale. Nitrate concentrations in samples from wells on the Sammamish Plateau were also relatively large. Although much of the area currently has sewers, septic tanks were widely used in the past and are a likely source.

Most of the samples having nitrate concentrations exceeding 1.0 mg/L came from wells less than 100 feet deep (table 9). The nitrate most probably originated from local sources such as septic tanks, pastures, or lawn

Table 9.--*Wells and springs with sample concentrations of nitrate exceeding 1.0 milligram per liter*
[mg/L, milligrams per liter]

Local well number	Date	Geohydrologic unit	Land surface elevation (feet)	Depth of well (feet)	Nitrate (mg/L as nitrogen)
23N/08E-04L01	08-08-91	Qal	430	47	1.1
24N/06E-02E01	08-02-91	Qvt	530	40	1.2
24N/06E-09E03	08-01-91	Qva	385	251	1.9
24N/06E-10H02	08-08-91	Qva	455	155.2	1.4
24N/07E-08A02	08-15-91	Qvt	310	39	4.4
24N/07E-15D01	07-29-91	Qal	105	49.5	1.9
24N/07E-16F01	08-06-91	Qvr	150	122	2.4
24N/07E-17B01	08-05-91	Qvr	210	74	3.8
24N/07E-18F03	08-05-91	Qva	520	80	3.8
25N/06E-24K01	08-01-91	Qvt	420	120	3.3
25N/06E-25E01	07-31-91	Q(A)c	190	49	1.7
25N/06E-32F03	08-02-91	Q(A)c	50	116	4.9
25N/07E-07P01	08-03-91	Qvr	130	39	1.4
25N/07E-23Q01S	08-16-91	Qvt	340	spring	1.1
25N/07E-26F01S	08-07-91	Qvr	380	spring	6.3
25N/07E-28Q01	08-05-91	Qal	85	25	1.2
25N/07E-33Q01	08-05-91	Q(A)c	80	100	3.1
26N/06E-13J01	08-16-91	Qva	405	90	1.1
26N/07E-06K01	08-14-91	Br	50	40	2.7
26N/07E-08A01	08-05-91	Br	600	120	1.6
26N/07E-09F02	08-07-91	Br	295	30	2.8
26N/07E-18B01	08-07-91	Qva	60	46	1.3
26N/07E-28E02	08-08-91	Qva	500	113	2.5
26N/07E-30P01	08-06-91	Qvt	410	60	1.9
26N/07E-33Q02	08-09-91	Qvr	290	134	2.7

fertilizers. Some of the wells sampled were indeed located in or adjacent to pastures with livestock, a common nitrate source. Deeper wells may also contain nitrate from local sources, but the reason for this may be poor well construction that allows seepage of surface water into the ground next to the well casing.

Nitrate concentrations were generally larger in the upper aquifers, as indicated by the median nitrate concentration for each geohydrologic unit (table 8). This is because nitrate sources are typically on or near the land surface. However, because depths to the geohydrologic units vary considerably throughout the study area, nitrate concentrations exceeding 1.0 mg/L can be found in almost all of the units (table 9). Also, because of this variability in unit depth and the large number of wells with small concentrations, there was no strong correlation of nitrate concentration with either geohydrologic unit or well depth.

Iron and Manganese

Iron concentrations ranged from <3 μg/L to 14,000 μg/L, with a median concentration of 24 μg/L (table 7). Median concentrations ranged from 13 to 52 μg/L for all geohydrologic units except Q(B)c, which had a median concentration of 372 μg/L (table 8). However, four of the six concentrations exceeding 1,000 μg/L were observed in samples from Qal. Areal distributions of iron concentrations varied, but some patterns were noted (plate 4). Large numbers of samples with iron concentrations of 30 μg/L or less were from wells located west of Fall City, east of Carnation, and on the Sammamish Plateau. Conversely, large iron concentrations exceeding 300 μg/L were found in samples from a few wells north of North Bend, and in two wells close to Fall City. In general, however, these delineations are subtle; the concentration of iron is geographically highly variable.

Manganese concentrations ranged from <1 μg/L to 920 μg/L, and the median concentration was 17 μg/L. Like iron, the median concentration for individual units was largest (134 μg/L) for samples from Q(B)c; median concentrations in all other units ranged from 3 μg/L to 42 μg/L. Areally, manganese concentrations followed the same general pattern as iron concentrations, although some large concentrations were also noted east of Duvall.

The variation and range of iron and manganese concentrations in east King County are typical of western Washington ground waters (Van Denburgh and Santos, 1965; Turney, 1986a, 1990; Dion and others, 1994), and usually are due to natural processes. These processes are closely dependent upon ambient geochemical conditions, in particular the concentration of dissolved oxygen. Water that is depleted of oxygen will dissolve iron from the surrounding minerals as the chemically reduced ferrous (Fe^{2+}) form of iron. Iron is highly soluble under these conditions and large concentrations can result. If the water is reoxygenated, then the iron is oxidized to the ferric (Fe^{3+}) form, which is much less soluble than the ferrous form and will precipitate as an oxide or a carbonate, resulting in a lower dissolved-iron concentration. Manganese undergoes a similar set of reactions. Because these reactions are oxygen-sensitive and the oxygen content of the ground water may vary considerably in a given area, dissolved iron and manganese concentrations may also vary greatly. Regardless, neither iron nor manganese concentrations correlated well with dissolved-oxygen concentrations in this study. This may be because the occurrence of iron and manganese in the aquifer material varies greatly. Additionally, the dissolution of iron from the aquifer material depends, to a degree, on the particle size of the material, which also is highly variable.

The large iron and manganese concentrations in Q(B)c are due in part to the small dissolved-oxygen concentrations in that unit. Water samples from Q(B)c had a median dissolved-oxygen concentration of only 0.1 mg/L, the smallest of any unit (table 8). Although dissolved oxygen is an obvious factor, this unit may also have more iron- and manganese-rich minerals than do the other unconsolidated units.

Trace Elements

Concentrations of most trace elements were small. For all except zinc and radon, the median concentrations were 5 μg/L or less (table 10). Nevertheless, some of the trace elements, most notably arsenic and radon, are present at levels that may indicate regional ground-water problems.

Arsenic concentrations ranged from <1 to 77 μg/L, with a median concentration of 2 μg/L. Arsenic was present in samples from 79 wells (64 percent) and of these, 18 (15 percent) had concentrations of 20 μg/L or larger. Areally, most of the samples with larger concentrations were from wells along or east of the Snoqualmie River, between Carnation and Duvall (plate 4). Median concentrations were 2 μg/L or less for all geohydrologic units except Q(A)f and Q(A)c, which had median concentrations of 12 and 6 μg/L, respectively. The current USEPA maximum contaminant level (MCL) for arsenic is 50 μg/L, however that value is being reviewed and may be lowered to 3 μg/L or less. Therefore some concern over the arsenic present is warranted.

Table 10.--*Summary of concentrations of selected trace elements*

[Concentrations in micrograms per liter unless otherwise noted. All are dissolved concentrations. Values are for samples from 124 wells and springs; <, not detected at the given concentration; pCi/L, picocuries per liter]

Element	Concentrations Minimum	 25th percentile	 Median	 75th percentile	 Maximum	Wells with trace element present Number	 Percent
Arsenic	<1	<1	2	8	77	79	64
Barium	<2	2	5	9	75	98	79
Cadmium	<1	<1	<1	<1	<1	0	0
Chromium	<1	<1	<1	<1	5	21	17
Copper	<1	<1	1	4	180	69	56
Lead	<1	<1	<1	<1	5	4	3
Mercury	<.1	<.1	<.1	<.1	.8	8	6
Selenium	<1	<1	<1	<1	<1	0	0
Silver	<1	<1	<1	<1	<1	0	0
Zinc	<3	5	15	62	550	106	85
Radon (pCi/L)[1]	<80	165	250	340	530	[1]15	88

[1] Based on 17 samples.

The source of the arsenic in the ground water is probably natural. Arsenic is present in many igneous rocks, such as andesite, diorite, and basalt, which are common in the Br unit. Igneous rocks are also a source of much of the material in the unconsolidated, glacial units. Furthermore, arsenic tends to concentrate in alumino-silicate minerals and igneous rocks that contain iron oxide (Welch and others, 1988), both of which are present in the study area. Elevated concentrations of arsenic have been documented in nearby areas of western Washington and are thought to be due to natural conditions. In particular, in Snohomish County to the immediate north of the study area, concentrations as large as 15,000 µg/L have been observed (Ficklen and others, 1989). Frost and others (1991) also found considerable seasonal variations in arsenic concentrations in Snohomish County and recommended additional sampling of wells with samples having concentrations larger than 10 µg/L.

Radon concentrations ranged from <80 pCi/L (picocuries per liter) to 530 pCi/L, with a median concentration of 250 pCi/L. (The picocurie is a measure of radioactivity, not mass.) Radon is a naturally occurring element and is part of the radioactive decay chain of uranium. Radon concentrations showed no areal or geohydrologic patterns. The USEPA has proposed an MCL of 300 pCi/L, so there may be cause for concern in the study area. However, the radon concentrations observed in east King County are less than those found in ground water in Clark and Thurston Counties, where radon concentrations ranged from <80 to 820 pCi/L and <80 to 660 pCi/L, respectively, with median concentrations of 315 and 410 pCi/L (Turney, 1990; Dion and others, 1994). The concentrations in east King County are not large compared with some other areas of the nation, such as Maine, where concentrations in excess of 10,000 pCi/L have been observed in water from granitic formations.

Barium was present in 98 samples (79 percent), ranging in concentration from <2 to 75 µg/L (table 10); the median concentration was 5 µg/L. The presence of some barium is natural, and concentrations were well below the MCL of 2,000 µg/L, so the presence of barium poses no concern.

Copper and zinc were present in most samples, and the concentrations were highly variable (table 10). This is because a major source of the copper and zinc is pipe used in wells and in home plumbing systems. These metals may be leached from the pipes, especially if the water is slightly acidic and low in dissolved-solids concentration, as is much of the ground water in east King County. Concentrations of copper and zinc were well within applicable drinking water regulations in all cases.

The remaining trace elements, rarely present, were not found at significant concentrations when compared with USEPA standards. Chromium was present in 21 samples (17 percent) but the maximum concentration was 5 µg/L. Such a level is likely due to the natural occurrence of chromium in the mineral matrix. Lead was present in only four samples (3 percent) with a maximum concentration of 5 µg/L. Like copper and zinc, lead may come from plumbing systems, specifically the lead-based solder used in some older homes. Mercury was present in eight samples (6 percent) at concentrations as large as 0.8 µg/L. However, there are no obvious ground-water sources for the mercury, natural or otherwise. The mercury could be due to isolated instances of sample contamination from the mercuric chloride preservative used for the nutrient samples, but mercury was not found in any of the quality-assurance samples collected. Finally, cadmium, selenium, and silver were not detected in any samples.

Volatile Organic Compounds

Of the individual volatile organic compounds listed in table 11, none were detected in any of the samples collected from 11 wells (plate 4). Any volatile organic

Table 11.--*Summary of concentrations of volatile organic compounds*

[Volatile organic compounds listed are those analyzed for in samples from 11 wells. None was present at the detection limit of 0.2 micrograms per liter]

Constituents
Chloromethane
Dichloromethane
Trichloromethane
Tetrachloromethane
Bromomethane
Dibromomethane
Tribromomethane
Bromodichloromethane
Dibromochloromethane
Trichlorofluoromethane
Dichlorodifluoromethane
Chloroethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1,1-Trichloroethane
1,1,2-Trichloroethane
1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
1,2-Dibromoethane
Chloroethene
1,1-Dichloroethene
1,2-Dichloroethene
Trichloroethene
Tetrachloroethene
1,2-Dichloropropane
1,3-Dichloropropane
2,2-Dichloropropane
1,2,3-Trichloropropane
1,1-Dichloropropene
cis 1,3-Dichloropropene
trans 1,3-Dichloropropene
Benzene
Chlorobenzene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Bromobenzene
Toluene
2-Chlorotoluene
4-Chlorotoluene
Dimethylbenzene
Ethylbenzene
Ethenylbenzene

compound detected generally has an anthropogenic source. As discussed earlier, the wells sampled were selected because they were in more populated areas, increasing the likelihood of detecting these compounds. Because none was detected, it may therefore be concluded that no widespread sources of these compounds exist. However, because the 11 wells sampled provide a limited geographic coverage of the study area, smaller localized sources of these compounds may remain undetected.

Pesticides

Samples from 12 wells were analyzed for concentrations of chlorophenoxy and triazine herbicides (table 12, plate 4). These groups of pesticides include many of those commonly used within the study area. Of these pesticides, only dicamba and 2,4-D were detected in any samples. Dicamba and 2,4-D are used for weed control in many different applications in the study area. None of the triazine herbicides was detected.

Dicamba was present at a small concentration of 0.01 µg/L in samples from three wells (table 13). Well 25N/07E-21C01 is located near a Christmas tree farm, and well 25N/07E-28Q01 is next to a pasture with 50 to 100 head of cattle. The wells are 35 and 25 feet deep, respectively, so the presence of dicamba may be related to the nearby agricultural activities. Moderate levels of nitrate also are present in both samples, so some type of contamination appears probable. Well 26N/06E-13D03 is in a city park and near a major State highway, and pesticides used

Table 12.--*Summary of concentrations of selected pesticides*

[Concentrations in micrograms per liter. The chlorophenoxy herbicides are total concentrations and the triazine herbicides are dissolved concentrations. Values are from samples from 12 wells; <, not detected at given concentration]

	Concentrations			Number of wells where pesticide was detected
Pesticide	Minimum	Median	Maximum	
Chlorophenoxy herbicides				
2,4-D	<0.01	<0.01	0.02	1
2,4-DP	<.01	<.01	<.01	0
2,4,5-T	<.01	<.01	<.01	0
Silvex	<.01	<.01	<.01	0
Dicamba	<.01	<.01	.01	3
Picloram	<.01	<.01	<.01	0
Triazine herbicides				
Alachlor	<.05	<.05	<.05	0
Ametryn	<.05	<.05	<.05	0
Atrazine	<.05	<.05	<.05	0
Cyanazine	<.2	<.2	<.2	0
De-ethylatrazine	<.05	<.05	<.05	0
De-isopropyl atrazine	<.05	<.05	<.05	0
Metolachlor	<.05	<.05	<.05	0
Metribuzin	<.05	<.05	<.05	0
Prometon	<.05	<.05	<.05	0
Prometryn	<.05	<.05	<.05	0
Propazine	<.05	<.05	<.05	0
Simazine	<.05	<.05	<.0.5	0

Table 13.--*Concentrations of pesticides in samples where they were detected*

[Concentrations in micrograms per liter except where indicated. All are total concentrations; <, not detected at given concentration]

Local well number	Well depth (feet)	2,4-D	Dicamba	Nitrate (mg/L as nitrogen)
24N/07E-08A02	39	0.02	<0.01	4.4
25N/07E-21C01	35	<.01	.01	.32
25N/07E-28Q01	25	<.01	.01	1.2
26N/06E-13D03	215	<.01	.01	<.05

in the maintenance of these areas might be a possible source of dicamba. However, the well is 215 feet deep and flowing, so it is unlikely that surface contaminants from the immediate vicinity of the well can migrate deeply enough in the ground-water system to enter the well. A more distant source of contaminants is likely for this well.

The 2,4-D was detected in only one sample, from well 24N/07E-08A02, at a concentration of 0.02 µg/L (table 13). This well is 39 feet deep, and some agricultural activities, including a berry farm and a dairy farm are in the vicinity. The nitrate concentration is large, 4.4 mg/L, so some contamination is present. However, given the widespread use of 2,4-D in various applications, including use on private lawns and gardens, it is not possible to determine the source at this time.

Septage-Related Compounds

Concentrations of methylene blue active substances (MBAS), boron, and dissolved organic carbon (DOC) were determined for samples from 19 wells (plate 4) located mostly in areas with septic systems. Nitrate is also a septic-related compound, and has been discussed earlier. MBAS and boron are present in household waste-water as detergent residues and have been identified in septage-contaminated ground water (LeBlanc, 1984). Large concentrations of DOC may indicate the presence of several types of organic compounds, including septage compounds, oil and grease, or solvents. The concentrations of MBAS, boron, and DOC, in conjunction with nitrate, can provide an indication of the degree of ground-water contamination from septic tanks.

MBAS were not detected in any of the samples (table 14). The median value of <0.02 mg/L is less than 0.02 mg/L, the concentration above which ground-water quality can be considered degraded (Hughes, 1975). The lack of MBAS in the ground water does not by itself lead to the conclusion that septic tanks are not contributing to ground-water contamination. However, in conjunction with the overall small nitrate concentrations observed in the study area, contamination by septic tanks on a large areal scale does not appear likely. A meaningful statistical correlation between MBAS and nitrate could not be made because MBAS was not detected in any of the samples. A good correlation might be seen if the two had a similar source, such as septic tanks. Such a correlation was observed in Thurston County (Dion and others, 1994).

The median concentration of boron, 10 µg/L, was also quite low (table 14). Samples from only three wells had concentrations exceeding 20 µg/L, and the maximum concentration of 120 µg/L was observed in a sample from well 25N/07E-15C01. Although these elevated boron concentrations could be associated with septic systems, the boron concentrations correlated poorly with nitrate; a better correlation might have been observed if septic systems were the true source. It is likely that the elevated boron concentrations are merely due to natural causes. Natural boron concentrations in excess of 100 µg/L are actually common (Hem, 1985).

Most DOC concentrations were 1.0 mg/L or less (table 14). The median concentration was 0.5 mg/L, smaller than the value of 0.7 mg/L given by Thurman (1985) as the median concentration of DOC in ground waters throughout the United States. Samples from only three wells had concentrations exceeding 1.0 mg/L, and the maximum concentration was 1.6 mg/L. Overall, the correlations of DOC concentrations with nitrate and boron concentrations were low. Given the diversity of sources and the lack of correlation with other septage-related

Table 14.--*Summary of concentrations of septage-related compounds*

[Concentrations are in milligrams per liter unless otherwise noted. All except methylene blue active substances are dissolved concentrations. Based on samples from 19 wells; <, not detected at given concentration; µg/L, micrograms per liter]

Constituent	Minimum	25th percentile	Median	75th percentile	Maximum
Methylene blue active substances (MBAS, or detergents)	<0.02	<0.02	<0.02	<0.02	<0.02
Boron (µg/L)	<10	<10	10	20	120
Dissolved organic carbon (DOC)	.2	.4	.5	.8	1.6

compounds, it is difficult to attribute the few larger concentrations of DOC to septic systems. In addition to the anthropogenic sources of DOC mentioned, there are several natural sources, including surface organic matter and kerogen, the fossilized organic matter present in most aquifer materials (Thurman, 1985).

Bacteria

Bacteria were present in samples from 16 of 121 wells and springs (3 wells were not sampled for bacteria). Fecal streptococci were present in all 16 samples and 2 samples also contained fecal coliform (table 15). Median concentrations of both fecal-coliform and fecal-streptococci bacteria were less than 1 colony per 100 milliliters. Both types of bacteria are indicators; they are not normally pathogenic themselves, but they can be indicative of pathogenic bacteria. A quantitative relation between fecal coliform and salmonellae (a pathogen) has been observed (Geldreich and Van Donsel, 1970).

The sites from which samples contained bacteria are listed in table 16. Some of the wells, including 26N/07E-06K01 and 26N/07E-33Q02, were located near pastures, which suggests that farm animals may be a source of the bacteria. Other wells were near septic tanks, another potential source of bacteria. Nitrate concentrations in most bacteria-contaminated wells were less than 1.0 mg/L, and most of the wells were over 100 feet deep, suggesting a source other than local septic systems or animal wastes. Areally, half of the samples having bacteria were collected from wells in township 26N/07E, east of Duvall. Nevertheless, most samples from that township contained no bacteria, and the presence of bacteria in ground water in the study area appears to have been limited to isolated areas.

Drinking Water Regulations

The USEPA has established drinking water regulations with several sets of laws. Two sets of regulations were applicable when these samples were collected. Primary drinking water regulations generally concern chemicals that affect human health. The maximum concentration allowed for each constituent is referred to by the USEPA as the maximum contaminant level (MCL) (U.S. Environmental Protection Agency, 1988a, 1988b, 1989, 1991), and is legally enforceable by the USEPA or State regulatory agencies. Secondary drinking water regulations (U.S. Environmental Protection Agency, 1988c, 1991) pertain to the esthetic quality of water and are guidelines only. A secondary maximum contaminant level (SMCL) is not enforceable by a Federal agency. Both sets of regulations legally apply only to public supplies, but can also be used to help assess the quality of private systems.

The drinking water regulations for all constituents analyzed in this study are shown in table 17. Because the regulations are subject to revision, this report uses the MCL or SMCL in effect at the time the samples were collected. Along with each MCL or SMCL, the number of wells from which samples did not meet the regulation is also shown in table 17.

Table 15.--*Summary of concentrations of bacteria*

[All concentrations are in colonies per 100 milliliters; <, not detected at given concentration; >, concentration is greater than the given value]

Bacteria type	Concentrations			Number of wells sampled	Number of wells with bacteria present	Number of springs with bacteria present
	Minimum	Median	Maximum			
Fecal coliform	<1	<1	>60	121	2	0
Fecal streptococci	<1	<1	17	121	15	1

Table 16.--*Concentrations of bacteria in samples where they were detected*

[mg/L, milligrams per liter; cols. per 100 mL, colonies per 100 milliliters; <, not detected at given concentration; >, concentration is greater than the given value]

Local well number	Geo hydro-logic unit	Depth of well (feet)	Nitrate (mg/L as nitrogen)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)
23N/08E-13N01	Qal	194	0.40	<1	1
23N/08E-22A01	Qal	18.2	.30	<1	7
24N/06E-10H02	Qva	155.2	[1]1.4	<1	[1]7
24N/07E-10K01	Qal	36	<.05	>60	2
24N/08E-24Q01S	Br	Spring	.55	<1	1
24N/08E-26K01	Qal	59	.49	<1	1
25N/06E-34D01	Qva	214	.53	<1	1
25N/07E-34E02	Qvr	220	.64	<1	8
26N/07E-03M01	Br	160	<.05	<1	1
26N/07E-06K01	Br	40	2.7	5	7
26N/07E-08A01	Br	120	1.6	<1	1
26N/07E-14G02	Br	182	.10	<1	2
26N/07E-19J02	Q(A)f	416	<.05	<1	17
26N/07E-20E01	Qva	260	.40	<1	2
26N/07E-33Q02	Qvr	134	2.7	<I	1
26N/07E-35D01	Qva	138	<.05	<1	2

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[1] Average value for two samples.

Table 17.--*Drinking water regulations and the number of samples not meeting them*

[mg/L, milligrams per liter; µg/L, micrograms per liter; cols. per 100 mL, colonies per 100 milliliters]

Constituent	Maximum contaminant level (MCL) or secondary MCL (SMCL)	Number of wells with samples not meeting MCL or SMCL	Percentage of wells not meeting MCL	Total number of wells sampled
	Primary drinking water regulations (MCLs)			
Inorganic				
Fluoride	4 mg/L	0	0	124
Nitrate (as nitrogen)	10 mg/L	0	0	124
Arsenic	50 µg/L	1	1	124
Barium	2,000 µg/L	0	0	124
Cadmium	5 µg/L	0	0	124
Chromium	100 µg/L	0	0	124
Lead	50 µg/L	0	0	124
Mercury	2 µg/L	0	0	124
Selenium	50 µg/L	0	0	124
Silver	50 µg/L	0	0	124
Organic				
Trihalomethanes[1]	100 µg/L	0	0	11
Tetrachloromethane	5 µg/L	0	0	11
1,2-Dichloroethane	5 µg/L	0	0	11
1,1,1-Trichloroethane	200 µg/L	0	0	11
1,2-Dibromoethane	.05 µg/L	0	0	11
Chloroethene	2 µg/L	0	0	11
1,1-Dichloroethene	7 µg/L	0	0	11
cis 1,2-Dichloroethene[2]	70 µg/L	0	0	11
trans 1,2-Dichloroethene[2]	100 µg/L	0	0	11
Trichloroethene	5 µg/L	0	0	11
Tetrachloroethene	5 µg/L	0	0	11
1,2-Dichloropropane	5 µg/L	0	0	11
Benzene	5 µg/L	0	0	11
Chlorobenzene	100 µg/L	0	0	11
1,2-Dichlorobenzene	600 µg/L	0	0	11
1,3-Dichlorobenzene	600 µg/L	0	0	11
1,4-Dichlorobenzene	75 µg/L	0	0	11
Toluene	1,000 µg/L	0	0	11
Xylene	10,000 µg/L	0	0	11
Ethylbenzene	700 µg/L	0	0	11
Ethenylbenzene	100 µg/L	0	0	11

Table 17.--*Drinking water regulations and the number of samples not meeting them--Continued*

Constituent	Maximum contaminant level (MCL) or secondary MCL (SMCL)	Number of wells with samples not meeting MCL or SMCL	Percentage of wells not meeting MCL	Total number of wells sampled
	Primary drinking water regulations (MCLs)--Continued			
Organic				
2,4-D	70 µg/L	0	0	12
Alachlor	2 µg/L	0	0	12
Atrazine	3 µg/L	0	0	12
Silvex	50 µg/L	0	0	12
Microbiological				
Total coliform[3]	0 cols. per 100 mL	2	2	121
	Secondary drinking water regulations (SMCLs)			
Inorganic				
pH	6.5-8.5 units	27	22	124
Sulfate	250 mg/L	0	0	124
Chloride	250 mg/L	0	0	124
Fluoride	2 mg/L	1	1	124
Dissolved solids	500 mg/L	1	1	124
Iron	300 µg/L	14	11	124
Manganese	50 µg/L	36	29	124
Copper	1,000 µg/L	0	0	124
Silver	100 µg/L	0	0	124
Zinc	5,000 µg/L	0	0	124
Organic				
MBAS (methylene blue active substances)	.5 mg/L	0	0	19

[1] Includes trichloromethane, tribromomethane, bromodichloromethane, and dibromochloromethane.

[2] The concentration for these two compounds is reported in the data tables as a combined concentration under 1,2-dichloroethene.

[3] The presence of fecal-coliform bacteria indicates that this standard has been exceeded.

The only primary MCL that was not met was the one for arsenic; one sample, from well 26N/06E-14D01, had an arsenic concentration of 77 µg/L. The arsenic MCL of 50 µg/L is based on the concentration at which arsenic can cause chronic poisoning if continually ingested. The current MCL does not take into account the carcinogenic effects of arsenic, but the USEPA is considering lowering the MCL, possibly to 3 µg/L or less, on the basis of these carcinogenic effects. Samples from 42 wells (34 percent) would not meet a lower MCL of 3 µg/L.

Total coliform bacteria were not analyzed for, but the presence of fecal-coliform bacteria in samples from two sites implies that this MCL was exceeded. The presence of fecal-coliform bacteria suggests some type of contamination, and as such, is considered a drinking water problem.

More samples did not meet the SMCL for manganese than for any other constituent. Of 124 wells sampled, samples from 36 (29 percent) did not meet the SMCL of 50 μg/L. However, as described previously, these large manganese concentrations are natural and common. The SMCL for manganese is based on the level at which laundry and plumbing fixtures may be stained (the stain is usually black or purple). The taste of the water may also be affected at concentrations greater than 50 μg/L. Extremely large concentrations of manganese may cause human health problems, but no such concentrations have ever been reported in the United States (U.S. Environmental Protection Agency, 1986).

Concentrations of iron in samples from 14 wells (11 percent) did not meet the SMCL of 300 μg/L for iron. As with manganese, these large concentrations are likely due to natural causes. Iron concentrations exceeding the SMCL may cause objectionable tastes and may stain plumbing fixtures a characteristic red or brown color. Some industrial applications, such as paper production, food processing, and chemical production, may require concentrations less than 300 μg/L.

Samples from 27 wells (22 percent) had pH values outside the acceptable range of 6.5 to 8.5. Of these, 10 (8 percent) had values less than 6.5 and 17 (14 percent) had values greater than 8.5. The SMCL for pH is based on several criteria (U.S. Environmental Protection Agency, 1986). The range used is based on the acceptable pH limits for marine aquatic life, which are not directly applicable to ground-water systems. A pH range from 5 to 9 is usually considered acceptable for domestic uses (U.S. Environmental Protection Agency, 1986), and samples from only four wells were above this range. None had a pH value below this range. Water with small pH values may be corrosive to pipes and plumbing and can increase copper, lead, zinc, and cadmium concentrations. Water with large pH values may adversely affect the chlorination process and may cause carbonate deposits to form in pipes.

The SMCLs of 500 mg/L for dissolved solids and 2 mg/L for fluoride each were exceeded once, in the same sample. The sample collected from well 23N/08E-08K01 had a dissolved-solids concentration of 551 mg/L and a fluoride concentration of 2.5 mg/L. The source of these elevated concentrations is most likely natural. The SMCL for dissolved solids is based mostly on taste, although other undesirable properties such as corrosiveness or hardness may be associated with large dissolved-solids concentrations. The SMCL for fluoride is based on the concentration at which teeth may become mottled.

The USEPA is in the process of establishing an MCL for radon. A value of 300 pCi/L was under consideration at the time of this study. Samples from five wells (29 percent) would not meet this proposed MCL.

All other applicable USEPA drinking water regulations were met. For certain constituents, even if the MCL for a particular regulation was met, the presence of the constituent indicates contamination. This is especially true for the organic compounds 2,4-D and dicamba. As discussed previously in this report, because these compounds don't occur naturally their mere presence indicates some degree of contamination.

Because the study was designed to determine large-scale areal variation, the areal density of wells may have been too sparse to detect relatively small areas where drinking water regulations were not met. The identification of small areas of contamination was outside the scope of this study.

For more information on drinking water regulations, refer to documents of the U.S. Environmental Protection Agency (1976, 1986, 1988a, 1988b, 1988c, 1989, 1991).

Factors Affecting Water Quality

Although elevated constituent concentrations in ground water were not observed over large areas of east King County, isolated occurrences of elevated concentrations have been identified and attributed to one or more potential contamination sources. Sometimes the elevated concentrations are a health concern; at other times they affect only the esthetic qualities of the water. In either instance, a water-quality problem exists, and it is helpful to better understand the source and its impact on water quality and water chemistry. A complete description of all the sources of water-quality problems in east King County is beyond the scope of this report. However, brief discussions of the more important sources of ground-water-quality problems are presented below. In addition to the source, the extent and severity of water-quality problems depend on many geohydrologic conditions, such as aquifer mineralogy, ground-water flow direction and rate, depth to water, recharge rate, and water chemistry.

Agricultural Activities

Agricultural activities in the study area include crop production, dairy farming, livestock production, and forestry. These activities can result in several types of water-quality problems, most commonly the presence of various nitrogen species, pesticides and associated compounds, and bacteria. Sulfate, chloride, and phosphorous also may be present. Most problems are related to fertilizer or pesticide application, or barnyard wastes.

Virtually all fertilizers include some type of nitrogen. In some, the nitrogen is part of a solid organic compound and is released over several days or weeks to the soil; in others, an aqueous solution of nitrogen, usually as ammonia, is injected directly into the soil and is released immediately. Any nitrogen is usually converted by bacteria to nitrite and then to nitrate during the process of nitrification. Some nitrate is then taken up by crops. Any remaining nitrate may be transported down through the soil and the unsaturated zone to the water table. Nitrate generally does not sorb, or attach, to the aquifer material, therefore it is transported at a rate similar to that of the ground water. In some instances, unconverted nitrogen may be transported to the ground water, either as ammonia or as part of an organic compound. Ammonia tends to sorb to soil particles, so it may not be transported as quickly as nitrate. Usually, any ammonia or ammonia compound reaching the ground water ultimately will be converted to nitrate. Fertilizers also contain other chemicals that may be introduced into the ground water, such as potassium, sulfate, and phosphorous, but the resulting effects on natural concentrations are usually minimal.

Barnyard wastes, including those from dairies and feedlots, contain urea, chloride, and bacteria, along with other constituents in smaller quantities. Urea is eventually converted to nitrate, which is transported to the aquifer in a manner similar to nitrate from fertilizers. Chloride is generally unreactive and will also be transported to the water table. Many different types of bacteria are present in barnyard wastes, including the indicator bacteria (fecal coliform and fecal streptococci) analyzed for in this study. Their transport to and within the ground water depends on such factors as depth to water and water temperature, which greatly affects bacterial survival. Other constituents that may also be transported to the ground water from barnyard wastes are sodium, potassium, sulfate, and phosphorous, but natural sources generally mask these contributions.

The transport of pesticides and their associated compounds to the ground water is complex. Most pesticides undergo chemical and biological transformations as part of one or more of the following processes: biodegradation, photolysis, hydrolysis, or oxidation. The products of these reactions may be as great a contamination problem as the original pesticide. Also, solvents and carriers, such as toluene, are applied with pesticides to assure an even application of the pesticide and can themselves become contaminants. The transport of all these pesticide-related compounds is affected by physical processes such as dissolution in the water, sorption to aquifer material, and volatilization to the atmosphere as soil gas. Because all of these variables, the occurrence of pesticides in ground water can vary widely over both space and time.

One group of agricultural activities that is not included in the above assessment is that which is sometimes referred to as hobby farming. Hobby farming consists of agricultural activities similar to those discussed, but on a smaller scale for private rather than commercial use. Examples include backyard gardens, pet pens or corrals, and lawns. Most hobby farms are in suburban or urban areas, and as such are not considered commercial agricultural activities. However, pesticide and fertilizer use is extensive, and these chemicals are commonly overapplied because of a lack of knowledge, experience, or motive for cost effectiveness. Little documentation has been done on hobby farming, but researchers have reported that urban lawn fertilizers may contribute as much nitrate to ground water as do septic systems (Porter, 1980).

The most important agriculture-related water-quality problem identified in east King County is the presence of small amounts of pesticides in samples from 4 of 12 sampled wells. Three samples contained dicamba and the fourth contained 2,4-D. The occurrences were isolated and likely were due to local sources of pesticides; however, the exact sources have not been positively identified. Production agriculture is a likely source in some instances, but hobby farming activities or nonagricultural activities, such as roadside spraying for weed control, are also possible sources.

Barnyard wastes likely contributed to elevated nitrate concentrations in a few isolated instances, but this does not appear to be a widespread problem. The overall small nitrate concentrations indicate there are likely no large inputs from barnyards, or, for that matter, any agricultural sources. The data may be somewhat misleading because few shallow wells were available to sample in the northern part of the Snoqualmie River Valley, where several dairy farms are located. However, ground water likely discharges directly to the river in this area, so contamination could be present in the shallow ground water and transported directly to the river without entering the deeper ground-water system. Such contamination could go undetected because the shallow ground water is not used extensively and the contaminants are greatly diluted in the river.

Septic Systems

A septic system, consisting of a septic tank and drainfield, can be a source of several constituents in ground water. The most familiar of these is nitrate, but others are sodium, potassium, sulfate, chloride, phosphorous, ammonia, boron, MBAS, and bacteria. Because septic systems are used virtually everywhere that central sewer systems are not available, they can be a widespread source of these constituents and may remain so even after they are abandoned.

In the operation of a septic system, household sewage is piped into a tank that has an average capacity of approximately 1,000 to 1,500 gal for a single household unit. In the tank, solids settle to the bottom and liquids discharge to a drainfield, which is a subsurface trench filled with permeable material such as sand or gravel. This allows the liquid to infiltrate the natural soil or geologic formation over a large area. Ultimately, the effluent flows through the unsaturated zone to the ground water. Where septic tanks are used in densely populated areas, the combined discharge from them may be a large component of the total ground-water recharge.

Once in the unsaturated zone, the individual constituents in the effluent are susceptible to the same chemical and biological transformations as constituents that originate at land surface. Urea is transformed to ammonia and eventually to nitrate. The nitrate, along with chloride, then flows through the aquifer at a rate similar to the ground water. Sodium, potassium, sulfate, MBAS, and other constituents, however, may undergo sorption, ion exchange, or degradation reactions that can hinder their transport to and within the ground water.

As with agricultural activities, the small overall nitrate concentrations observed in this study indicate that septic tanks are not contributing to water-quality problems on a large areal basis. The low MBAS, boron, and DOC concentrations, and lack of correlation among them and nitrate concentrations, support this conclusion. However, some isolated large nitrate concentrations are likely due to instances of local contamination by septic tanks.

Commercial and Industrial Activities

Commercial and industrial activities in east King County are minimal, but in some of them, chemicals are used that are potential ground-water contaminants. Service stations are sources of benzene and benzene-related compounds from fuels and oils. Dry cleaners and paint shops are potential sources of solvents such as 1,1,1-trichloroethane and trichloroethene. Solvents, along with metals such as chromium, copper, zinc, and lead, can come from electronic, machine, and automotive-repair shops. Parking lots and roads may also be sources of many of these chemicals. In general, most of the chemicals are volatile organic compounds or trace elements. Industrial activities such as shipping, manufacturing, and food processing can also be sources of these chemicals, but there are few of these activities in east King County. Roadside spraying to inhibit the growth of vegetation along road shoulders is a possible source of pesticides in the ground water, but this practice is diminishing in the study area.

Chemicals are sometimes spilled or dumped onto the ground where they are dissolved or otherwise incorporated into the recharge water. Also, runoff water from impervious areas, such as roads and parking lots, can carry chemicals to permeable areas and into the ground. In the case of large spills of liquids such as fuels or oils, the chemicals may travel into the unsaturated zone unaltered. In other instances the chemicals may reach the ground water only after being subjected to physical or chemical transformation processes, such as volatilization, sorption, biodegradation, hydrolysis, or oxidation. As a result, the contaminants in ground water may include any of the compounds initially spilled or their transformation products.

Contamination of east King County ground water by commercial and industrial activities appears to be minimal. No volatile organic compounds were detected, but the presence of pesticides in samples from four wells could be related to roadside spraying, in addition to agricultural sources. No large concentrations of trace elements were associated with these activities.

Natural Conditions

Most of the water-quality problems in the study area were due to natural conditions. Large concentrations of arsenic, iron, and manganese are the most widespread problems, and the chemistry of those three elements was discussed previously. Elevated radon concentrations and pH values outside of the accepted range are also due to natural causes.

NEED FOR MONITORING AND ADDITIONAL STUDIES

Many gaps or deficiencies in the available data were noted during the course of this study. In some instances, a reported calculation or number was not as accurate as would be preferred; in others, entire geographic areas could not be considered because there were no data available. Sometimes questions were raised that would require more data in order to be answered. Listed below are the major information gaps that were identified, with no implied priority.

There are few long-term (5 years or more) water-level data sets for the area as a whole. As part of this study, water levels were measured monthly in more than 40 wells beginning in May 1991. This effort could be continued, with a reduced number of wells. A representative mix of geohydrologic units, however, needs to be maintained. The resulting data would provide a good baseline for ground-water levels and allow the delineation of future trends.

Throughout much of the study area, and especially in the Snoqualmie River Valley, the depth to bedrock, and therefore the thickness of the potential water-bearing sediments, is unknown. Geophysical work in the Snoqualmie River Valley would help determine the geometry of the underlying bedrock. This also would help answer questions about the dimensions of the valley fill and its potential as a significant source of ground water. The information gathered would help to guide any future drilling efforts.

In three major areas--the Snoqualmie River Valley, the Sammamish Plateau, and the Cascade Range foothills --the geologic framework could not be readily determined because of a lack of deep wells. There are presently (1992) few wells of any depth in the Cascade Range foothills, east of the Snoqualmie River, because this area has not been developed. Nevertheless, if the ground-water resource is to be further investigated or developed in any coordinated manner, more deep wells (500 to 1,000 ft deep) will be needed in these three areas to further define the geologic framework.

The effects of ground-water development on the ground-water system and the Snoqualmie River cannot be reasonably estimated or quantified at present. A ground-water model of the Snoqualmie River Valley would help predict these effects and would be valuable if the ground-water resource in the valley is developed further. Some additional data would be required, however, to construct and calibrate the model.

There are virtually no long-term water-chemistry data available for the study area. Water samples could be collected from selected wells quarterly and analyzed for concentrations of nitrate, bacteria, and arsenic. At the time of sampling, pH, specific conductance, dissolved oxygen, and temperature also could be measured. Twice a year, at times of the highest and lowest water levels, samples also could be collected and analyzed for concentrations of common ions and trace elements. These data could be compared with data collected in this study; this comparison would help identify any cyclic or long-term changes in water chemistry.

Pesticides were found in 4 of 12 wells sampled in the study area, but no other pesticide data for the study area exist. The wells where pesticides were present could be sampled twice more, during times of high and low water levels. Besides the pesticide groups analyzed for (chlorophenoxy and triazine herbicides), others should be considered, including the organochlorine and organophosphate pesticides. If any pesticides are present in the subsequent samples, a study to determine the sources could be undertaken. If no pesticides are present, samples could be collected from a dozen or so wells every 2 years and analyzed for concentrations of chlorophenoxy and triazine herbicides.

Although no volatile organic compounds were detected in samples collected in the study, few other data exist. Samples could be collected every 2 years from a network of a dozen or so wells and analyzed for concentrations of volatile organic compounds. The wells should be located in suburban and commercial areas.

Given the health implications of the widespread presence of arsenic in the ground water, it is important to understand its source, fate, and transport. A thorough geochemical study, investigating the mineralogy of the various units, water chemistry, and flow paths in relation to arsenic concentrations, would provide some insight into the specific conditions under which arsenic is present in ground water.

Excessive iron and manganese concentrations probably are the most widespread water-quality problems in the study area, and indeed, in the Puget Sound area. Although iron and manganese are generally not considered health threats (though some concerns are beginning to be voiced about that), they undoubtedly cause significant expenses because of the need for water-treatment systems and the replacement of stained plumbing fixtures, appliances, and clothing. A geochemical study, similar to that proposed for arsenic, would help identify the conditions under which large iron and manganese concentrations are present, and might help reduce the number of wells with related problems.

Any of these efforts, once implemented, would be reviewed annually and modified as necessary to make sure that goals and objectives continue to be met. This is especially true of the monitoring efforts. Also, monitoring and study efforts need to be integrated with other ongoing work. For example, the bacteria, nitrate, and volatile organic compound samplings could be coordinated with sampling required by the Washington State Department of Health, if possible.

SUMMARY AND CONCLUSIONS

East King County encompasses 250 mi^2 of King County east of Seattle and Lake Sammamish, and includes much of the Snoqualmie River Valley and Sammamish Plateau. The population in the study area tripled to about 56,500 from 1970 to 1990, and is projected to double from 1990 to 2020. This rapid population growth has brought an attendant increase in the demand for water, which, if growth continues as projected, will increase into the future. Ground-water resources have been developed to meet much of this present demand and probably will be developed further to meet the future needs.

The importance of ground water in east King County has led to, among other things, this study of the ground-water system with the following objectives:

(1) Describe and quantify the ground-water system to the extent allowed using available and readily collectable data;

(2) describe the general water chemistry of the major geohydrologic units and any regional patterns of contamination;

(3) evaluate the potential for ground-water development on the basis of aquifer characteristics, ground-water interaction with surface water, and ground-water recharge; and

(4) determine what additional data are needed to further quantify ground-water availability.

East King County is underlain by as much as 1,200 feet of Quaternary unconsolidated deposits, which are of both glacial and nonglacial origin. Beneath these unconsolidated deposits is bedrock, composed of Tertiary and pre-Tertiary consolidated rocks. A net of 12 geohydrologic sections was constructed and used to delineate 10 geohydrologic units. They are, in order of increasing geologic age:

(1) Quaternary alluvium (Qal);
(2) Vashon recessional outwash (Qvr);
(3) Vashon till (Qvt);
(4) Vashon advance outwash (Qva);
(5) Upper fine-grained unit (Q(A)f);
(6) Upper coarse-grained unit (Q(A)c);
(7) Lower fine-grained unit (Q(B)f);
(8) Lower coarse-grained unit (Q(B)c);
(9) Deepest unconsolidated and undifferentiated deposits (Q(C)); and
(10) Bedrock (Br).

In general, the unconsolidated deposits are lithologically variable and have a limited areal extent, especially to the southwest and east where these units begin to pinch out over the rising bedrock. The extent of Qal is limited to the floor of the Snoqualmie River Valley and its major tributaries, but the river has eroded away some of the older unconsolidated units so that Q(A)f is the youngest unit that is continuous from one side of the Snoqualmie River Valley to the other.

Units Qal, Qvr, Qva, and Q(A)c form the major aquifers of the study area, but usable quantities of ground water can sometimes be obtained from Br. Units Qvt and Q(A)f generally act as confining beds, although numerous wells produce water from local lenses of sand and gravel within these deposits. The deeper unconsolidated units, Q(B)f, Q(B)c, and Q(C) are tapped by a few wells, but it is likely that Q(B)f is a confining bed and Q(B)c may produce significant quantities of water. The productivity of Q(c) is unknown.

Precipitation is estimated to be 57 in/yr over the entire study area. Of this, 31 in. (413,000 acre-ft) is estimated to enter the ground-water system as recharge. Recharge, like precipitation, varies considerably throughout the study area, but tends to be largest in the east where precipitation is highest.

Within the major aquifers, some ground water in the study area flows toward the Snoqualmie River Valley, then northward up the valley and out of the study area. Ground water in much of the Sammamish Plateau flows westward, toward Lake Sammamish. Flow to the deeper regional ground-water system is unknown, but may be significant. Gradients range from less than 5 ft/mi in the Snoqualmie River Valley floor to more than 1,000 ft/mi over short distances near Snoqualmie Falls. Vertical flow tends to be downward in upland areas such as the Sammamish Plateau. In the lower Snoqualmie River Valley, vertical flows tend to be upward, resulting in several flowing wells in the valley floor near the base of the uplands. Median hydraulic conductivities ranged from 34 to 130 ft/day for the aquifers (Qal, Qvr, Qva, Q(A)c, and Q(B)c). The median hydraulic conductivities for confining units Q(A)f and Q(B)f were much lower, 9.0 and 15 ft/day, respectively. The median hydraulic conductivity for Qvt was 51 ft/day, relatively higher than most of the other units, including some of the aquifers. This was attributed to the heterogeneity of the unit and the fact that wells in Qvt tend to be preferentially completed in coarser zones. The median hydraulic conductivity of Br was only 0.88 ft/day, indicating it is not a reliable source of large quantities of water.

Ground water in the study area discharges as seepage to lakes and streams, spring flow, transpiration by plants, seepage to valley walls, ground-water flow out of the study area, and withdrawals from wells. Discharges to the Snoqualmie River and Lake Sammamish were estimated to total 98,500 acre-ft/yr, on the basis of low-flow measurements made in September 1991. Discharges to known major springs were estimated to be 9,540 acre-ft/yr, and ground-water withdrawals from wells were estimated to be 4,270 acre-ft/yr. The remaining 300,700 acre-ft of recharge is thought to discharge mostly as ground water flowing north and west out of the study area, but this estimate is high because the estimates of river and spring discharge and ground-water withdrawals are incomplete.

In addition to the 4,270 acre-ft of ground water withdrawn from wells in 1990, another 5,290 acre-ft of spring discharge was put to beneficial use. Of the 9,560 total acre-ft used, 4,460 acre-ft (47 percent) was used by Class I and Class II public supply systems, which supply water to 48,100 people, or 85 percent of the total population. An additional 2,280 acre-ft of water was imported from outside the study area to augment these public supplies. Some 3,010 acre-ft (31 percent), all from springs, was used for aquaculture. The remaining ground water used is primarily for domestic supplies, irrigation, and dairy cattle.

The chemical quality of ground water in the study area was typical for western Washington. Dissolved-solids concentrations ranged from 37 to 551 mg/L, with a median concentration of 115 mg/L, and tended to increase in the lower units. Some 95 percent of the water samples were classified as soft or moderately hard. The major cations were calcium and magnesium, but sodium was predominant in a few samples. The major anion was bicarbonate. Calcium/bicarbonate and calcium-magnesium/bicarbonate were the most common water types in samples from wells finished in the unconsolidated deposits. These water types also are typical of glacial deposits of western Washington. Sodium/bicarbonate and sodium-calcium/bicarbonate water types were common in Br.

Nitrate concentrations were small, ranging from <0.05 mg/L to 6.3 mg/L, with a median concentration of only 0.07 mg/L. These small concentrations suggest that there is no widespread contamination from septic tanks or agricultural activities. However, 20 percent of the nitrate concentrations exceeded 1.0 mg/L, and most of these came from samples from wells less than 100 feet deep. Local contamination from septic tanks, pastures, or lawn fertilizers is the probable source.

Water-quality problems in east King County, when present, were commonly due to natural causes. Iron concentrations were as large as 14,000 µg/L, and manganese concentrations were as large as 920 µg/L. At these levels, taste may be adversely affected and plumbing fixtures may be stained red, brown, or black. These problems were evident throughout much of the study area, and are common throughout western Washington. These large concentrations are due to the dissolution of iron and manganese present in the aquifer minerals.

Another natural water-quality problem, and perhaps the one of largest concern, is the presence of arsenic in ground water throughout much of the study area. Arsenic concentrations ranged from <1 to 77 µg/L, with a median concentration of 2 µg/L. Arsenic was present in samples from 79 wells (64 percent) and 18 samples (15 percent) had concentrations of 20 µg/L or larger. Most of the larger concentrations were from wells along or east of the Snoqualmie River, between Carnation and Duvall. The arsenic is likely natural, as it is commonly associated with igneous rocks that constitute much of the Br. Igneous rocks are also a source of much of the unconsolidated glacial material.

Radon concentrations ranged from <80 to 530 pCi/L, with a median concentration of 250 pCi/L. Radon concentrations observed in the study area are smaller than those observed in other areas of western Washington. The presence of other trace elements and the septage-related compounds was minimal. Concentrations exceeding natural levels were rare, and no water-quality problems were indicated.

No volatile organic compounds were detected in the samples collected from 11 wells. Although the absence of these compounds suggests industrial contamination is not widespread, it does not eliminate the possibility of their presence locally in the ground water.

The pesticide dicamba was present at a concentration of 0.01 µg/L in samples from 3 of the 12 wells sampled. In another sample, 2,4-D was present at a concentration of 0.02 µg/L. The presence of these pesticides suggests some type of contamination, possibly related to agricultural activities or road maintenance. Although these concentrations are small and no widespread contamination is evident, further investigation as to the potential sources may be warranted.

Concentrations of selected constituents were compared with maximum contaminant levels, or MCLs, for applicable USEPA drinking water regulations. The only primary MCL that was not met in all cases was the one for arsenic, which is 50 µg/L. One sample had an arsenic concentration of 77 µg/L. However, the USEPA is reviewing the arsenic MCL, and may lower it to 3 µg/L or less to consider the carcinogenic effects of arsenic. Samples from 42 wells (34 percent) would not meet this lower MCL. The presence of fecal-coliform bacteria in samples from two sites suggests the MCL for total coliform was not met. More samples did not meet the secondary maximum contaminant level (SMCL) for manganese than for any other standard. Some 29 percent of all wells had samples that did not meet the manganese SMCL of 50 µg/L. Likewise, 11 percent did not meet the SMCL of 300 µg/L for iron. The SMCL for pH was not met in 22 percent of the samples; 8 percent of the samples had values below the lower limit of 6.5, and 14 percent of the samples had values larger than the upper limit of 8.5. The SMCL of 500 mg/L for dissolved solids and 2 mg/L for fluoride were each not met once, in the same sample. This sample was collected from a well completed in bedrock and the dissolved-solids concentration of 551 mg/L and fluoride concentration of 2.5 mg/L are most likely due to natural conditions. All other applicable drinking water regulations were met, including those for trace elements and organic compounds. However, samples from five wells, or 29 percent, would not meet the proposed radon MCL of 300 pCi/L.

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APPENDIX A.--PHYSICAL AND HYDROLOGIC DATA FOR THE INVENTORIED WELLS AND SPRINGS

[--, not determined]

Explanation

Geohydrologic Unit:	Qal, alluvium; Qvr, Vashon recessional outwash; Qvt, Vashon till; Qva, Vashon advance outwash; Q(A)f, Upper fine-grained unit; Q(A)c, Upper coarse-grained unit; Q(B)f, Lower fine-grained unit; Q(B)c, Lower coarse-grained unit; Br, Bedrock; for more explanation, see figure 10 in the text.
Use of Water:	C, commercial; H, domestic; I, irrigation; N, industrial; P, public supply; R, recreational; S, stock; T, institutional; and U, unused.
Water Level:	Code indicates status of well at time of visit: F, flowing; P, pumping; R, recently pumping; S, nearby well pumping; and T, nearby well recently pumping.
Remarks:	L, driller's (lithologic) log available; W, project observation well for water level; M, sampled for major ions, bacteria, trace metals, and field parameters; V, sampled for volatile organic compounds; P, sampled for pesticides; and S, sampled for detergents, boron, and dissolved organic carbon.

Table A1.--*Physical and hydrologic data for the inventoried wells and springs*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
23N/07E-01C01	473042	1215124	Q(A)c	870	92	6	H	46.57 R	05-31-90	120	L
23N/07E-01C02	473045	1215121	Q(A)c	860	96	6	U	--	--	--	L
23N/07E-01D01	473047	1215143	Br	1,030	163	8	H	67.48	10-22-90	.10	L
23N/07E-02A01	473041	1215205	Br	980	140	6	P	41.80	09-19-90	17	L
23N/07E-02A02	473042	1215205	Br	983	180	6	P	44.36	09-19-90	--	L
23N/07E-02D01	473045	1215252	Br	985	379	8	U	40.61	07-10-90	--	--
23N/07E-02F01	473039	1215245	Br	970	170	8	P	--	--	3.6	L
23N/07E-02G01	473026	1215213	Br	920	78	8	H	3.11	05-31-90	69	L
23N/08E-03E02	473028	1214626	Qal	432	60	6	P	10.57	05-02-90	300	L
23N/08E-03F01	473028	1214620	Qal	428	49	6	H	5.53	05-02-90	11	L
23N/08E-03L03	473019	1214612	Qal	435	230	6	H	6.79 R	05-02-90	98	LWM
23N/08E-03P01	473009	1214619	Qal	437	35	6	H	4.45	05-02-90	32	L
23N/08E-04A01	473038	1214656	Qal	422	28	6	H	6.56 R	07-02-90	42	L
23N/08E-04G01	473037	1214706	Qal	418	36	6	H	7.06	05-03-90	51	L
23N/08E-04H01	473034	1214702	Qal	419	29.5	6	H	8.14	05-02-90	28	L
23N/08E-04L01	473012	1214730	Qal	430	47	6	1	8.75	06-05-90	--	LMVP
23N/08E-04P01	473012	1214733	Qal	430	22	33	U	6.85	05-03-90	--	--
23N/08E-05K01	473023	1214831	Qal	430	8.3	33	H	4.06	05-03-90	--	--
23N/08E-05K02	473015	1214822	Qal	430	39	6	H	4.96	05-03-90	220	LMVS
23N/08E-06F01	473038	1215014	Qva	970	80	6	C	5.68	09-06-90	250	L
23N/08E-08K01	472921	1214834	Br	680	240	6	H	35.10	05-09-90	--	LM
23N/08E-08K02	472927	1214827	Qvr	570	40	6	H	21.57	05-10-90	100	L
23N/08E-08K03	472927	1214823	Qvr	550	37	6	H	10.74	05-10-90	31	L
23N/08E-09J01	472926	1214701	Qal	443	16	36	R	8.76	05-03-90	--	W
23N/08E-10B01	472948	1214603	Qal	448	30	6	P	13.75	07-05-90	--	L
23N/08E-10F02	472934	1214618	Qal	450	14	36	U	4.98	05-03-90	--	--
23N/08E-10F03	472934	1214618	Qal	450	18.5	6	H	5.21	05-03-90	--	LMVS
23N/08E-10H01	472934	1214531	Qal	470	40	6	H	17.07	05-04-90	310	L
23N/08E-10J01	472919	1214543	Qal	473	78	8	H	9.06	05-10-90	--	--
23N/08E-10L01	472931	1214608	Qal	450	40	6	H	10.45	05-10-90	860	L
23N/08E-10P02	472910	1214622	Qal	463	50	8	H	12.74 R	05-04-90	1,000	L
23N/08E-12J01	472918	1214303	Qal	700	49	6	H	26.46	05-07-90	660	L
23N/08E-12J02	472920	1214255	Qvr	720	99	6	H	56.61	05-18-90	610	L
23N/08E-13G01	472837	1214329	Qal	650	183	8	H	136.32	11-29-90	74	L
23N/08E-13H01	472843	1214255	Qal	620	60	8	H	38.40	05-08-90	140	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
23N/08E-13N01	472812	1214354	Qal	595	194	8	H	75.01	05-07-90	78	LWM
23N/08E-13R01	472817	1214257	Qal	715	237	6	H	187.63	05-07-90	--	L
23N/08E-14B01	472902	1214438	Qal	555	81	6	H	43.01	05-08-90	310	L
23N/08E-14C01	472900	1214459	Qal	485	140	8	H	12.83	05-10-90	--	L
23N/08E-14G02	472838	1214438	Qal	510	57	6	H	21.95	05-08-90	--	L
23N/08E-14G03	472843	1214443	Qal	515	96	8	H	28.43	05-10-90	110	L
23N/08E-15A05	472859	1214543	Qal	484	43	6	H	16.97	05-09-90	180	L
23N/08E-15B05	472902	1214548	Qal	482	38	6	H	17.15	05-21-90	120	L
23N/08E-15D01	472904	1214627	Qal	462	53	8	H	11.04	05-11-90	920	L
23N/08E-15J06	472836	1214542	Qal	482	40	6	H	12.90	05-11-90	380	LWM
23N/08E-15K07	472827	1214556	Qal	475	57	6	H	8.77 R	05-11-90	--	L
23N/08E-15P01	472824	1214615	Qal	472	11	30	H	7.48	05-16-90	--	--
23N/08E-15P02	472827	1214615	Qal	470	12	30	I	4.93	05-16-90	--	--
23N/08E-16B01	472854	1214707	Qal	448	43	6	P	--	--	540	L
23N/08E-16C01	472858	1214740	--	525	41	6	U	37.08	05-22-90	--	--
23N/08E-16F01	472842	1214734	Br	650	400	6	H	89.19 R	05-15-90	15	L
23N/08E-16L01	472830	1214739	Br	750	415	6	H	115.48	06-01-90	.03	L
23N/08E-16M01	472834	1214739	Br	720	750	8	P	249.10 R	07-11-90	.12	LM
23N/08E-16Q01	472819	1214709	Br	510	53	6	H	8.17	05-16-90	6.6	L
23N/08E-22A01	472803	1214528	Qal	493.62	18.2	36	H	14.95	05-16-90	--	MVS
23N/08E-23A01	472808	1214430	Qal	525	60	8	P	--	--	--	L
23N/08E-23A02	472809	1214430	Qal	525	47	8	U	26.30 T	05-22-90	610	L
23N/08E-23A03	472811	1214430	Qal	525	62	8	P	--	--	--	L
23N/08E-23F02	472755	1214503	Qal	510	112	8	U	6.34	09-13-90	19	L
23N/08E-24A01	472807	1214258	Qal	680	207	8	C	153.97 R	05-17-90	160	L
23N/08E-24C01	472803	1214336	Qal	580	97	6	H	17.57 R	05-18-90	49	L
23N/08E-24H01	472754	1214314	Qal	610	119	8	H	70.31 R	05-22-90	--	L
23N/08E-24J01	472735	1214313	Br	580	178	8	H	5.20	05-30-90	2.2	LM
23N/08E-24J02	472735	1214304	Qal	590	25	8	U	3.05 P	05-30-90	--	L
23N/08E-25F01	472658	1214336	Qal	630	48	6	H	1.82	05-18-90	13	LM
23N/08E-25L01	472646	1214341	Qvt	660	82	6	H	14.07	05-18-90	2.2	L
23N/08E-25R01	472638	1214310	Qvr	780	78	6	H	48.25 R	05-21-90	150	L
23N/08E-25R02	472638	1214308	Qvr	780	215	6	H	161.52	05-30-90	49	L
23N/08E-26C01	472721	1214506	Br	795	144	6	U	57.82	05-21-90	--	--
23N/08E-26Q01	472638	1214439	Qvt	770	45	8	H	26.82 R	06-04-90	200	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo- hydro- logic unit	Land surface elev- ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia- meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure- ment (month/ day/year)	Hyd- raulic conduc- tivity (feet per day)	Remarks
23N/08E-27N01	472633	1214629	Br	1,130	240	6	H	28.89 R	05-31-90	0.17	L
23N/08E-27R01	472637	1214541	Qvr	975	196	6	U	66.31	06-14-90	--	L
23N/09E-07P01	472912	1214223	Qvr	875	111	6	H	102.73	06-29-90	--	L
23N/09E-07Q01	472905	1214215	Qal	860	99.5	6	H	59.00	06-28-90	--	L
23N/09E-18N01	472812	1214237	Qal	760	248	8	P	195.67	09-12-90	130	L
23N/09E-19N01	472718	1214249	Qal	590	54	6	H	1.52	06-29-90	28	L
24N/06E-01E01	473543	1215910	Qvr	450	17	20	U	--	--	--	--
24N/06E-02E01	473551	1220042	Qvt	530	40	6	P	11.84	07-09-90	220	LMS
24N/06E-02P01	473520	1220010	--	420	110	10	U	--	--	--	--
24N/06E-02P02	473518	1220011	--	420	100	6	U	--	--	--	--
24N/06E-03E01	473547	1220200	Qva	560.44	176	6	P	--	--	--	L
24N/06E-03P01	473529	1220136	Qva	380	68	6	U	26.68	07-10-90	28	L
24N/06E-03P02	473522	1220142	Qva	375	97	6	H	--	--	63	L
24N/06E-03R01	473519	1220054	Qvr	385	12	30	U	--	--	--	--
24N/06E-04J01	473533	1220220	Qvt	412.65	31.5	1.25	U	12.14	07-10-90	--	L
24N/06E-04K01	473533	1220235	Qvr	426.77	17	72	U	4.82	07-10-90	--	W
24N/06E-04N01	473527	1220302	Q(A)c	449	300	10	U	--	--	--	L
24N/06E-04N01P1	473527	1220302	Q(A)c	449	300	10	U	187.11	09-14-90	--	L
24N/06E-04N02	473527	1220303	Q(A)c	449	346	12	U	--	--	84	L
24N/06E-04N02P1	473527	1220303	Q(A)c	449	316	12	U	191.95	09-14-90	--	L
24N/06E-04N02P2	473527	1220303	Q(A)c	449	265	12	U	187.66	09-14-90	--	L
24N/06E-04P02	473519	1220257	Qvt	406.24	54.1	1.25	U	18.61	07-06-90	--	L
24N/06E-05D01	473606	1220416	Qal	130	6.5	36	U	3.61	07-13-90	--	--
24N/06E-05D02	473605	1220420	Qal	135	12	30	H	9.66	07-13-90	--	--
24N/06E-05H01	473551	1220324	Qva	350	153	6	H	--	--	--	L
24N/06E-06A05	473605	1220449	Q(A)c	25	87	6	H	-- F	07-10-90	1,100	LM
24N/06E-06J02	473542	1220448	Qva	125	143	6	H	51.38	07-13-90	46	L
24N/06E-08F01	473459	1220413	Q(A)c	355	342	6	H	--	--	--	L
24N/06E-08J01	473451	1220329	Qvt	384.32	25	84	Z	--	--	--	--
24N/06E-08K02	473450	1220343	Qvt	410	47	36	U	24.21	07-19-90	--	--
24N/06E-08P02	473433	1220409	Q(A)f	110	185	8	Z	--	--	--	L
24N/06E-09A07	473511	1220208	Qva	402.27	110	6	H	85.07	07-11-90	--	--
24N/06E-09A09	473517	1220205	Qvr	417.22	29.2	1.25	U	8.71	07-06-90	--	L
24N/06E-09A10	473517	1220214	Qvt	401.19	47.5	1.25	U	31.98	07-06-90	--	L
24N/06E-09A11	473518	1220214	Q(B)f	401.68	424	2	U	158.77	07-06-90	--	LW

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/06E-09A12	473518	1220214	Qva	401.70	123	2	U	72.81	07-06-90	--	W
24N/06E-09A13	473518	1220214	Q(A)f	401.87	231	2	U	87.96	07-06-90	--	W
24N/06E-09A14	473518	1220214	Qva	401.69	203	2	U	86.16	07-06-90	--	W
24N/06E-09A15	473518	1220214	Qva	401.51	170	2	U	85.34	07-09-90	--	W
24N/06E-09E03	473503	1220306	Qva	385	251	6	H	120.78	07-06-90	4.1	LM
24N/06E-09E04	473504	1220306	Q(A)f	386.27	420	2	U	75.23	07-06-90	--	L
24N/06E-09H02	473502	1220212	Qva	403.53	101	6	H	87.54	07-11-90	--	L
24N/06E-09J01	473449	1220205	Qva	430	130	12	C	115.72 S	07-12-90	3,400	L
24N/06E-09J02	473449	1220207	Qva	430	132.5	12	C	119.20 R	07-12-90	6,100	L
24N/06E-09N02	473429	1220302	Qva	310	199	6	H	99.40	07-11-90	10	LWM
24N/06E-09N03	473428	1220313	Q(A)f	350	202	6	H	99.08	07-11-90	32	L
24N/06E-10C01	473513	1220127	--	370	20	30	Z	--	--	--	--
24N/06E-10D01	473517	1220159	Qvr	387.12	31.7	1.25	U	6.17	07-13-90	--	L
24N/06E-10H01	473502	1220059	Qva	455	150	12	U	119.79	08-22-90	930	L
24N/06E-10H02	473501	1220059	Qva	455	155.2	16	P	120.96	08-22-90	1,400	LMVPS
24N/06E-10H03	473503	1220058	Qva	455	169	8	U	121.29	09-14-90	1,300	L
24N/06E-10L02	473441	1220128	Qvt	360	109	6	U	43.48	07-16-90	32	L
24N/06E-10P02	473430	1220124	Qva	355	72	6	H	--	--	46	LMS
24N/06E-11B01	473506	1215956	Qva	440	92	6	Z	--	--	--	--
24N/06E-11K01	473448	1215954	Qva	430	116	12	P	63.95	08-22-90	200	L
24N/06E-11L01P1	473439	1220016	Qva	420	135	8	U	65.18	09-14-90	--	LW
24N/06E-11L01P2	473439	1220016	Qva	420	95	8	U	66.45	09-14-90	--	LW
24N/06E-11L01P3	473439	1220016	Qvt	420	25	8	U	23.05	09-14-90	--	L
24N/06E-12B01	473510	1215845	Q(A)c	430	160	6	H	119.67	08-10-90	92	LM
24N/06E-12L01	473439	1215909	Q(A)f	440	362	6	H	--	--	12	LM
24N/06E-12N02	473425	1215915	Q(A)c	450	208	6	H	--	--	11	L
24N/06E-12R01	473429	1215819	Qva	450	108	8	P	80.10	07-16-90	1,100	L
24N/06E-13D01	473411	1215918	Qva	475	155	6	H	136.20	07-16-90	310	L
24N/06E-14H02	473410	1215943	Qva	480	124	6	H	91.13	07-16-90	540	L
24N/06E-14N01	473341	1220032	Multiple	460	198	6	U	111.93	07-17-90	--	L
24N/06E-14N02	473337	1220045	Qvr	470	146	6	Z	--	--	230	L
24N/06E-15C01	473420	1220137	Qva	355	79	6	H	19.69	07-17-90	9.6	L
24N/06E-15F01	473403	1220128	Qvt	370	156	6	H	-- F	07-17-90	.04	L
24N/06E-15N01	473334	1220148	Br	450	160	6	H	--	--	.72	L
24N/06E-16E01	473410	1220312	Q(A)c	125	196	6	H	54.06	09-26-90	--	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/06E-16E02	473406	1220310	--	60	10	48	Z	--	--	--	L
24N/06E-16L02	473354	1220301	--	55	84	6	H	-0.52 F	07-19-90	--	L
24N/06E-17H01	473413	1220330	Q(A)f	135	228	8	H	--	--	19	L
24N/06E-21A01	473328	1220216	Br	425	120	8	U	40.87	07-19-90	1.4	L
24N/06E-21B01	473332	1220231	Br	390	200	8	H	63.49	07-19-90	28	L
24N/06E-21J01	473306	1220221	Qva	55	150	6	P	-- F	10-30-90	150	L
24N/06E-22A02	473327	1220059	Qvt	450	85	6	I	49.53	08-10-90	61	L
24N/06E-22C01	473332	1220133	Br	420	240	6	H	51.90	08-09-90	.21	L
24N/06E-22F01	473319	1220136	Br	555	510	12	P	112.74	10-30-90	--	L
24N/06E-22H02	473311	1220105	Qvr	425	86	6	H	62.38	08-09-90	8.7	LM
24N/07E-03P01	473515	1215406	Q(A)c	90	320	6	H	-- F	09-28-90	6.8	LM
24N/07E-04E01	473540	1215534	Qal	75	65	6	H	12.53	10-05-90	9.7	LMP
24N/07E-04M01	473530	1215528	Qal	79	23	24	U	16.65	09-25-90	--	L
24N/07E-04M02	473527	1215528	Qal	76	60	6	I	16.38	09-25-90	240	L
24N/07E-05B01	473551	1215604	Qva	90	87	6	I	--	--	59	L
24N/07E-05F01	473548	1215628	Br	400	765	8	C	231.50	09-25-90	3.8	LM
24N/07E-06A01	473555	1215704	Q(A)c	270	211	6	H	148.47	09-25-90	150	L
24N/07E-06B01	473558	1215714	Q(A)c	230	106	6	H	90.88	10-11-90	--	LM
24N/07E-06B02	473601	1215723	Q(A)c	185	89	6	H	--	--	45	L
24N/07E-07Q01	473425	1215740	Q(A)f	480	247	6	H	--	--	--	L
24N/07E-08A01	473513	1215609	Qva	330	169	8	H	157.00	10-05-90	8.0	L
24N/07E-08A02	473510	1215607	Qvt	310	39	6	H	22.38	10-05-90	37	LMP
24N/07E-08B01	473512	1215612	Q(A)f	330	460	6	H	240.01	10-05-90	.03	L
24N/07E-08F02	473457	1215631	Q(B)c	90	880	10	U	-.78 F	09-13-90	1.4	LW
24N/07E-08G01	473453	1215623	Qal	85	8	30	H	6.21	10-05-90	--	LW
24N/07E-08J01	473440	1215552	Qvrl	95	104	6	Z	--	--	--	L
24N/07E-08P01	473425	1215631	Qvr	210	58	6	H	27.57	09-27-90	--	L
24N/07E-08R01	473433	1215601	Qvr	90	188	6	H	17.45	09-28-90	6.8	L
24N/07E-09D02	473507	1215546	Qva	120	72	6	S	--	--	3.0	L
24N/07E-09M01	473438	1215546	Q(A)f	105	353	6	H	22.12 R	09-26-90	9.1	L
24N/07E-09N01	473423	1215548	Qvr	120	114	6	H	69.93 R	09-26-90	.43	L
24N/07E-10C01	473505	1215356	Qal	85	52	8	Z	--	--	--	L
24N/07E-10K01	473436	1215334	Qal	85	36	6	S	9.25	09-26-90	410	LMVP
24N/07E-11L01S	473436	1215233	Qvr	330	--	--	U	--	--	--	--
24N/07E-12E01	473452	1215145	Qva	815	112	6	H	96.96	09-28-90	230	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/07E-12E02	473451	1215148	Qvr	815	115	6	H	96.33	10-19-90	450	LM
24N/07E-12F02	473455	1215119	Qvt	760	40	6	U	24.80	10-19-90	--	L
24N/07E-12J01	473433	1215044	Br	965	700	6	U	354.15	06-06-90	--	LM
24N/07E-12K01	473440	1215105	Qvr	950	255	6	S	223.75	10-23-90	--	L
24N/07E-12K02	473433	1215103	Q(A)f	970	360	8	H	218.19	10-26-90	9.0	L
24N/07E-12Q01	473428	1215107	Q(A)f	960	840	6	H	--	--	.34	L
24N/07E-13E01	473358	1215147	Br	295	398	8	H	194.28 R	09-27-90	--	LWM
24N/07E-13M01	473353	1215143	--	250	206	8	P	173.89 R	10-19-90	--	L
24N/07E-13Q01	473338	1215056	Q(A)c	240	240	6	H	120.84	07-10-90	--	L
24N/07E-13R01	473332	1215049	Br	185	298	6	H	81.94 R	09-20-90	--	L
24N/07E-13R02	473330	1215052	Q(A)c	178	246	6	H	74.44 R	09-20-90	27	L
24N/07E-14A01	473418	1215154	Qvr	580	221	5	H	--	--	2.7	L
24N/07E-14D01	473417	1215252	Qal	85	150	6	I	.66	10-11-90	15	LW
24N/07E-14D02	473419	1215252	Qal	86	13	38	U	2.29	10-11-90	--	W
24N/07E-14F02	473408	1215242	Qal	93	14.8	4	Z	--	--	--	--
24N/07E-14G01	473404	1215217	Qal	120	65	6	H	30.51	07-20-90	--	LM
24N/07E-14G02	473400	1215210	Br	140	545	6	H	149.57 R	08-09-90	--	L
24N/07E-14J01	473347	1215152	Br	190	185	6	H	91.77	07-20-90	--	L
24N/07E-14J02	473344	1215154	Qal	175	100	6	H	78.83	07-20-90	310	L
24N/07E-15A01	473408	1215320	Qal	85	46	10	I	13.55	08-03-90	660	L
24N/07E-15D01	473409	1215420	Qal	105	49.5	6	H	32.38	07-19-90	110	LWMVS
24N/07E-15F01	473401	1215357	Qvr	110	206	16	P	39.79 T	07-19-90	--	L
24N/07E-15F02	473401	1215356	Qvr	110	177	16	P	--	--	--	L
24N/07E-15K01	473347	1215333	Qal	117	150	6	H	31.49	07-20-90	--	L
24N/07E-16F01	473356	1215508	Qvr	150	122	6	H	34.65	09-21-90	--	LM
24N/07E-16L01	473347	1215526	Q(A)f	305	185	6	H	121.83 R	09-13-90	--	L
24N/07E-16L02	473349	1215517	Qvr	180	24	30	H	--	--	--	L
24N/07E-16R01	473330	1215446	Q(A)c	380	272	6	U	191.40	09-13-90	2.4	L
24N/07E-17A02	473418	1215554	Qvr	140	197	6	H	31.12	09-18-90	--	L
24N/07E-17B01	473418	1215625	Qvr	210	74	6	H	18.57	09-18-90	--	LM
24N/07E-17H01	473359	1215558	Qvr	240	58	6	H	-- F	09-07-90	18	L
24N/07E-17H02	473404	1215605	Qvr	240	82	6	H	30.23 R	09-18-90	5.6	L
24N/07E-18C03	473410	1215801	Multiple	465	210	6	H	119.90 R	09-07-90	--	L
24N/07E-18F02	473408	1215800	Qvt	475	60	6	H	23.19	09-07-90	46	L
24N/07E-18F03	473405	1215747	Qva	520	80	6	H	44.72	09-06-90	48	LM

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/07E-18G01	473405	1215733	Q(A)c	580	252	6	H	95.57 R	09-06-90	4.5	L
24N/07E-19L01	473253	1215751	Br	1,200	283	6	H	36.79	08-14-90	--	L
24N/07E-19P02	473246	1215756	Br	1,000	91	10	H	28.86	08-15-90	6.4	L
24N/07E-19R02	473250	1215719	Br	1,000	220	6	H	34.33 R	08-15-90	.05	LM
24N/07E-20F01	473308	1215638	Br	1,225	287	6	H	197.00 R	08-17-90	8.1	L
24N/07E-20H01	473309	1215549	Br	1,295	300	6	P	20.86	08-22-90	.21	L
24N/07E-20J01	473303	1215603	Br	1,280	149	6	H	47.99	08-17-90	.61	L
24N/07E-20J02	473301	1215555	Br	1,240	100	6	H	8.61	08-22-90	70	LM
24N/07E-20K01	473302	1215617	Br	1,260	125	6	H	27.02 R	08-23-90	.40	L
24N/07E-21H01	473308	1215440	Br	490	118	6	H	13.84	08-24-90	.29	LWM
24N/07E-21J01	473257	1215430	Br	550	140	6	H	36.41	08-23-90	.49	L
24N/07E-21M01	473300	1215545	Br	1,200	120	6	H	7.81	08-17-90	13	L
24N/07E-21P01	473238	1215527	Br	1,088	275	6	P	179.15	08-17-90	.48	L
24N/07E-22B01	473319	1215340	Q(B)c	240	567	16	P	182.69 R	09-12-90	1,100	L
24N/07E-22E01	473305	1215412	Q(B)f	450	378	6	H	--	--	24	L
24N/07E-22E02	473303	1215418	Qvt	495	92	6	H	57.29	08-23-90	120	L
24N/07E-22L01	473255	1215358	Qal	185	23	8	U	4.04	08-09-90	230	L
24N/07E-22P01	473246	1215404	Q(A)c	200	220	6	H	-- F	08-23-90	--	L
24N/07E-23A01	473325	1215152	Qal	115	52	8	U	19.09	07-18-90	--	L
24N/07E-23D01	473321	1215252	Qal	105	44	6	H	24.71	08-03-90	150	LM
24N/07E-23E01	473305	1215308	Multiple	340	473	8	U	55.22	08-09-90	--	L
24N/07E-23G01	473312	1215213	Q(B)f	115	362	8	H	37.72	08-03-90	6.0	L
24N/07E-23H01	473312	1215207	Qal	105	48	6	H	16.84 R	08-09-90	--	L
24N/07E-23H02	473310	1215154	Br	105	222	6	H	21.88 R	08-07-90	--	L
24N/07E-23H03	473311	1215158	Br	105	223	6	H	15.31	08-09-90	--	LM
24N/07E-24E01	473308	1215150	Br	120	230	6	H	38.30 R	07-13-90	.02	L
24N/07E-24G01	473303	1215107	Q(A)c	121	150.5	6	P	5.11	07-13-90	--	L
24N/07E-24Q01	473246	1215100	Qva	341	119	8	C	52.67 R	07-13-90	39	LM
24N/07E-25N01	473148	1215147	Q(A)c	760	782.3	8	U	407.10	06-27-90	6.1	LW
24N/07E-25P01	473145	1215129	Q(A)c	670	540	8	U	316.13	08-14-90	57	L
24N/07E-26G01	473221	1215214	Q(A)c	860	782	8	U	--	--	.38	L
24N/07E-26M01	473159	1215257	Q(A)c	878	282	6	P	259.82	08-02-90	--	L
24N/07E-26N01	473148	1215303	Q(A)c	900	295	8	P	264.72	08-07-90	1,700	L
24N/07E-27A01	473227	1215324	Q(B)f	818	1,050	8	U	--	--	--	L
24N/07E-27D01	473225	1215424	Q(A)c	250	91	6	H	-- F	08-03-90	--	LM

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/07E-27J01	473159	1215324	Qva	876	267	6	P	244.31	07-02-90	63	L
24N/07E-28K01	473209	1215450	Q(A)c	340	163	8	P	-- F	08-03-90	8.3	L
24N/07E-28Q01	473154	1215505	Q(A)c	370	136	8	H	-.75 F	09-19-90	27	L
24N/07E-29A01	473236	1215554	Br	1,085	240	6	H	146.36	08-14-90	11	L
24N/07E-29D01	473234	1215703	Qvt	880	194	6	H	34.21	08-22-90	18	L
24N/07E-29P02	473155	1215631	Qvr	510	49	8	N	8.80	09-19-90	670	L
24N/07E-29Q01	473146	1215614	Qvr	515	50	6	N	33.94 P	09-19-90	--	--
24N/07E-30C01	473231	1215746	Br	1,000	127	6	H	90.09 R	11-02-90	.17	L
24N/07E-32A01	473133	1215559	Br	523	205	8	Z	--	--	1.5	L
24N/07E-32A02	473134	1215559	Qvr	523	48	8	N	30.12	09-20-90	150	L
24N/07E-33D01	473132	1215545	Qvr	530	80	6	H	42.44	08-02-90	16	LM
24N/07E-33G01	473131	1215456	Multiple	620	320	6	U	--	--	--	L
24N/07E-33G02	473130	1215501	Qvr	580	76	6	H	39.98	07-13-90	140	L
24N/07E-34N02	473101	1215410	Q(A)c	985	432	12	T	354.96	08-07-90	190	L
24N/07E-34N03	473102	1215406	Multiple	950	413	12	I	336.88 P	08-07-90	--	L
24N/07E-36D02	473140	1215145	Qva	740	196	6	H	173.65	07-11-90	24	L
24N/07E-36G01	473122	1215100	--	750	393	6	U	358.40 R	07-17-90	--	L
24N/07E-36L01	473113	1215124	Q(A)c	760	410	6	U	--	--	18	L
24N/07E-36L02	473113	1215125	Q(A)c	765	185	6	H	93.97	09-10-90	--	L
24N/07E-36M01	473112	1215146	Q(A)c	850	260	6	H	190.13 R	07-10-90	13	LM
24N/07E-36P01	473101	1215120	Qva	730	59	6	H	30.07	07-09-90	33	L
24N/07E-36P02	473054	1215112	Qva	800	141	6	H	83.86	08-24-90	24	L
24N/07E-36R01	473058	1215038	Br	790	338	6	H	185.00	07-09-90	.60	LM
24N/08E-18K01	473343	1214947	Qvr	572	185	6	H	165.98	06-26-90	34	L
24N/08E-18K02	473343	1214942	Qva	575	217	6	H	--	--	16	LM
24N/08E-18Q02	473332	1214950	Qvr	550	361	8	P	311.35	06-26-90	210	L
24N/08E-19J01	473248	1214927	Qva	440	586	20	U	--	--	8.6	L
24N/08E-19J02	473250	1214925	Qvr	460	200	6	U	--	--	--	L
24N/08E-19J03	473247	1214928	Qvr	440	160	6	U	--	--	--	L
24N/08E-19M01	473256	1215025	Br	160	100	6	H	35.91	07-05-90	6.1	LM
24N/08E-20A01	473316	1214808	Qva	755	222	10	H	170.07	06-21-90	3.5	L
24N/08E-20H01	473306	1214805	Qva	740	90	6	H	69.50	06-22-90	38	L
24N/08E-20J01	473252	1214802	Qva	720	186	6	H	157.02 R	06-21-90	12	L
24N/08E-20M01	473255	1214906	Qvr	560	281	6	H	255.10	06-26-90	--	LWM
24N/08E-20M02	473256	1214902	Qvr	565	276	8	P	247.99	06-27-90	130	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
24N/08E-20P01	473248	1214842	Qvr	475	354	8	N	189.61 P	06-14-90	--	L
24N/08E-20R02	473249	1214809	Qvr	700	34	6	H	10.31	06-22-90	18	LMS
24N/08E-20R03	473240	1214813	Qva	745	356	6	H	243.17 R	06-20-90	9.8	L
24N/08E-21E01	473304	1214759	Qva	785	260	6	Z	--	--	--	L
24N/08E-21N01	473245	1214758	Br	715	420	6	H	256.33	06-20-90	--	L
24N/08E-21N02	473248	1214800	Qvr	718	210	6	H	--	--	--	L
24N/08E-24Q01S	473238	1214316	Br	680	--	--	P	--	--	--	M
24N/08E-26F01	473217	1214502	Qvr	490	68	6	U	50.98	06-18-90	--	L
24N/08E-26K01	473158	1214445	Qal	450	59	6	H	12.81	06-15-90	--	LM
24N/08E-26K02	473202	1214438	Qal	450	51	6	H	30.35	06-22-90	53	L
24N/08E-26P03	473150	1214450	Qal	470	50	6	U	--	--	160	L
24N/08E-26Q01	473146	1214434	Qvr	620	178	6	H	126.64	06-18-90	37	L
24N/08E-28E02	473218	1214742	Qvr	750	108	6	H	49.30	06-20-90	--	LWM
24N/08E-28G01	473217	1214718	Qva	840	138	6	H	83.55	06-07-90	77	L
24N/08E-28H01	473213	1214652	Qva	1,025	321	8	H	223.93	06-13-90	18	LM
24N/08E-28P01	473148	1214741	Qvr	565	81	6	H	46.63	06-13-90	320	L
24N/08E-29H01	473217	1214802	Qvr	725	212	6	H	180.42 R	06-07-90	26	L
24N/08E-30N01	473154	1215021	Qal	445	26	6	H	3.55	06-07-90	11	LMS
24N/08E-30N02	473155	1215026	Q(A)c	455	169	6	H	100.92 R	06-13-90	93	L
24N/08E-31Q01	473104	1214939	Q(A)f	430	130	4	Z	--	--	--	L
24N/08E-31Q02	473102	1214939	Q(A)f	435	130	4	Z	--	--	--	L
24N/08E-32F01	473130	1214851	Q(A)c	420	544	16	U	36.42	06-05-90	39	LM
24N/08E-35E01	473125	1214520	Qal	431	79	6	U	2.93	06-06-90	--	L
24N/08E-35E02	473122	1214516	Qal	431	43	6	P	2.26	06-06-90	380	L
24N/08E-35N01S	473102	1214523	Br	425	--	--	P	--	--	--	--
25N/06E-01F01	474050	1215904	Qal	75	57	38	P	10.72	05-11-90	--	--
25N/06E-01N01	474032	1215923	Qva	560	165	6	H	76.14	06-26-90	--	LM
25N/06E-02L01	474043	1220018	Q(A)c	600	270	6	P	--	--	18	L
25N/06E-02P01	474033	1220013	Br	590	460	6	H	413.17	05-11-90	24	L
25N/06E-10A02	474029	1220045	Qva	580	211	6	H	201.99	08-08-90	19	L
25N/06E-10J01	474001	1220050	Q(A)c	550	373	6	H	--	--	33	L
25N/06E-10J02	473955	1220050	Qva	550	194	6	H	149.60	07-06-90	33	LM
25N/06E-10R01	473943	1220050	Q(A)f	570	314	6	U	--	--	18	L
25N/06E-11L01	473958	1220013	Qva	550	90	6	H	46.27	06-27-90	4.8	L
25N/06E-11M01	473958	1220042	Qva	550	149	6	H	125.87	06-26-90	150	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
25N/06E-12E01	474004	1215923	Q(A)c	645	954	12	P	--	--	28	L
25N/06E-12H02	474007	1215826	Q(A)f	100	143	6	H	-- F	06-21-90	--	L
25N/06E-12J01	473953	1215816	Qva	145	73	6	H	55.70	05-11-90	97	L
25N/06E-13F01	473906	1215906	Qva	645	145	10	P	--	--	--	L
25N/06E-13F02	473906	1215905	Qva	645	260	12	U	--	--	7.0	L
25N/06E-14M01	473905	1220044	Qvt	485	58	6	H	44.60	06-21-90	110	LM
25N/06E-15A01	473928	1220055	Qva	535	47	6	H	20.43	06-21-90	--	L
25N/06E-15B01	473933	1220111	Q(A)c	495	370	6	H	335.39	06-21-90	61	L
25N/06E-15G01	473909	1220117	Q(A)f	395	260	6	H	242.81	07-03-90	37	L
25N/06E-15Q01	473847	1220119	Qvt	200	128	6	H	28.51 R	06-27-90	4.9	L
25N/06E-17E01	473912	1220425	Qal	110	68	6	H	23.63	06-28-90	660	L
25N/06E-18F05	473924	1220521	Qvr	105	75	6	H	39.02 R	05-10-90	180	L
25N/06E-18K01	473903	1220515	Q(B)c	100	297	6	P	-- F	06-27-90	--	L
25N/06E-19H03	473831	1220450	Q(A)c	60	78	12	P	9.33 R	05-10-90	--	--
25N/06E-20E01	473819	1220427	Q(B)c	70	122	6	H	24.97	05-10-90	--	LWM
25N/06E-23E03	473822	1220035	Q(A)c	140	69	10	H	-- F	07-06-90	920	L
25N/06E-23E04	473831	1220028	Q(A)c	175	175	20	U	--	--	--	L
25N/06E-23M02	473816	1220042	Q(A)c	260	414	6	H	124.00	06-28-90	--	L
25N/06E-23Q01	473751	1215948	Qal	130	21.5	36	H	15.35	06-28-90	--	L
25N/06E-24B01	473828	1215848	Qva	480	333	12	P	244.27	11-02-90	31	L
25N/06E-24K01	473801	1215839	Qvt	420	120	6	H	97.71	08-16-90	20	LWM
25N/06E-24Q01	473749	1215835	Q(A)c	395	342	6	H	201.06	08-09-90	43	L
25N/06E-25E01	473727	1215920	Q(A)c	190	49	6	H	--	--	370	LM
25N/06E-25F01	473747	1215906	Q(A)f	380	167	6	H	149.75	08-09-90	--	L
25N/06E-25K01	473719	1215844	Q(A)c	280	335	6	H	136.64	09-25-90	18	LWM
25N/06E-26A02	473748	1215945	Qal	115	60	8	H	10.73	06-29-90	1.7	L
25N/06E-26P01	473712	1220020	Qvr	345	63	6	H	8.88	09-14-90	11	L
25N/06E-27J01	473718	1220056	Qvr	405	152	6	P	128.58 R	09-19-90	26	L
25N/06E-27K01	473719	1220108	Qvr	370	150	6	P	87.34	09-19-90	8.3	L
25N/06E-27N01	473712	1220145	Qvr	425	238	6	H	229.93	08-08-90	--	LW
25N/06E-28H01	473728	1220207	Qvr	425	47	6	H	11.26	07-03-90	24	LM
25N/06E-29C01	473742	1220407	Q(B)c	100	178	8	H	-- F	06-28-90	97	L
25N/06E-32F03	473645	1220403	Q(A)c	50	116	6	H	-- F	06-28-90	31	LM
25N/06E-32L02	473626	1220406	Q(A)c	100	101	12	H	-- F	06-28-90	--	L
25N/06E-33K01	473623	1220239	Q(A)c	480	337	6	H	273.72	12-12-90	--	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
25N/06E-33N03	473616	1220310	Qva	410	200	6	H	163.27	08-07-90	--	L
25N/06E-34D01	473659	1220148	Qva	360	214	6	H	174.35 P	07-03-90	860	LMS
25N/06E-34E02	473634	1220144	Q(B)c	370	714	20	P	--	--	37	LM
25N/06E-34M01	473633	1220150	Q(B)c	360	717	12	P	237.15	08-22-90	--	L
25N/07E-01N01	474026	1215132	Qvt	260	98	6	H	64.65	09-18-90	--	LM
25N/07E-01N02	474024	1215128	Qal	240	72	6	H	14.59	09-18-90	--	L
25N/07E-04J01	474039	1215423	Qal	60	108	6	S	4.99	10-03-90	1.1	LM
25N/07E-06B01	474108	1215720	Q(A)c	40	490	6	H	-- F	10-28-90	21	LM
25N/07E-06L01	474040	1215730	--	75	728	14	S	--	--	--	L
25N/07E-06R01	474035	1215702	Q(A)c	55	630	16	U	-- F	09-26-90	--	L
25N/07E-07E01	474005	1215753	Q(A)c	55	647	10	H	-- F	12-08-90	72	LWM
25N/07E-07N01	473940	1215804	Qva	120	110	6	H	-- F	09-26-90	--	L
25N/07E-07P01	473942	1215748	Qvr	130	39	6	H	27.40	09-26-90	650	LM
25N/07E-08D01	474017	1215647	Qva	135	161	12	U	7.17	09-26-90	93	L
25N/07E-08D02	474016	1215644	Q(A)c	135	729	12	S	61.33	09-26-90	48	LM
25N/07E-08M01	473945	1215642	Qva	390	380	8	P	153.82	05-11-90	500	L
25N/07E-10C01	474017	1215347	Qva	175	44	6	H	-- F	09-18-90	88	L
25N/07E-10D01	474017	1215407	Qal	75	90	6	H	--	--	.64	L
25N/07E-10E01	474006	1215406	Qal	70	44	6	H	31.35	09-20-90	120	LWM
25N/07E-10J01	473950	1215310	Qva	460	150	6	H	109.20	09-18-90	15	LM
25N/07E-10J02	473952	1215317	Br	450	305	6	H	190.30 R	09-26-90	--	L
25N/07E-10L01	473954	1215400	Q(A)f	60	145	6	H	-- F	09-26-90	--	L
25N/07E-11A01	474011	1215157	Qal	230	60	8	P	1.39	09-25-90	20	L
25N/07E-11B01	474021	1215213	Q(A)f	580	260	8	U	--	--	--	L
25N/07E-11K01	473945	1215213	Q(A)c	200	225	6	P	-- F	10-12-90	--	--
25N/07E-11M01	473950	1215300	Qva	460	160	6	H	138.24	10-03-90	10	L
25N/07E-11Q01	473942	1215219	Q(A)c	190	177	6	H	14.16	09-27-90	31	LM
25N/07E-14C01	473925	1215229	--	180	177	6	U	--	--	--	L
25N/07E-14M01	473853	1215250	Q(A)f	135	350	6	C	1.29	09-25-90	18	L
25N/07E-14N01	473851	1215300	Q(A)f	135	64	6	H	2.36	09-25-90	34	L
25N/07E-15B01	473927	1215330	--	310	220	6	U	61.63	09-26-90	--	L
25N/07E-15C01	473923	1215358	Q(A)c	65	103	6	H	19.62	09-26-90	--	LMS
25N/07E-15E01	473907	1215408	Qal	75	41	6	H	21.77	10-11-90	330	L
25N/07E-15M01	473857	1215416	Qal	90	101	10	U	--	--	1,800	L
25N/07E-15P01	473849	1215338	Qal	115	35	6	H	25.52	09-20-90	310	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydrologic unit	Land surface elevation (feet above sea level)	Depth of well below land surface (feet)	Surface casing diameter (inches)	Use of water	Water level below land surface (feet)	Date of water level measurement (month/ day/year)	Hydraulic conductivity (feet per day)	Remarks
25N/07E-15R02	473847	1215308	Qvr	240	115	6	H	79.35	09-20-90	74	LWM
25N/07E-16B01	473925	1215452	Qal	60	30	6	H	8.56	09-25-90	230	L
25N/07E-16R01	473851	1215424	Qal	85	110	10	P	--	--	--	--
25N/07E-17A01	473929	1215548	Qva	425	247	6	H	214.22	09-26-90	170	LWMS
25N/07E-18C01	473922	1215749	Qva	190	101	6	H	22.80	10-03-90	82	L
25N/07E-18M01	473858	1215806	Q(A)c	360	268	8	P	--	--	69	L
25N/07E-18P01D1	473841	1215742	--	310	198	38	I	96.33	09-19-90	--	L
25N/07E-19A01	473828	1215709	Qvr	270	36	6	H	--	--	--	--
25N/07E-19A02	473832	1215711	--	255	13.5	36	U	12.70	09-26-90	--	--
25N/07E-19E01	473816	1215757	Qvr	390	205	8	P	--	--	460	L
25N/07E-19E02	473816	1215756	Qvr	390	201	10	P	170.28 R	05-11-91	390	L
25N/07E-20L01	473809	1215619	Q(A)f	400	265	6	H	126.35	09-19-90	26	L
25N/07E-20M01	473812	1215645	Q(A)c	540	392	10	P	--	--	4.8	L
25N/07E-20P01	473756	1215618	Q(A)c	160	269	6	H	73.95	09-19-90	37	LM
25N/07E-20P02	473757	1215625	Q(A)f	240	88	6	U	--	--	--	L
25N/07E-20Q01	473755	1215615	Qal	120	71	6	H	52.90	10-22-90	95	L
25N/07E-21C01	473836	1215458	Qal	70	35	6	H	10.27	09-20-90	--	LWMVPS
25N/07E-22C01	473835	1215345	Qal	110	30	6	P	11.68	10-03-90	610	L
25N/07E-22G01	473828	1215335	Qal	100	60	6	P	19.86	10-03-90	--	--
25N/07E-22G02	473826	1215334	Qal	110	60	8	P	17.50	10-03-90	--	--
25N/07E-23D01	473836	1215245	Q(A)f	180	138	6	H	-- F	10-22-90	11	L
25N/07E-23E01S	473815	1215246	Qvr	290	--	--	U	--	--	--	--
25N/07E-23M01	473816	1215259	Q(A)f	150	215	6	U	14.47	10-03-90	1.0	L
25N/07E-23M02	473813	1215247	Qvr	280	113	6	H	19.43	03-01-91	--	L
25N/07E-23Q01S	473755	1215215	Qvt	450	--	--	P	--	--	--	M
25N/07E-26F01	473726	1215237	Qvr	350	96	6	H	37.92	10-16-90	--	L
25N/07E-26F01S	473726	1215233	Qvr	380	--	--	I	--	--	--	M
25N/07E-26K01	473718	1215224	Qvt	460	54	6	H	35.22	10-16-90	--	L
25N/07E-26K02	473715	1215223	Qvt	440	60	6	H	22.57	10-16-90	120	L
25N/07E-26L01	473718	1215239	Q(A)c	340	244	6	H	28.52	10-16-90	61	L
25N/07E-27D01	473742	1215411	Qvr	100	95	6	H	--	--	61	LMV
25N/07E-27D02	473742	1215404	Q(A)f	100	195	6	H	2.29 R	10-11-90	8.2	L
25N/07E-27M01	473714	1215405	Qva	140	128	18	R	14.54	10-04-90	--	L
25N/07E-27M02	473712	1215413	Qal	120	16.5	36	H	7.08	10-04-90	--	L
25N/07E-27N01	473656	1215419	Qal	101	27	6	H	4.84	08-03-90	25	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
25N/07E-28Q01	473658	1215444	Qal	85	25	36	H	11.47	10-11-90	--	MP
25N/07E-28R01	473658	1215424	--	100	180	6	H	--	--	--	L
25N/07E-29H02	473728	1215539	Q(A)c	70	214	6	H	2.83 R	10-16-90	--	LMPS
25N/07E-29N01	473705	1215647	Qva	400	97	6	U	--	--	28	L
25N/07E-29N01D1	473705	1215647	Q(A)c	400	190	6	U	--	--	--	L
25N/07E-30C01	473735	1215748	Q(A)c	365	360	6	H	164.96	10-03-90	41	L
25N/07E-30F01	473733	1215735	Q(A)c	425	241	6	H	208.30	09-25-90	--	LM
25N/07E-30H01	473723	1215657	Q(A)c	520	560	8	P	--	--	11	L
25N/07E-30H02	473734	1215658	Qvt	570	41	6	U	12.41	05-11-91	400	L
25N/07E-30H03	473734	1215659	Qvt	570	38	10	U	--	--	1,900	L
25N/07E-30M01	473721	1215754	Qva	120	98	6	I	10.13	10-16-90	23	L
25N/07E-31D01	473647	1215752	Qal	115	95	6	H	6.45	10-16-90	13	LMP
25N/07E-31E02	473631	1215752	Qva	160	87	6	H	--	--	--	L
25N/07E-31J01	473623	1215659	Q(A)c	315	241	6	H	166.36	10-12-90	22	LM
25N/07E-31M01	473618	1215750	Qva	160	50	6	H	--	--	430	L
25N/07E-31N01	473612	1215751	Qva	160	200	6	H	152.35	10-12-90	82	L
25N/07E-31R01	473607	1215706	Q(A)c	290	193	6	H	--	--	19	L
25N/07E-32F01	473635	1215627	Q(A)f	100	93	6	H	--	--	3.8	L
25N/07E-32G01	473643	1215600	--	70	18	48	Z	--	--	--	--
25N/07E-32G02	473643	1215600	Qal	70	79	6	H	9.75	10-16-90	--	--
25N/07E-32J01	473624	1215539	Qal	70	21	36	H	--	--	--	--
25N/07E-32R01	473608	1215540	Qal	70	25	1.5	H	--	--	--	--
25N/07E-33A01	473653	1215428	Qal	97	141	6	H	--	--	63	L
25N/07E-33G01	473642	1215441	Qal	80	21	30	H	2.40	10-11-90	--	--
25N/07E-33J01	473619	1215436	Qal	80	84	6	H	--	--	--	L
25N/07E-33N01	473608	1215534	Qal	60	43	6	I	16.92	10-12-90	--	--
25N/07E-33N02	473608	1215535	Q(A)c	60	238	6	H	9.63	10-12-90	--	L
25N/07E-33Q01	473616	1215446	Q(A)c	80	100	6	H	7.56	12-08-90	30	LM
25N/07E-34C01	473654	1215347	Qal	120	52	6	H	27.53	10-11-90	46	L
25N/07E-34E01	473632	1215403	Q(A)f	215	260	6	U	--	--	--	L
25N/07E-34E02	473638	1215404	Qvr	280	220	6	H	196.40	10-04-90	120	LM
25N/07E-34M01	473619	1215408	Q(A)c	140	284	6	H	48.60	10-11-90	.79	LW
25N/07E-34N01	473616	1215418	Qvr	105	87	6	H	19.91	10-16-90	--	L
26N/06E-02B01	474622	1220002	Q(A)c	90	200	8	H	82.50 P	07-06-90	--	L
26N/06E-02E01	474610	1220030	Q(A)c	550	290	6	H	174.39 R	07-06-90	8.9	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
26N/06E-02M01	474603	1220039	Q(A)c	490	229	6	H	168.91	08-06-90	--	LWM
26N/06E-03C01	474623	1220134	Qva	423	79	6	H	-1.26 F	07-12-90	2.8	L
26N/06E-03D01	474629	1220155	Qva	490	120	6	H	13.88	07-05-90	--	L
26N/06E-03D02	474632	1220158	Qva	510	208	6	H	33.90	07-06-90	.13	L
26N/06E-03J01	474605	1220052	Qva	530	148.5	6	H	120.97	11-27-90	--	L
26N/06E-03P01	474547	1220127	Br	510	420	6	P	--	--	--	L
26N/06E-03P02	474548	1220127	Qva	510	226	6	P	--	--	14	L
26N/06E-04J01	474604	1220205	Qva	493	90	6	H	58.21 R	07-12-90	41	L
26N/06E-04J02	474605	1220208	Br	500	200	6	P	135.94 P	07-13-90	430	LMS
26N/06E-09A02	474537	1220208	Qva	460	58	6	H	42.80	07-05-90	19	L
26N/06E-09B02	474532	1220222	Qva	435	90	6	H	11.37	07-06-90	10	LM
26N/06E-09L02	474508	1220246	Qva	370	80	6	H	11.38	11-29-90	--	L
26N/06E-10A01	474539	1220100	Qva	470	112	6	H	97.23 R	07-06-90	25	LMS
26N/06E-10H01	474518	1220046	Q(A)f	330	300	6	U	132.09	07-17-90	2.3	L
26N/06E-10H02	474529	1220055	Multiple	374	301	6	H	111.17 P	07-18-90	--	L
26N/06E-11C01	474538	1220015	Q(A)f	230	273	6	H	153.92	07-05-90	1.4	L
26N/06E-11E01	474524	1220034	Qva	340	63	6	H	22.39 R	07-09-90	46	L
26N/06E-13D03	474443	1215907	Q(A)c	45	215	6	P	-- F	08-01-90	--	LMVP
26N/06E-13D04	474441	1215906	Q(A)c	45	229	6	U	--	--	--	L
26N/06E-13J01	474420	1215813	Qva	405	90	6	H	--	--	--	LM
26N/06E-13N01	474407	1215908	Q(A)c	100	236	6	I	38.90	11-28-90	--	LW
26N/06E-13Q01	474409	1215834	Qva	295	99.5	6	H	--	--	--	L
26N/06E-14D01	474446	1220027	Q(A)c	230	83	6	H	74.43	08-03-90	400	LM
26N/06E-14D02	474448	1220034	Q(A)c	270	305	6	H	79.18	02-11-91	--	L
26N/06E-22K01	474326	1220112	Q(A)f	560	194	6	H	151.38 R	07-18-90	2.3	L
26N/06E-22K02	474325	1220118	Qva	548	190	6	H	137.17	08-01-90	130	LWM
26N/06E-22K03	474322	1220110	Q(A)f	533	337	6	H	192.65	08-03-90	1.8	L
26N/06E-24D01	474345	1215906	Q(A)c	125	251	6	H	76.48 R	08-01-90	--	LM
26N/06E-25A01	474251	1215810	Qva	240	75	6	H	33.87	07-10-90	19	L
26N/06E-25A02	474259	1215812	Qva	261	197	6	H	--	--	37	L
26N/06E-25A03	474256	1215817	Qva	240	76	6	H	19.89	10-31-90	24	L
26N/06E-25C02	474300	1215856	Q(B)c	190	823.5	12	U	114.64	11-16-90	32	LW
26N/06E-25F01	474242	1215857	Qvt	60	58	6	H	4.09 R	07-17-90	--	LMP
26N/06E-25H01	474237	1215812	Qva	260	63	6	H	41.25	08-08-90	120	L
26N/06E-25J02	474228	1215807	Qva	255	60	6	H	19.01	08-10-90	6.0	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
26N/06E-25R01	474216	1215818	Qva	225	217	6	H	35.77	08-03-90	5.6	L
26N/06E-26D01	474300	1220040	Qva	375	118	6	H	67.40	07-11-90	20	L
26N/06E-26D02	474301	1220034	Qva	200	271	6	H	189.18	11-27-90	1.6	L
26N/06E-26D03	474303	1220035	Qva	250	101	6	H	36.10	12-06-90	--	LM
26N/06E-26E01	474245	1220042	Qvt	360	50	6	H	--	--	2.8	L
26N/06E-27G01	474240	1220123	Q(B)c	510	1,010	10	U	435.91	02-11-91	8.6	L
26N/06E-35E01	474153	1220039	Qva	500	100	8	P	--	--	540	L
26N/06E-35L01	474140	1220011	Multiple	510	350	6	H	255.44	11-30-90	--	L
26N/07E-03L01	474557	1215353	Br	848	295	6	U	--	--	360	L
26N/07E-03L02	474557	1215353	Br	850	345	8	P	--	--	--	L
26N/07E-03M01	474557	1215407	Br	778	160	6	H	79.34	07-16-90	3.3	LM
26N/07E-04A01	474621	1215424	Br	890	200	6	H	17.63	08-22-90	--	L
26N/07E-04D01	474624	1215529	Br	920	50	6	H	8.33	11-21-90	8.2	LMS
26N/07E-04F01	474620	1215503	Qvt	740	108	6	H	65.62	08-29-90	--	L
26N/07E-04J01	474557	1215424	Br	730	175	6	H	--	--	--	L
26N/07E-04N01	474540	1215525	Multiple	590	54	6	H	9.75	09-24-90	--	L
26N/07E-04P01	474536	1215457	Br	560	425	8	H	--	--	.01	L
26N/07E-04R01	474547	1215436	Br	690	215	6	U	113.12	10-25-90	--	L
26N/07E-05D01	474624	1215636	Br	820	200	6	U	--	--	--	L
26N/07E-05D02	474624	1215643	Br	850	540	6	U	--	--	--	L
26N/07E-05F01	474618	1215635	Br	800	166	6	H	111.00 R	09-25-90	--	L
26N/07E-05K01	474602	1215558	Br	776	505	8	H	121.36 R	08-23-90	.03	L
26N/07E-05P01	474541	1215634	Br	685	185	6	H	34.30 R	08-23-90	--	L
26N/07E-05P02	474548	1215632	--	700	302	6	H	--	--	--	L
26N/07E-06B01	474630	1215725	Qvt	70	100	6	S	20.89 R	10-22-90	61	L
26N/07E-06F01	474613	1215743	--	35	338	6	Z	--	--	--	--
26N/07E-06G01	474608	1215715	Br	60	58	6	H	28.56 P	10-30-90	75	L
26N/07E-06K01	474603	1215717	Br	50	40	6	S	--	--	150	LMP
26N/07E-08A01	474532	1215558	Br	600	120	6	H	27.98	10-25-90	.94	LM
26N/07E-08D01	474532	1215643	Br	520	260	6	H	102.39	08-29-90	.05	L
26N/07E-09F01	474510	1215456	Br	365	137	6	H	121.45 R	08-24-90	.03	L
26N/07E-09F02	474508	1215508	Br	295	30	6	H	9.30	09-24-90	2.4	LWM
26N/07E-09G01	474515	1215451	Br	410	340	6	H	--	--	.54	L
26N/07E-09Q01	474454	1215447	Br	270	146	6	H	94.07 R	08-27-90	.00	L
26N/07E-14F01	474423	1215224	Qvt	550	138	6	H	11.54	10-30-90	1.6	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
26N/07E-14G01	474417	1215211	Br	670	300	6	H	62.30	11-01-90	--	L
26N/07E-14G02	474416	1215210	Br	640	182	6	H	18.90	12-08-90	--	LM
26N/07E-14J01	474406	1215146	Br	890	305	6	H	-- F	09-27-90	--	L
26N/07E-14K01	474406	1215218	Br	530	132	6	H	6.72	10-29-90	1.2	L
26N/07E-14L01	474402	1215234	--	582	233	6	H	69.15	08-29-90	--	L
26N/07E-14P01	474358	1215229	Br	560	130	6	H	25.84 R	09-26-90	.01	LW
26N/07E-15E01	474417	1215411	Br	390	360	6	H	--	--	--	L
26N/07E-15F01	474423	1215352	Br	380	300	6	H	--	--	--	L
26N/07E-16A01	474428	1215422	Br	260	96	6	H	--	--	.05	LM
26N/07E-16A02	474428	1215424	Br	280	43	6	H	9.73	10-22-90	.88	L
26N/07E-16H01	474421	1215434	Br	330	195	6	H	--	--	--	L
26N/07E-16L01	474414	1215503	Qvt	420	66.7	6	H	53.91	10-23-90	26	L
26N/07E-16L02	474402	1215459	Qva	450	134	6	H	106.92	10-25-90	3.2	LM
26N/07E-16L03	474410	1215455	Qva	390	118	6	H	84.79	11-15-90	1.8	L
26N/07E-17B01	474438	1215613	Qvr	100	98	6	H	--	--	220	L
26N/07E-17C01	474429	1215622	Q(A)f	80	211	10	H	-- F	09-24-90	2.6	LM
26N/07E-17C02	474436	1215626	Qal	70	35	6	H	11.25	09-24-90	310	L
26N/07E-17N01	474355	1215643	Qva	450	130	6	H	86.63	11-21-90	46	L
26N/07E-18B01	474445	1215712	Qva	60	46	6	P	14.49	09-24-90	200	LM
26N/07E-18M01	474417	1215801	Qva	430	73	6	H	56.78	11-16-90	610	L
26N/07E-18N01	474409	1215800	Q(A)c	418	210	6	H	180.06	08-31-90	330	LM
26N/07E-18R01	474402	1215709	Qva	472	250	6	H	226.45	08-31-90	300	L
26N/07E-19G01	474327	1215719	Qva	455	260	8	H	220.97 R	10-26-90	--	L
26N/07E-19J01	474315	1215652	Q(A)f	470	419	6	H	192.32	09-27-90	--	L
26N/07E-19J02	474313	1215655	Q(A)f	460	416	6	H	296.26	11-07-90	--	LM
26N/07E-19K01	474324	1215724	Qva	470	274	6	U	--	--	--	L
26N/07E-19K02	474325	1215722	Q(A)f	460	322	6	Z	--	--	--	L
26N/07E-19P01	474304	1215743	Qva	305	113	6	H	--	--	28	LMV
26N/07E-20E01	474332	1215647	Qva	485	260	6	H	231.61 R	10-29-90	18	LWM
26N/07E-21P01	474257	1215455	Qva	510	103	6	H	75.88	09-27-90	93	L
26N/07E-22C01	474336	1215353	Qva	520	164	6	U	--	--	--	L
26N/07E-22C02	474335	1215347	Qva	490	60	6	P	--	--	230	L
26N/07E-22D01	474338	1215403	Qva	480	45	6	H	6.68	10-31-90	--	LMS
26N/07E-22E01	474324	1215401	Multiple	440	132	6	H	12.66	09-26-90	--	L
26N/07E-22L01	474315	1215352	Qva	350	109	6	H	43.69	11-16-90	20	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
26N/07E-23E01	474325	1215247	Qva	545	58	6	H	29.61	09-04-90	15	L
26N/07E-23G01	474328	1215216	Br	520	325	6	H	38.28 R	09-25-90	.08	L
26N/07E-23G02	474321	1215202	Br	535	120	6	H	--	--	--	L
26N/07E-23M01	474311	1215244	Br	590	117	6	H	106.50	09-26-90	--	L
26N/07E-26Q01	474208	1215211	Qva	535	57	6	U	10.90	11-28-90	12	L
26N/07E-27F01	474232	1215340	Br	347	225	6	H	--	--	.02	LM
26N/07E-27G01	474231	1215328	Q(A)f	423	118	6	H	--	--	31	L
26N/07E-27G02	474236	1215335	Br	360	220	6	H	-- F	10-30-90	--	L
26N/07E-27M01	474229	1215411	Qva	385	243	8	H	177.13	11-20-90	42	L
26N/07E-27P01	474210	1215347	Qvr	310	40	6	H	4.26	11-01-90	--	L
26N/07E-27P02	474211	1215342	Qvr	325	40	6	H	9.97	11-01-90	--	L
26N/07E-28B01	474245	1215438	Qvr	455	56	6	H	19.90	09-06-90	110	L
26N/07E-28C01	474249	1215500	Qvt	517	122	6	H	112.00	09-06-90	--	L
26N/07E-28E01	474232	1215526	Q(A)f	485	60	6	U	25.20	11-15-90	--	L
26N/07E-28E02	474236	1215521	Qva	500	113	6	H	83.62	10-30-90	330	LWMS
26N/07E-28J01	474218	1215434	Q(A)f	385	253	6	U	140.77	12-08-90	24	L
26N/07E-29C01	474245	1215630	Qvt	450	34	6	U	2.76	09-27-90	56	L
26N/07E-29E01	474237	1215650	Qva	400	95	6	H	41.80	09-06-90	20	L
26N/07E-29G01	474240	1215553	Q(A)f	455	123	6	H	31.98 R	09-28-90	6.7	L
26N/07E-29H01	474234	1215551	Qvt	460	70	6	H	17.01	10-30-90	66	L
26N/07E-30A01	474247	1215653	Qva	445	160	6	H	84.03	09-28-90	5.7	LM
26N/07E-30C01	474257	1215730	Qva	330	43	8	P	.39 R	11-13-90	17	L
26N/07E-30G01	474238	1215712	Qvt	290	53	6	H	32.85 R	11-08-90	46	L
26N/07E-30H01	474244	1215654	Q(A)c	420	302	6	H	212.30	11-19-90	--	L
26N/07E-30M01	474231	1215757	--	280	86	--	Z	--	--	--	L
26N/07E-30M02	474231	1215757	Multiple	280	460	6	H	--	--	--	L
26N/07E-30P01	474207	1215746	Qvt	410	60	6	H	47.48	11-06-90	340	LWM
26N/07E-31B01	474201	1215727	Qva	460	125	6	H	116.63	11-08-90	370	L
26N/07E-31B02	474200	1215727	Qva	480	138	6	H	121.31	09-28-90	150	LM
26N/07E-32E01	474148	1215636	Q(A)c	180	180	6	H	96.77 R	11-08-90	44	L
26N/07E-32J01	474128	1215541	Qva	410	78	6	H	53.60	11-07-90	--	L
26N/07E-32K01	474132	1215604	Q(A)c	445	333	6	H	264.14	11-09-90	--	LM
26N/07E-32M01	474132	1215634	Q(A)f	130	227	6	H	123.62	11-07-90	--	LM
26N/07E-32M02	474129	1215636	Q(A)c	85	116	6	H	--	--	37	L
26N/07E-32R01	474120	1215544	Q(A)c	340	256	6	P	202.69 R	11-09-90	46	L

Table A1.--*Physical and hydrologic data for the inventoried wells and springs--Continued*

Local well number	Latitude (degrees/ minutes/ seconds)	Longitude (degrees/ minutes/ seconds)	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Surface casing dia-meter (inches)	Use of water	Water level below land surface (feet)	Date of water level measure-ment (month/ day/year)	Hyd-raulic conduc-tivity (feet per day)	Remarks
26N/07E-33M01	474127	1215531	Qvr	365	18	36	H	2.90	11-08-90	--	L
26N/07E-33M02	474127	1215533	--	385	11.4	38	U	.55	11-08-90	--	--
26N/07E-33M03	474127	1215533	--	388	280	6	H	220.06 R	11-08-90	--	--
26N/07E-33N01	474120	1215533	Qvr	320	75	6	H	50.06	11-09-90	8.3	L
26N/07E-33Q01	474117	1215443	Qvr	310	115	6	H	99.68	11-16-90	--	L
26N/07E-33Q02	474116	1215438	Qvr	290	134	6	H	90.63 R	11-28-90	18	LM
26N/07E-34D01	474202	1215415	Qvr	365	9.5	28	H	4.97 R	11-28-90	--	--
26N/07E-34L01	474136	1215345	Qva	470	152	6	P	129.95	11-26-90	12	L
26N/07E-35D01	474200	1215245	Qva	550	138	6	H	57.75	12-04-90	--	LM

APPENDIX B.--WATER-QUALITY DATA TABLES

[deg. C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; <, not detected at the given concentration; >, concentration is greater than the given value; cols. per 100 mL, colonies per 100 milliliters; --, not determined; Geohydrologic unit: Qal, alluvium; Qvr, Vashon recessional outwash; Qvt, Vashon till; Qva, Vashon advance outwash; Q(A)f, Upper fine-grained unit; Q(A)c, Upper coarse-grained unit; Q(B)f, Lower fine-grained unit; Q(B)c, Lower coarse-grained unit; Br, Bedrock; for more explanation, see figure 10 in the text.]

Table B1.--*Values of field measurements and concentrations of common constituents*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Temper-ature, water (deg. C)	Spe-cific con-duct-ance, field (µS/cm)	Spe-cific con-duct-ance, lab (µS/cm)
23N/08E-03L03	07-30-91	1545	Qal	435	230	10.0	121	112
23N/08E-04L01	08-08-91	1215	Qal	430	47	15.0	81	80
23N/08E-05K02	08-16-91	0900	Qal	430	39	9.5	127	103
23N/08E-08K01	08-15-91	0840	Br	680	240	15.5	830	863
23N/08E-10F03	08-15-91	1425	Qal	450	18.5	11.0	115	116
	08-15-91	1430	Qal	450	18.5	11.0	115	118
23N/08E-13N01	07-30-91	1415	Qal	595	194	11.0	98	100
23N/08E-15J06	07-30-91	1115	Qal	482	40	10.5	141	147
23N/08E-16M01	08-08-91	1500	Br	720	750	16.5	374	379
23N/08E-22A01	08-15-91	1015	Qal	494	18.2	10.0	52	52
23N/08E-24J01	08-15-91	1220	Br	580	178	11.0	267	274
23N/08E-25F01	08-15-91	1845	Qal	630	48	9.0	127	133
24N/06E-02E01	08-02-91	1540	Qvt	530	40	11.5	160	161
24N/06E-06A05	08-03-91	1150	Q(A)c	25	87	13.5	169	169
24N/06E-09E03	08-01-91	1440	Qva	385	251	14.5	172	172
24N/06E-09N02	07-31-91	1345	Qva	310	199	10.0	141	147
	07-31-91	1350	Qva	310	199	10.0	141	146
24N/06E-10H02	08-08-91	1110	Qva	455	155.2	11.0	167	167
	08-08-91	1115	Qva	455	155.2	11.0	167	167
24N/06E-10P02	08-08-91	1400	Qva	355	72	16.0	149	149
24N/06E-12B01	08-02-91	1255	Q(A)c	430	160	12.5	141	142
24N/06E-12L01	08-02-91	1410	Q(A)f	440	362	10.5	154	155
24N/06E-22H02	08-02-91	1110	Qvr	425	86	13.0	166	165
24N/07E-03P01	08-05-91	1215	Q(A)c	90	320	18.5	641	636
24N/07E-04E01	08-09-91	1045	Qal	75	65	15.0	256	283
24N/07E-05F01	08-09-91	1335	Br	400	765	10.5	171	190
24N/07E-06B01	08-09-91	1200	Q(A)c	230	106	12.0	171	189
24N/07E-08A02	08-15-91	1025	Qvt	310	39	11.0	157	156
24N/07E-10K01	08-09-91	0855	Qal	85	36	13.0	152	131
24N/07E-12E02	08-07-91	1445	Qvr	815	115	11.0	86	87
	08-07-91	1450	Qvr	815	115	11.0	86	87
24N/07E-12J01	08-15-91	1130	Br	965	700	10.5	151	152
24N/07E-13E01	07-31-91	1030	Br	295	398	12.5	189	195
24N/07E-14G01	08-07-91	1320	Qal	120	65	14.0	120	122
24N/07E-15D01	07-29-91	1435	Qal	105	49.5	10.5	121	125
24N/07E-16F01	08-06-91	1115	Qvr	150	122	12.5	129	132
24N/07E-17B01	08-05-91	1210	Qvr	210	74	15.0	185	191
24N/07E-18F03	08-05-91	1400	Qva	520	80	10.5	117	118
24N/07E-19R02	08-07-91	1130	Br	1,000	220	15.0	271	276
24N/07E-20J02	08-02-91	1325	Br	1,240	100	12.0	424	446

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	pH, field (standard units)	pH, lab (standard units)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium, percent
23N/08E-03L03	7.7	7.6	0.1	54	16	3.5	3.1	11
23N/08E-04L01	5.9	6.5	2.3	31	9.7	1.7	3.4	19
23N/08E-05K02	6.9	6.7	.0	43	13	2.5	4.4	18
23N/08E-08K01	8.6	8.4	7.0	22	5.1	2.3	200	95
23N/08E-10F03	7.0	7.1	4.7	54	17	2.7	3.0	11
	7.0	7.0	4.7	54	17	2.8	3.0	11
23N/08E-13N01	8.2	8.0	7.2	47	16	1.7	2.3	10
23N/08E-15J06	6.9	7.1	5.5	64	20	3.5	3.3	10
23N/08E-16M01	9.5	9.4	.6	2	.81	.03	88	99
23N/08E-22A01	6.4	6.7	6.0	21	6.8	.97	2.1	18
23N/08E-24J01	8.4	8.2	.1	95	29	5.4	19	30
23N/08E-25F01	7.8	7.6	6.2	61	18	3.9	3.1	10
24N/06E-02E01	7.3	7.5	5.8	68	12	9.3	6.5	17
24N/06E-06A05	8.3	8.0	.5	72	14	9.1	5.7	14
24N/06E-09E03	6.8	7.1	5.8	70	14	8.6	5.9	15
24N/06E-09N02	7.1	7.2	.6	62	9.2	9.4	5.6	16
	7.1	7.3	.6	61	9.0	9.3	5.5	16
24N/06E-10H02	6.7	7.0	9.0	72	15	8.4	6.0	15
	6.7	7.0	9.0	72	15	8.5	6.1	15
24N/06E-10P02	7.8	7.9	.1	64	15	6.5	5.1	14
24N/06E-12B01	8.3	8.3	.1	61	14	6.2	4.5	14
24N/06E-12L01	8.4	8.4	.1	63	16	5.5	4.8	13
24N/06E-22H02	7.8	7.9	.0	70	16	7.2	5.2	14
24N/07E-03P01	8.4	8.3	.1	170	55	7.6	51	39
24N/07E-04E01	8.1	7.8	.0	100	27	8.0	21	31
24N/07E-05F01	7.3	7.5	2.5	86	18	10	5.6	12
24N/07E-06B01	7.6	7.7	2.7	80	14	11	5.9	13
24N/07E-08A02	6.7	6.9	8.0	64	13	7.6	6.4	18
24N/07E-10K01	6.5	6.6	.2	55	15	4.3	5.7	18
24N/07E-12E02	7.0	7.4	7.8	35	7.4	4.0	3.6	18
	7.0	7.4	7.8	35	7.4	4.0	3.6	18
24N/07E-12J01	8.6	8.3	.3	32	10	1.6	22	60
24N/07E-13E01	8.9	8.6	.0	15	5.3	.51	38	84
24N/07E-14G01	6.2	6.8	3.4	51	10	6.4	4.9	17
24N/07E-15D01	6.3	6.5	5.5	44	12	3.3	7.0	25
24N/07E-16F01	6.5	7.2	6.5	53	13	5.1	5.2	17
24N/07E-17B01	6.8	7.2	3.5	75	19	6.6	9.3	21
24N/07E-18F03	6.0	7.3	7.2	45	11	4.3	5.7	21
24N/07E-19R02	9.3	9.3	2	3	1.1	.05	64	98
24N/07E-20J02	7.5	7.7	1.0	250	54	27	4.5	4

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as CaCO$_3$)	Alkalinity, lab (mg/L as CaCO$_3$)	Sulfate, dissolved (mg/L as SO$_4$)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO$_2$)
23N/08E-03L03	0.2	0.9	52	52	7.4	2.4	0.1	12
23N/08E-04L01	.3	.4	--	28	3.8	2.1	<.1	15
23N/08E-05K02	.3	.8	65	53	.1	1.8	<.1	37
23N/08E-08K01	18	1.8	--	266	170	.3	2.5	9.0
23N/08E-10F03	.2	.8	--	51	4.3	2.0	<.1	12
	.2	.8	--	51	4.4	1.2	<.1	13
23N/08E-13N01	.1	.4	--	45	3.1	1.7	.1	12
23N/08E-15J06	.2	.9	--	65	4.3	1.6	.1	15
23N/08E-16M01	26	.3	--	183	6.2	1.0	.9	8.8
23N/08E-22A01	.2	.4	--	22	1.9	1.1	<.1	8.9
23N/08E-24J01	.8	.7	--	70	43	17	<.1	17
23N/08E-25F01	.2	.5	--	55	5.2	.6	<.1	16
24N/06E-02E01	.3	.9	--	74	2.5	2.8	<.1	29
24N/06E-06A05	.3	2.0	--	80	3.8	2.9	<.1	38
24N/06E-09E03	.3	1.3	--	69	5.0	4.9	<.1	28
24N/06E-09N02	.3	1.9	--	62	6.1	3.8	<.1	25
	.3	1.7	--	62	6.1	4.2	.1	25
24N/06E-10H02	.3	1.3	--	68	4.1	5.0	<.1	27
	.3	1.2	--	68	4.0	4.9	<.1	27
24N/06E-10P02	.3	1.9	--	79	2.0	.7	.1	27
24N/06E-12B01	.3	1.7	--	66	4.6	2.1	<.1	25
24N/06E-12L01	.3	3.6	--	69	6.7	2.3	<.1	24
24N/06E-22H02	.3	1.6	--	73	5.1	3.6	<.1	30
24N/07E-03P01	2	2.4	--	81	6.1	140	.1	18
24N/07E-04E01	.9	2.8	--	113	1.1	24	.1	34
24N/07E-05F01	.3	2.0	--	86	8.3	1.5	.1	27
24N/07E-06B01	.3	2.2	--	86	5.9	1.2	.1	31
24N/07E-08A02	.3	1.0	--	55	3.4	3.3	<.1	28
24N/07E-10K01	.3	1.2	77	65	<.1	1.5	<.1	24
24N/07E-12E02	.3	.5	--	37	2.6	2.2	.1	19
	.3	.5	--	35	2.6	2.2	<.1	19
24N/07E-12J01	2	.8	--	75	1.9	.6	.1	23
24N/07E-13E01	4	.4	--	88	10	1.0	<.1	24
24N/07E-14G01	.3	.9	--	53	4.9	3.1	.1	25
24N/07E-15D01	.5	1.4	--	46	3.6	4.7	.1	23
24N/07E-16F01	.3	1.0	--	53	1.5	3.0	<.1	26
24N/07E-17B01	.5	1.4	--	62	7.1	8.2	<.1	21
24N/07E-18F03	.4	.7	--	35	2.8	4.1	<.1	25
24N/07E-19R02	16	.1	--	133	5.1	.5	.1	8.8
24N/07E-20J02	.1	.5	--	239	6.2	4.1	<.1	14

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Solids, sum of constituents, dissolved (mg/L)	Nitrate plus nitrite, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)
23N/08E-03L03	78	<0.05	1,400	73	<1	<1
23N/08E-04L01	58	1.1	580	8	<1	<1
23N/08E-05K02	109	<.05	9,700	390	<1	<1
23N/08E-08K01	551	.14	6	1	<1	<1
23N/08E-10F03	75	.49	8	<1	<1	<1
	75	.49	8	<1	<1	<1
23N/08E-13N01	66	.40	<3	<1	<1	1
23N/08E-15J06	92	.83	35	4	<1	<1
23N/08E-16M01	216	.10	6	<1	<1	<1
23N/08E-22A01	37	.30	17	<1	<1	7
23N/08E-24J01	173	<.05	55	53	<1	<1
23N/08E-25F01	85	1.0	6	2	<1	<1
24N/06E-02E01	113	1.2	<3	<1	<1	<1
24N/06E-06A05	124	.08	46	130	<1	<1
24N/06E-09E03	118	1.9	8	5	<1	<1
24N/06E-09N02	101	.55	230	23	<1	<1
	101	.56	250	23	<1	<1
24N/06E-10H02	114	1.4	<3	<1	<1	6
	114	1.5	<3	<1	<1	8
24N/06E-10P02	106	<.05	75	110	<1	<1
24N/06E-12B01	98	<.05	110	54	<1	<1
24N/06E-12L01	104	<.05	33	47	<1	<1
24N/06E-22H02	113	<.05	440	270	<1	<1
24N/07E-03P01	329	<.05	48	86	<1	<1
24N/07E-04E01	186	<.05	110	110	<1	<1
24N/07E-05F01	125	.30	<3	<1	<1	<1
24N/07E-06B01	127	.96	5	<1	<1	<1
24N/07E-08A02	115	4.4	8	2	<1	<1
24N/07E-10K01	111	<.05	13,000	410	>60	2
24N/07E-12E02	65	.81	10	3	<1	<1
	64	.82	9	3	<1	<1
24N/07E-12J01	105	<.05	63	39	<1	<1
24N/07E-13E01	132	<.05	11	9	<1	<1
24N/07E-14G01	89	.44	14	1	<1	<1
24N/07E-15D01	91	1.9	12	<1	<1	<1
24N/07E-16F01	97	2.4	5	2	<1	<1
24N/07E-17B01	127	3.8	3	<1	<1	<1
24N/07E-18F03	91	3.8	4	<1	<1	<1
24N/07E-19R02	160	<.05	9	2	<1	<1
24N/07E-20J02	254	.05	47	33	<1	<1

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Temper-ature, water (deg. C)	Spe-cific con-duct-ance, field (µS/cm)	Spe-cific con-duct-ance, lab (µS/cm)
24N/07E-21H01	07-29-91	1625	Br	490	118	9.5	158	163
24N/07E-23D01	08-15-91	1640	Qal	105	44	13.5	264	272
24N/07E-23H03	08-02-91	1105	Br	105	223	12.5	305	313
24N/07E-24Q01	08-06-91	1330	Qva	341	119	10.5	166	172
24N/07E-27D01	08-01-91	1415	Q(A)c	250	91	16.0	567	590
24N/07E-33D01	08-01-91	1035	Qvr	530	80	13.0	143	128
24N/07E-36M01	08-01-91	1245	Q(A)c	850	260	14.5	148	152
24N/07E-36R01	07-31-91	1415	Br	790	338	12.0	132	136
24N/08E-18K02	07-30-91	1505	Qva	575	217	13.5	162	168
	07-30-91	1510	Qva	575	217	13.5	162	161
24N/08E-19M01	08-06-91	1445	Br	160	100	13.0	577	595
24N/08E-20M01	07-29-91	1025	Qvr	560	281	12.5	379	407
24N/08E-20R02	07-29-91	1335	Qvr	700	34	11.0	177	175
24N/08E-24Q01S	07-29-91	1040	Br	680	--	9.0	82	84
24N/08E-26K01	07-30-91	1330	Qal	450	59	11.5	75	77
24N/08E-28E02	07-29-91	1240	Qvr	750	108	9.5	156	163
24N/08E-28H01	07-30-91	1100	Qva	1,025	321	11.0	143	148
24N/08E-30N01	07-31-91	1150	Qal	445	26	15.0	50	49
24N/08E-32F01	08-16-91	1040	Q(A)c	420	544	13.5	185	194
25N/06E-01N01	08-01-91	1155	Qva	560	165	12.0	96	95
25N/06E-10J02	08-01-91	1310	Qva	550	194	12.0	123	121
25N/06E-14M01	07-31-91	1445	Qvt	485	58	12.0	253	219
25N/06E-20E01	07-31-91	1600	Q(B)c	70	122	11.5	199	209
25N/06E-24K01	08-01-91	1100	Qvt	420	120	10.5	154	160
25N/06E-25E01	07-31-91	1300	Q(A)c	190	49	11.5	138	139
25N/06E-25K01	08-01-91	1450	Q(A)c	280	335	11.0	177	186
25N/06E-28H01	07-31-91	1130	Qvr	425	47	12.0	186	188
25N/06E-32F03	08-02-91	1715	Q(A)c	50	116	11.5	274	274
25N/06E-34D01	08-02-91	1130	Qva	360	214	10.0	162	170
25N/06E-34E02	08-08-91	0940	Q(B)c	370	714	12.0	154	151
25N/07E-01N01	08-09-91	1450	Qvt	260	98	12.0	380	377
25N/07E-04J01	08-03-91	1555	Qal	60	108	12.5	300	292
	08-03-91	1600	Qal	60	108	12.5	300	293
25N/07E-06B01	08-06-91	1455	Q(A)c	40	490	13.5	330	329
25N/07E-07E01	08-02-91	1545	Q(A)c	55	647	11.0	156	163
25N/07E-07P01	08-03-91	1435	Qvr	130	39	12.0	144	142
25N/07E-08D02	08-06-91	1325	Q(A)c	135	729	13.0	289	288
25N/07E-10E01	08-02-91	1340	Qal	70	44	11.0	160	168
25N/07E-10J01	08-06-91	1145	Qva	460	150	10.5	127	126
25N/07E-11Q01	08-07-91	1415	Q(A)c	190	177	11.0	170	169

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	pH, field (standard units)	pH, lab (standard units)	Oxygen, dis-solved (mg/L)	Hard-ness, total (mg/L as $CaCO_3$)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Sodium, percent
24N/07E-21H01	8.7	8.3	0.9	31	12	0.29	24	63
24N/07E-23D01	7.3	7.3	.1	110	27	10	15	23
24N/07E-23H03	8.8	8.8	.2	9	3.4	.23	70	94
24N/07E-24Q01	8.2	8.2	.2	76	19	6.9	5.1	12
24N/07E-27D01	8.4	8.2	.2	150	46	8.7	55	44
24N/07E-33D01	6.7	6.9	.1	51	13	4.6	5.5	19
24N/07E-36M01	8.4	8.3	.1	53	17	2.6	11	30
24N/07E-36R01	9.1	9.0	.2	11	4.3	.16	27	84
24N/08E-18K02	8.2	8.2	.1	68	19	5.0	7.7	19
	8.2	8.2	.1	68	19	5.1	8.0	20
24N/08E-19M01	8.3	8.2	.1	80	25	4.3	94	71
24N/08E-20M01	7.0	7.2	3.9	200	47	20	12	11
24N/08E-20R02	6.5	6.8	.1	49	12	4.6	16	41
24N/08E-24Q01S	6.8	7.1	10.6	37	12	1.7	1.9	10
24N/08E-26K01	7.1	7.5	9.4	33	11	1.4	2.0	11
24N/08E-28E02	8.4	8.1	.1	77	21	5.9	2.5	7
24N/08E-28H01	8.5	8.3	5.0	71	20	5.1	2.4	7
24N/08E-30N01	5.6	6.0	.7	18	4.7	1.5	2.4	22
24N/08E-32F01	8.2	8.1	.1	76	23	4.5	9.9	21
25N/06E-01N01	6.0	6.3	4.2	36	8.8	3.3	4.7	22
25N/06E-10J02	7.6	7.7	.1	48	12	4.3	6.2	22
25N/06E-14M01	6.5	6.5	.1	91	20	9.9	8.0	16
25N/06E-20E01	7.5	7.7	.0	87	19	9.6	8.5	17
25N/06E-24K01	6.6	6.8	7.8	61	18	3.9	7.8	22
25N/06E-25E01	7.0	7.5	3.2	56	13	5.8	5.3	17
25N/06E-25K01	8.3	8.1	.0	66	21	3.4	13	29
25N/06E-28H01	6.8	7.3	2.0	83	15	11	6.8	15
25N/06E-32F03	6.6	6.8	5.0	120	22	16	8.6	13
25N/06E-34D01	7.2	7.3	2.3	74	15	8.9	5.7	14
25N/06E-34E02	8.2	8.2	.1	61	18	3.9	7.6	20
25N/07E-01N01	7.7	7.8	2.1	41	11	3.2	77	80
25N/07E-04J01	8.7	8.1	.1	37	9.4	3.3	54	74
	8.7	8.1	.1	37	9.3	3.3	51	73
25N/07E-06B01	8.2	8.2	.2	71	21	4.4	44	55
25N/07E-07E01	8.6	8.2	.1	65	17	5.5	8.9	23
25N/07E-07P01	7.4	7.2	5.1	59	11	7.6	5.3	16
25N/07E-08D02	8.2	8.2	.1	100	26	8.4	21	30
25N/07E-10E01	6.7	6.9	6.0	71	14	8.7	6.5	16
25N/07E-10J01	7.6	7.7	2.1	56	13	5.8	4.5	14
25N/07E-11Q01	8.2	8.1	.6	56	16	3.8	13	32

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)	Alkalinity, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
24N/07E-21H01	2	0.1	--	77	5.4	1.0	0.1	11
24N/07E-23D01	.6	2.6	141	141	.6	1.8	<.1	31
24N/07E-23H03	10	.7	--	132	2.8	17	.4	30
24N/07E-24Q01	.3	2.6	--	79	6.5	3.0	.1	28
24N/07E-27D01	2	2.0	--	107	<.1	130	.1	17
24N/07E-33D01	.3	1.0	58	51	8.3	3.7	<.1	20
24N/07E-36M01	.7	1.5	--	76	1.1	.8	<.1	15
24N/07E-36R01	3	.1	--	67	2.7	.9	.1	11
24N/08E-18K02	.4	1.0	--	77	7.6	2.3	.1	19
	.4	1.0	--	77	7.6	2.2	.1	19
24N/08E-19M01	5	1.4	--	139	5.3	100	.2	27
24N/08E-20M01	.4	1.3	--	202	9.6	4.7	<.1	25
24N/08E-20R02	1	1.6	58	58	3.9	19	.1	24
24N/08E-24Q01S	.1	.3	--	34	3.7	.7	<.1	8.5
24N/08E-26K01	.2	.3	--	30	4.5	1.4	.1	9.4
24N/08E-28E02	.1	.4	--	68	12	1.0	<.1	13
24N/08E-28H01	.1	.4	--	62	7.9	3.2	<.1	14
24N/08E-30N01	.2	.2	20	20	1.6	1.9	<.1	16
24N/08E-32F01	.5	4.0	--	96	.8	4.9	.1	30
25N/06E-01N01	.3	.4	--	36	4.4	3.3	<.1	15
25N/06E-10J02	.4	1.1	--	59	1.3	1.3	.1	35
25N/06E-14M01	.4	1.1	103	84	20	3.9	.1	35
25N/06E-20E01	.4	1.5	--	93	8.5	4.2	<.1	22
25N/06E-24K01	.4	.7	--	61	1.9	3.7	<.1	30
25N/06E-25E01	.3	1.3	--	54	6.4	2.6	<.1	21
25N/06E-25K01	.7	1.4	--	91	.9	1.7	<.1	19
25N/06E-28H01	.3	1.3	--	85	5.0	4.0	.1	31
25N/06E-32F03	.3	1.5	--	98	11	8.6	<.1	32
25N/06E-34D01	.3	1.4	--	79	3.9	5.7	<.1	30
25N/06E-34E02	.4	2.8	--	77	.2	3.2	.1	30
25N/07E-01N01	5	1.5	--	197	<.1	7.3	.2	15
25N/07E-04J01	4	2.9	--	139	6.5	7.7	.2	26
	4	3.3	--	139	6.7	7.8	.2	27
25N/07E-06B01	2	7.0	--	159	1.3	11	.2	27
25N/07E-07E01	.5	.9	--	79	3.3	3.1	.1	19
25N/07E-07P01	.3	1.6	--	58	6.4	2.1	<.1	31
25N/07E-08D02	.9	6.7	--	135	11	.7	.1	31
25N/07E-10E01	.3	.9	--	76	4.4	3.1	<.1	28
25N/07E-10J01	.3	1.3	--	54	7.1	2.5	.1	23
25N/07E-11Q01	.8	3.2	--	89	2.3	.6	.2	33

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Solids, sum of constituents, dissolved (mg/L)	Nitrate plus nitrite, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)
24N/07E-21H01	100	0.07	<3	2	<1	<1
24N/07E-23D01	174	<.05	1,500	370	<1	<1
24N/07E-23H03	204	<.05	6	7	<1	<1
24N/07E-24Q01	119	<.05	33	82	<1	<1
24N/07E-27D01	324	<.05	440	64	<1	<1
24N/07E-33D01	97	<.05	5,700	160	<1	<1
24N/07E-36M01	95	<.05	35	32	<1	<1
24N/07E-36R01	86	<.05	11	3	<1	<1
24N/08E-18K02	108	<.05	91	61	<1	<1
	108	<.05	91	60	--	--
24N/08E-19M01	341	<.05	250	83	<1	<1
24N/08E-20M01	245	.89	8	<1	<1	<1
24N/08E-20R02	118	<.05	620	920	<1	<1
24N/08E-24Q01S	52	.55	<3	<1	<1	1
24N/08E-26K01	50	.49	6	<1	<1	1
24N/08E-28E02	97	<.05	22	19	<1	<1
24N/08E-28H01	95	1.0	<3	<1	<1	<1
24N/08E-30N01	41	.07	230	10	<1	<1
24N/08E-32F01	135	<.05	94	80	<1	<1
25N/06E-01N01	65	.52	370	36	<1	<1
25N/06E-10J02	97	<.05	540	160	<1	<1
25N/06E-14M01	174	<.05	14,000	230	<1	<1
25N/06E-20E01	130	<.05	720	230	<1	<1
25N/06E-24K01	117	3.3	8	2	<1	<1
25N/06E-25E01	96	1.7	<3	1	<1	<1
25N/06E-25K01	115	<.05	110	48	<1	<1
25N/06E-28H01	128	.71	13	2	<1	<1
25N/06E-32F03	180	4.9	<3	4	<1	<1
25N/06E-34D01	120	.53	5	<1	<1	1
25N/06E-34E02	112	<.05	23	38	<1	<1
25N/07E-01N01	234	.12	130	26	<1	<1
25N/07E-04J01	193	<.05	39	35	<1	<1
	192	<.05	42	36	<1	<1
25N/07E-06B01	211	<.05	25	35	<1	<1
25N/07E-07E01	105	<.05	43	40	<1	<1
25N/07E-07P01	106	1.4	18	1	<1	<1
25N/07E-08D02	186	<.05	18	41	<1	<1
25N/07E-10E01	114	.67	4	4	<1	<1
25N/07E-10J01	92	.42	14	13	<1	<1
25N/07E-11Q01	126	<.05	58	43	<1	<1

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Temper-ature, water (deg. C)	Spe-cific con-duct-ance, field (µS/cm)	Spe-cific con-duct-ance, lab (µS/cm)
25N/07E-15C01	08-07-91	1300	Q(A)c	65	103	12.5	262	262
25N/07E-15R02	08-05-91	1245	Qvr	240	115	11.0	135	141
25N/07E-17A01	08-01-91	1255	Qva	425	247	10.5	111	115
25N/07E-20P01	08-05-91	1600	Q(A)c	160	269	11.5	316	312
25N/07E-21C01	08-05-91	1500	Qal	70	35	8.5	57	59
25N/07E-23Q01S	08-16-91	1530	Qvt	450	--	9.5	119	120
25N/07E-26F01S	08-07-91	1600	Qvr	380	--	17.5	111	109
25N/07E-27D01	08-09-91	1240	Qvr	100	95	10.5	245	244
25N/07E-28Q01	08-05-91	1425	Qal	85	25	13.5	127	127
25N/07E-29H02	08-07-91	1135	Q(A)c	70	214	12.0	312	307
25N/07E-30F01	08-03-91	1325	Q(A)c	425	241	10.5	148	148
25N/07E-31D01	08-09-91	1045	Qal	115	95	13.0	147	147
25N/07E-31J01	08-05-91	1800	Q(A)c	315	241	16.5	233	230
25N/07E-33Q01	08-05-91	1320	Q(A)c	80	100	12.5	178	178
25N/07E-34E02	08-16-91	0930	Qvr	280	220	14.5	130	129
26N/06E-02M01	08-07-91	1300	Q(A)c	490	229	10.0	158	163
26N/06E-04J02	08-08-91	1020	Br	500	200	12.5	142	156
26N/06E-09B02	08-08-91	0900	Qva	435	90	11.0	188	207
26N/06E-10A01	08-06-91	1000	Qva	470	112	13.0	199	220
26N/06E-13D03	08-05-91	1320	Q(A)c	45	215	11.0	267	296
26N/06E-13J01	08-16-91	1250	Qva	405	90	14.5	148	147
	08-16-91	1255	Qva	405	90	14.5	148	147
26N/06E-14D01	08-05-91	1145	Q(A)c	230	83	12.0	209	232
26N/06E-22K02	08-07-91	1525	Qva	548	190	11.0	82	84
26N/06E-24D01	08-06-91	0830	Q(A)c	125	251	12.0	263	296
26N/06E-25F01	08-07-91	1510	Qvt	60	58	17.0	240	266
26N/06E-26D03	08-14-91	1450	Qva	250	101	15.5	216	214
26N/07E-03M01	08-06-91	1205	Br	778	160	12.5	435	489
26N/07E-04D01	08-06-91	1435	Br	920	50	11.0	233	255
	08-06-91	1440	Br	920	50	11.0	233	254
26N/07E-06K01	08-14-91	1320	Br	50	40	15.5	260	258
26N/07E-08A01	08-05-91	1620	Br	600	120	11.0	194	216
26N/07E-09F02	08-07-91	1100	Br	295	30	11.0	108	111
26N/07E-14G02	08-16-91	1115	Br	640	182	16.5	220	206
26N/07E-16A01	08-06-91	1640	Br	260	96	10.5	194	216
26N/07E-16L02	08-08-91	1405	Qva	450	134	13.0	109	121
26N/07E-17C01	08-07-91	1130	Q(A)f	80	211	12.5	228	253
26N/07E-18B01	08-07-91	1635	Qva	60	46	11.0	98	111
26N/07E-18N01	08-07-91	1400	Q(A)c	418	210	11.0	201	217
26N/07E-19J02	08-08-91	1125	Q(A)f	460	416	14.0	291	322

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	pH, field (standard units)	pH, lab (standard units)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium, percent
25N/07E-15C01	8.2	8.2	0.1	44	12	3.4	43	66
25N/07E-15R02	7.3	7.7	6.2	58	15	4.9	5.5	17
25N/07E-17A01	7.5	7.5	1.7	47	6.1	7.7	4.1	15
25N/07E-20P01	8.1	8.1	.1	150	39	12	7.6	10
25N/07E-21C01	6.5	6.8	4.2	23	7.1	1.4	2.0	15
25N/07E-23Q01S	6.6	7.5	8.6	46	11	4.5	4.2	16
25N/07E-26F01S	6.5	6.7	10.3	38	8.7	3.9	5.9	25
25N/07E-27D01	8.6	8.4	.2	67	18	5.4	27	46
25N/07E-28Q01	6.0	6.3	2.5	45	12	3.6	6.5	22
25N/07E-29H02	8.1	8.0	.1	120	32	8.7	19	25
25N/07E-30F01	7.8	7.5	8.3	59	11	7.7	5.1	15
25N/07E-31D01	8.3	8.1	.3	64	15	6.5	4.5	13
25N/07E-31J01	8.0	8.0	.1	100	22	11	8.5	15
25N/07E-33Q01	6.8	7.1	5.6	75	17	7.8	7.0	17
25N/07E-34E02	7.1	7.5	9.1	39	10	3.4	12	40
26N/06E-02M01	8.3	8.0	.1	73	18	6.8	5.1	13
26N/06E-04J02	7.3	7.5	6.6	64	16	5.8	5.8	16
26N/06E-09B02	7.9	8.1	.0	79	24	4.7	12	24
26N/06E-10A01	7.0	7.2	1.7	95	20	11	11	20
26N/06E-13D03	8.6	8.4	.3	83	25	5.0	36	48
26N/06E-13J01	6.4	7.3	5.4	62	13	7.2	4.9	14
	6.4	7.8	5.4	62	13	7.2	4.9	14
26N/06E-14D01	8.6	8.4	.2	33	10	1.9	43	73
26N/06E-22K02	7.9	7.7	7.2	32	7.1	3.4	4.7	24
26N/06E-24D01	8.6	8.5	.5	54	18	2.2	48	65
26N/06E-25F01	8.2	8.1	.1	110	26	11	12	18
26N/06E-26D03	8.2	8.2	.2	100	27	8.8	5.7	11
26N/07E-03M01	8.9	8.7	.1	7	1.8	.55	120	97
26N/07E-04D01	6.9	7.0	1.2	89	24	7.0	17	29
	6.9	7.0	1.2	90	24	7.2	18	30
26N/07E-06K01	6.6	6.9	6.1	110	25	12	12	19
26N/07E-08A01	6.9	7.1	6.4	82	25	4.7	15	28
26N/07E-09F02	6.0	6.3	8.2	45	15	1.8	5.1	20
26N/07E-14G02	8.4	9.1	1.8	3	1.0	.12	44	94
26N/07E-16A01	8.6	8.3	--	2	.79	.11	52	97
26N/07E-16L02	8.2	8.0	.0	50	14	3.7	4.4	16
26N/07E-17C01	8.6	8.3	.5	45	12	3.6	41	64
26N/07E-18B01	6.8	7.1	6.2	45	9.9	5.0	3.8	15
26N/07E-18N01	7.9	7.8	.0	90	21	9.0	11	20
26N/07E-19J02	8.4	8.4	.2	61	19	3.2	54	65

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)	Alkalinity, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
25N/07E-15C01	3	2.9	--	133	6.6	0.7	0.2	20
25N/07E-15R02	.3	.9	--	59	8.4	4.1	<.1	21
25N/07E-17A01	.3	1.5	--	48	4.9	2.8	<.1	29
25N/07E-20P01	.3	3.7	--	128	34	3.2	<.1	29
25N/07E-21C01	.2	.4	--	23	4.3	1.6	<.1	9.5
25N/07E-23Q01S	.3	.9	--	49	5.4	2.1	<.1	20
25N/07E-26F01S	.4	.4	--	24	1.4	2.8	<.1	24
25N/07E-27D01	1	1.6	--	122	3.8	6.4	<.1	17
25N/07E-28Q01	.4	4.1	--	47	7.9	4.0	<.1	17
25N/07E-29H02	.8	6.7	--	148	12	7.4	.2	34
25N/07E-30F01	.3	1.9	--	63	3.7	4.4	<.1	29
25N/07E-31D01	.2	1.5	--	59	16	1.2	<.1	21
25N/07E-31J01	.4	3.8	--	121	<.1	3.2	.2	43
25N/07E-33Q01	.4	1.2	--	68	4.3	4.5	<.1	28
25N/07E-34E02	.8	.8	--	52	8.2	3.5	<.1	20
26N/06E-02M01	.3	1.6	--	71	9.5	2.8	.1	18
26N/06E-04J02	.3	2.8	--	63	12	2.1	.1	43
26N/06E-09B02	.6	4.4	--	97	9.9	.7	.2	36
26N/06E-10A01	.5	1.0	--	105	8.1	7.1	.2	21
26N/06E-13D03	2	2.5	--	149	1.7	6.3	<.1	15
26N/06E-13J01	.3	1.1	--	61	7.2	3.1	<.1	21
	.3	1.1	--	61	7.3	3.1	<.1	21
26N/06E-14D01	3	.9	--	116	3.5	1.4	.1	17
26N/06E-22K02	.4	.6	--	38	.8	2.1	.1	27
26N/06E-24D01	3	1.9	--	143	6.6	6.8	<.1	14
26N/06E-25F01	.5	5.5	--	126	12	3.8	.1	30
26N/06E-26D03	.2	1.6	--	96	16	2.8	<.1	20
26N/07E-03M01	20	.9	--	242	9.7	8.3	.3	21
26N/07E-04D01	.8	.3	--	78	50	2.7	.1	38
	.8	.2	--	74	50	2.7	.1	38
26N/07E-06K01	.5	.2	--	105	7.8	9.5	<.1	37
26N/07E-08A01	.7	.4	--	98	5.1	3.3	.1	25
26N/07E-09F02	.3	.5	--	40	2.2	3.9	<.1	21
26N/07E-14G02	11	2.3	--	96	4.2	6.1	<.1	23
26N/07E-16A01	15	.4	--	111	2.0	3.0	.2	15
26N/07E-16L02	.3	1.0	--	54	4.8	.6	.1	20
26N/07E-17C01	3	4.0	--	131	.1	3.4	<.1	24
26N/07E-18B01	.2	1.2	--	42	5.9	3.6	.1	23
26N/07E-18N01	.5	3.3	--	110	.2	3.5	.2	32
26N/07E-19J02	3	2.5	--	175	<.1	4.2	<.1	15

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Solids, sum of constituents, dissolved (mg/L)	Nitrate plus nitrite, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)
25N/07E-15C01	169	<0.05	34	34	<1	<1
25N/07E-15R02	96	.18	23	1	--	--
25N/07E-17A01	89	.80	39	43	<1	<1
25N/07E-20P01	205	<.05	47	130	<1	<1
25N/07E-21C01	42	.32	13	2	--	--
25N/07E-23Q01S	82	1.1	6	5	<1	<1
25N/07E-26F01S	89	6.3	15	3	<1	<1
25N/07E-27D01	152	<.05	10	22	<1	<1
25N/07E-28Q01	89	1.2	92	2	<1	<1
25N/07E-29H02	209	<.05	55	100	<1	<1
25N/07E-30F01	104	.65	8	2	<1	<1
25N/07E-31D01	101	<.05	24	110	<1	<1
25N/07E-31J01	165	<.05	210	180	<1	<1
25N/07E-33Q01	124	3.1	4	4	<1	<1
25N/07E-34E02	92	.64	13	6	<1	8
26N/06E-02M01	105	<.05	180	66	<1	<1
26N/06E-04J02	126	.12	25	50	<1	<1
26N/06E-09B02	150	<.05	150	52	<1	<1
26N/06E-10A01	144	.28	44	25	<1	<1
26N/06E-13D03	181	<.05	21	24	<1	<1
26N/06E-13J01	99	1.1	11	5	<1	<1
	99	1.1	9	4	<1	<1
26N/06E-14D01	147	<.05	12	11	<1	<1
26N/06E-22K02	71	.42	16	4	<1	<1
26N/06E-24D01	183	<.05	14	15	<1	<1
26N/06E-25F01	176	<.05	23	54	<1	<1
26N/06E-26D03	140	<.05	180	77	--	--
26N/07E-03M01	308	<.05	84	7	<1	1
26N/07E-04D01	186	<.05	70	290	<1	<1
	185	<.05	74	290	--	--
26N/07E-06K01	178	2.7	15	<1	5	7
26N/07E-08A01	145	1.6	15	5	<1	1
26N/07E-09F02	86	2.8	86	6	<1	<1
26N/07E-14G02	139	.10	47	3	<1	2
26N/07E-16A01	140	.07	5	1	<1	<1
26N/07E-16L02	81	<.05	200	91	<1	<1
26N/07E-17C01	167	<.05	70	29	<1	<1
26N/07E-18B01	83	1.3	5	12	<1	<1
26N/07E-18N01	147	<.05	500	260	<1	<1
26N/07E-19J02	203	<.05	130	28	<1	17

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Land surface elev-ation (feet above sea level)	Depth of well below land surface (feet)	Temper-ature, water (deg. C)	Spe-cific con-duct-ance, field (µS/cm)	Spe-cific con-duct-ance, lab (µS/cm)
26N/07E-19P01	08-08-91	1240	Qva	305	113	11.5	160	174
26N/07E-20E01	08-06-91	1530	Qva	485	260	10.5	177	178
26N/07E-22D01	08-07-91	0955	Qva	480	45	11.0	103	115
26N/07E-27F01	08-07-91	1230	Br	347	225	12.5	593	653
26N/07E-28E02	08-08-91	1130	Qva	500	113	9.0	128	133
26N/07E-30A01	08-08-91	1600	Qva	445	160	10.0	164	173
26N/07E-30P01	08-06-91	1325	Qvt	410	60	9.5	96	99
26N/07E-31B02	08-06-91	1145	Qva	480	138	9.5	140	146
26N/07E-32K01	08-09-91	1200	Q(A)c	445	333	11.0	175	180
26N/07E-32M01	08-08-91	1410	Q(A)f	130	227	12.0	173	181
26N/07E-33Q02	08-09-91	1220	Qvr	290	134	9.0	172	178
26N/07E-35D01	08-15-91	1335	Qva	550	138	11.5	417	413
BLANK - Deionized water	07-30-91	1530	--	--	--	--	--	1
	08-03-91	1630	--	--	--	--	--	4
	08-06-91	1505	--	--	--	--	--	3
	08-07-91	1330	--	--	--	--	--	2
	08-07-91	1515	--	--	--	--	--	1
	08-08-91	1140	--	--	--	--	--	2
	08-15-91	1455	--	--	--	--	--	2
	08-16-91	1320	--	--	--	--	--	3

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	pH, field (standard units)	pH, lab (standard units)	Oxygen, dis-solved (mg/L)	Hard-ness, total (mg/L as $CaCO_3$)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Sodium, percent
26N/07E-19P01	7.9	7.7	0.1	77	21	5.9	6.3	15
26N/07E-20E01	8.0	7.9	7.4	79	20	7.1	7.3	16
26N/07E-22D01	7.4	7.7	3.8	47	12	4.1	5.7	21
26N/07E-27F01	8.0	8.0	.3	95	35	1.9	100	69
26N/07E-28E02	7.4	7.5	4.8	57	11	7.1	4.1	13
26N/07E-30A01	8.2	8.0	.1	73	21	5.1	6.9	17
26N/07E-30P01	6.7	7.0	7.6	40	8.6	4.6	4.1	18
26N/07E-31B02	7.5	7.6	6.9	62	11	8.3	6.1	17
26N/07E-32K01	8.5	8.2	.0	58	17	3.8	14	33
26N/07E-32M01	8.5	8.1	.0	68	20	4.5	11	25
26N/07E-33Q02	6.9	7.1	5.0	79	19	7.6	6.1	14
26N/07E-35D01	7.8	7.9	.1	160	40	15	33	30
BLANK - Deionized water	--	7.5	--	0	.04	.04	<.2	--
	--	7.4	--	--	<.02	<.01	<.2	--
	--	6.9	--	0	.07	.04	<.2	--
	--	6.4	--	--	<.02	<.01	<.2	--
	--	7.2	--	--	<.02	.03	<.2	--
	--	6.6	--	0	.05	.07	<.2	--
	--	6.5	--	0	.04	.06	<.2	--
	--	7.2	--	0	.03	.02	<.2	--

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Sodium ad-sorp-tion ratio	Potas-sium, dis-solved (mg/L as K)	Alka-linity, field (mg/L as CaCO$_3$)	Alka-linity, lab (mg/L as CaCO$_3$)	Sulfate, dis-solved (mg/L as SO$_4$)	Chlo-ride, dis-solved (mg/L as Cl)	Fluo-ride, dis-solved (mg/L as F)	Silica, dis-solved (mg/L as SiO$_2$)
26N/07E-19P01	0.3	2.8	--	87	1.5	0.7	0.2	24
26N/07E-20E01	.4	2.8	--	86	6.6	3.1	.2	21
26N/07E-22D01	.4	.7	--	49	6.8	2.3	.1	18
26N/07E-27F01	4	1.2	--	219	.7	77	.2	18
26N/07E-28E02	.2	.8	--	49	3.9	3.0	.1	21
26N/07E-30A01	.4	2.0	--	85	1.2	.7	.2	19
26N/07E-30P01	.3	.6	--	34	4.8	2.9	.1	22
26N/07E-31B02	.3	1.1	--	66	6.5	3.0	.1	26
26N/07E-32K01	.8	2.7	--	90	4.7	.6	<.1	25
26N/07E-32M01	.6	2.6	--	87	4.9	.7	.1	27
26N/07E-33Q02	.3	1.1	--	69	5.8	5.3	<.1	25
26N/07E-35D01	1	1.6	--	231	.9	3.5	.1	22
BLANK - Deionized water	--	<.1	--	2.0	.1	<.1	<.1	<.1
	--	<.1	--	2.7	<.1	.4	<.1	.1
	--	<.1	--	2.5	.2	.4	<.1	.3
	--	<.1	--	2.1	.1	.5	<.1	.1
	--	<.1	--	1.3	<.1	<.1	<.1	.1
	--	<.1	--	3.0	.1	.8	<.1	.1
	--	<.1	--	2.0	<.1	<.1	<.1	<.1
	--	<.1	--	2.5	<.1	<.1	<.1	.1

Table B1.--*Values of field measurements and concentrations of common constituents--Continued*

Local well number	Solids, sum of constituents, dissolved (mg/L)	Nitrate plus nitrite, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)
26N/07E-19P01	115	<0.05	230	340	<1	<1
26N/07E-20E01	122	.40	6	1	<1	2
26N/07E-22D01	80	22	24	33	<1	<1
26N/07E-27F01	366	<.05	200	46	<1	<1
26N/07E-28E02	92	2.5	7	2	<1	<1
26N/07E-30A01	107	<.05	120	56	<1	<1
26N/07E-30P01	77	1.9	20	1	<1	<1
26N/07E-31B02	103	.29	13	<1	<1	<1
26N/07E-32K01	122	<.05	32	48	<1	<1
26N/07E-32M01	123	<.05	32	86	<1	<1
26N/07E-33Q02	123	2.7	9	<1	<1	1
26N/07E-35D01	255	<.05	210	180	<1	2
BLANK - Deionized water	--	<.05	<3	<1	--	--
	--	<.05	<3	<1	--	--
	--	<.05	14	1	--	--
	--	<.05	<3	<1	--	--
	--	<.05	<3	<1	--	--
	--	<.05	4	<1	--	--
	--	<.05	5	<1	--	--
	--	<.05	3	<1	--	--

Table B2.--*Concentrations of selected trace elements*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Cadmium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Copper, dis-solved (µg/L as Cu)
23N/08E-03L03	07-30-91	1545	Qal	3	7	<1	<1	<1
23N/08E-04L01	08-08-91	1215	Qal	<1	<2	<1	<1	6
23N/08E-05K02	08-16-91	0900	Qal	19	6	<1	<1	<1
23N/08E-08K01	08-15-91	0840	Br	<1	10	<1	<1	61
23N/08E-10F03	08-15-91	1425	Qal	<1	5	<1	<1	<1
	08-15-91	1430	Qal	1	5	<1	<1	<1
23N/08E-13N01	07-30-91	1415	Qal	3	<2	<1	<1	<1
23N/08E-15J06	07-30-91	1115	Qal	<1	3	<1	<1	1
23N/08E-16M01	08-08-91	1500	Br	1	21	<1	<1	<1
23N/08E-22A01	08-15-91	1015	Qal	<1	2	<1	<1	2
23N/08E-24J01	08-15-91	1220	Br	5	6	<1	<1	<1
23N/08E-25F01	08-15-91	1845	Qal	2	2	<1	<1	<1
24N/06E-02E01	08-02-91	1540	Qvt	2	3	<1	5	<1
24N/06E-06A05	08-03-91	1150	Q(A)c	<1	8	<1	<1	<1
24N/06E-09E03	08-01-91	1440	Qva	1	4	<1	<1	13
24N/06E-09N02	07-31-91	1345	Qva	1	6	<1	<1	<1
	07-31-91	1350	Qva	1	6	<1	<1	<1
24N/06E-10H02	08-08-91	1110	Qva	1	2	<1	1	6
	08-08-91	1115	Qva	1	<2	<1	<1	6
24N/06E-10P02	08-08-91	1400	Qva	9	3	<1	<1	13
24N/06E-12B01	08-02-91	1255	Q(A)c	4	6	<1	<1	<1
24N/06E-12L01	08-02-91	1410	Q(A)f	9	6	<1	<1	<1
24N/06E-22H02	08-02-91	1110	Qvr	2	5	<1	1	<1
24N/07E-03P01	08-05-91	1215	Q(A)c	11	28	<1	<1	<1
24N/07E-04E01	08-09-91	1045	Qal	5	14	<1	<1	<1
24N/07E-05F01	08-09-91	1335	Br	2	2	<1	2	1
24N/07E-06B01	08-09-91	1200	Q(A)c	2	3	<1	3	2
24N/07E-08A02	08-15-91	1025	Qvt	<1	2	<1	<1	1
24N/07E-10K01	08-09-91	0855	Qal	10	8	<1	<1	<1
24N/07E-12E02	08-07-91	1445	Qvr	<1	<2	<1	<1	4
	08-07-91	1450	Qvr	<1	<2	<1	2	2
24N/07E-12J01	08-15-91	1130	Br	8	2	<1	<1	<1
24N/07E-13E01	07-31-91	1030	Br	9	<2	<1	<1	<1
24N/07E-14G01	08-07-91	1320	Qal	<1	5	<1	<1	6
24N/07E-15D01	07-29-91	1435	Qal	10	4	<1	<1	2
24N/07E-16F01	08-06-91	1115	Qvr	<1	2	<1	<1	76
24N/07E-17B01	08-05-91	1210	Qvr	1	3	<1	<1	2
24N/07E-18F03	08-05-91	1400	Qva	<1	2	<1	<1	7
24N/07E-19R02	08-07-91	1130	Br	<1	<2	<1	<1	2
24N/07E-20J02	08-02-91	1325	Br	2	75	<1	1	1

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Lead, dis-solved (µg/L as Pb)	Mercury, dis-solved (µg/L as Hg)	Sele-nium, dis-solved (µg/L as Se)	Silver, dis-solved (µg/L as Ag)	Zinc, dis-solved (µg/L as Zn)	Radon 222, total (pCi/L)
23N/08E-03L03	<1	<0.1	<1	<1.0	71	--
23N/08E-04L01	<1	<.1	<1	<1	100	450
23N/08E-05K02	<1	<.1	<1	<1	19	--
23N/08E-08K01	5	<.1	<1	<1	99	180
23N/08E-10F03	<1	<.1	<1	<1	<3	--
	<1	<.1	<1	<1	6	--
23N/08E-13N01	<1	<.1	<1	<1	<3	--
23N/08E-15J06	<1	<.1	<1	<1	170	--
23N/08E-16M01	<1	<.1	<1	<1	<3	--
23N/08E-22A01	<1	<.1	<1	<1	9	--
23N/08E-24J01	<1	<.1	<1	<1	10	<80
23N/08E-25F01	<1	<.1	<1	<1	4	--
24N/06E-02E01	<1	<.1	<1	<1	<3	--
24N/06E-06A05	<1	.2	<1	<1	<3	--
24N/06E-09E03	<1	<.1	<1	<1	150	--
24N/06E-09N02	<1	<.1	<1	<1	20	--
	<1	<.1	<1	<1	18	--
24N/06E-10H02	<1	<.1	<1	<1	15	260
	<1	<.1	<1	<1	14	220
24N/06E-10P02	<1	<.1	<1	<1	10	--
24N/06E-12B01	<1	<.1	<1	<1	23	--
24N/06E-12L01	<1	<.1	<1	<1	3	--
24N/06E-22H02	<1	<.1	<1	<1	11	--
24N/07E-03P01	<1	<.1	<1	<1	3	--
24N/07E-04E01	<1	<.1	<1	<1	9	--
24N/07E-05F01	<1	<.1	<1	<1	14	260
24N/07E-06B01	<1	<.1	<1	<1	33	--
24N/07E-08A02	<1	.1	<1	<1	55	--
24N/07E-10K01	<1	<.1	<1	<1	62	--
24N/07E-12E02	<1	<.1	<1	<1	130	190
	<1	<.1	<1	<1	130	240
24N/07E-12J01	<1	<.1	<1	<1	120	--
24N/07E-13E01	<1	<.1	<1	<1	<3	--
24N/07E-14G01	<1	<.1	<1	<1	43	--
24N/07E-15D01	<1	<.1	<1	<1	7	530
24N/07E-16F01	<1	<.1	<1	<1	21	210
24N/07E-17B01	<1	<.1	<1	<1	76	--
24N/07E-18F03	<1	<.1	<1	<1	4	--
24N/07E-19R02	<1	<.1	<1	<1	<3	--
24N/07E-20J02	<1	<.1	<1	<1	70	--

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Cadmium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Copper, dis-solved (µg/L as Cu)
24N/07E-21H01	07-29-91	1625	Br	5	<2	<1	<1	<1
24N/07E-23D01	08-15-91	1640	Qal	11	17	<1	<1	<1
24N/07E-23H03	08-02-91	1105	Br	<1	<2	<1	<1	<1
24N/07E-24Q01	08-06-91	1330	Qva	8	7	<1	<1	1
24N/07E-27D01	08-01-91	1415	Q(A)c	8	10	<1	<1	2
24N/07E-33D01	08-01-91	1035	Qvr	1	8	<1	<1	<1
24N/07E-36M01	08-01-91	1245	Q(A)c	1	3	<1	<1	<1
24N/07E-36R01	07-31-91	1415	Br	4	<2	<1	<1	<1
24N/08E-18K02	07-30-91	1505	Qva	8	5	<1	<1	<1
	07-30-91	1510	Qva	9	6	<1	<1	<1
24N/08E-19M01	08-06-91	1445	Br	3	9	<1	<1	<1
24N/08E-20M01	07-29-91	1025	Qvr	2	7	<1	<1	3
24N/08E-20R02	07-29-91	1335	Qvr	2	11	<1	1	<1
24N/08E-24Q01S	07-29-91	1040	Br	<1	4	<1	<1	2
24N/08E-26K01	07-30-91	1330	Qal	<1	2	<1	<1	<1
24N/08E-28E02	07-29-91	1240	Qvr	6	7	<1	<1	<1
24N/08E-28H01	07-30-91	1100	Qva	6	9	<1	<1	<1
24N/08E-30N01	07-31-91	1150	Qal	<1	<2	<1	<1	4
24N/08E-32F01	08-16-91	1040	Q(A)c	3	14	<1	<1	<1
25N/06E-01N01	08-01-91	1155	Qva	<1	2	<1	<1	61
25N/06E-10J02	08-01-91	1310	Qva	10	6	<1	<1	<1
25N/06E-14M01	07-31-91	1445	Qvt	<1	15	<1	<1	<1
25N/06E-20E01	07-31-91	1600	Q(B)c	2	13	<1	<1	<1
25N/06E-24K01	08-01-91	1100	Qvt	<1	4	<1	1	2
25N/06E-25E01	07-31-91	1300	Q(A)c	2	<2	<1	<1	14
25N/06E-25K01	08-01-91	1450	Q(A)c	19	9	<1	<1	<1
25N/06E-28H01	07-31-91	1130	Qvr	1	5	<1	<1	17
25N/06E-32F03	08-02-91	1715	Q(A)c	<1	6	<1	<1	8
25N/06E-34D01	08-02-91	1130	Qva	2	3	<1	<1	<1
25N/06E-34E02	08-08-91	0940	Q(B)c	<1	8	<1	<1	12
25N/07E-01N01	08-09-91	1450	Qvt	9	21	<1	<1	<1
25N/07E-04J01	08-03-91	1555	Qal	26	10	<1	<1	<1
	08-03-91	1600	Qal	26	10	<1	<1	<1
25N/07E-06B01	08-06-91	1455	Q(A)c	31	15	<1	<1	6
25N/07E-07E01	08-02-91	1545	Q(A)c	<1	<2	<1	<1	<1
25N/07E-07P01	08-03-91	1435	Qvr	2	3	<1	2	24
25N/07E-08D02	08-06-91	1325	Q(A)c	19	12	<1	<1	<1
25N/07E-10E01	08-02-91	1340	Qal	<1	3	<1	<1	3
25N/07E-10J01	08-06-91	1145	Qva	2	5	<1	<1	2
25N/07E-11Q01	08-07-91	1415	Q(A)c	9	11	<1	<1	<1

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Lead, dis- solved (µg/L as Pb)	Mercury, dis- solved (µg/L as Hg)	Sele- nium, dis- solved (µg/L as Se)	Silver, dis- solved (µg/L as Ag)	Zinc, dis- solved (µg/L as Zn)	Radon 222, total (pCi/L)
24N/07E-21H01	<1	<0.1	<1	<1	18	--
24N/07E-23D01	<1	<.1	<1	<1	19	--
24N/07E-23H03	<1	<.1	<1	<1	<3	--
24N/07E-24Q01	<1	<.1	<1	<1	15	--
24N/07E-27D01	<1	<.1	<1	<1	5	--
24N/07E-33D01	<1	<.1	<1	<1	62	--
24N/07E-36M01	<1	<.1	<1	<1	18	--
24N/07E-36R01	<1	<.1	<1	<1	7	--
24N/08E-18K02	<1	<.1	<1	<1	28	--
	<1	<.1	<1	<1	28	--
24N/08E-19M01	<1	<.1	<1	<1	<3	--
24N/08E-20M01	<1	<.1	<1	<1	150	--
24N/08E-20R02	<1	<.1	<1	<1	11	--
24N/08E-24Q01S	<1	<.1	<1	<1	6	--
24N/08E-26K01	<1	<.1	<1	<1	<3	--
24N/08E-28E02	<1	<.1	<1	<1	32	--
24N/08E-28H01	<1	<.1	<1	<1	66	190
24N/08E-30N01	<1	.2	<1	<1	140	--
24N/08E-32F01	<1	<.1	<1	<1	<3	--
25N/06E-01N01	<1	<.1	<1	<1	510	--
25N/06E-10J02	<1	.1	<1	<1	77	--
25N/06E-14M01	<1	<.1	<1	<1	10	440
25N/06E-20E01	<1	<.1	<1	<1	48	--
25N/06E-24K01	<1	.1	<1	<1	22	--
25N/06E-25E01	<1	<.1	<1	<1	270	--
25N/06E-25K01	<1	<.1	<1	<1	5	150
25N/06E-28H01	<1	<.1	<1	<1	81	--
25N/06E-32F03	<1	<.1	<1	<1	5	--
25N/06E-34D01	<1	<.1	<1	<1	5	--
25N/06E-34E02	<1	<.1	<1	<1	<3	--
25N/07E-01N01	<1	<.1	<1	<1	<3	--
25N/07E-04J01	<1	<.1	<1	<1	<3	--
	<1	<.1	<1	<1	<3	--
25N/07E-06B01	<1	.8	<1	<1	<3	--
25N/07E-07E01	<1	<.1	<1	<1	<3	--
25N/07E-07P01	<1	<.1	<1	<1	4	280
25N/07E-08D02	<1	<.1	<1	<1	5	--
25N/07E-10E01	<1	<.1	<1	<1	<3	--
25N/07E-10J01	<1	<.1	<1	<1	15	--
25N/07E-11Q01	<1	<.1	<1	<1	29	--

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Cadmium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Copper, dis-solved (µg/L as Cu)
25N/07E-15C01	08-07-91	1300	Q(A)c	30	9	<1	<1	<1
25N/07E-15R02	08-05-91	1245	Qvr	2	<2	<1	1	3
25N/07E-17A01	08-01-91	1255	Qva	2	4	<1	<1	1
25N/07E-20P01	08-05-91	1600	Q(A)c	14	10	<1	<1	4
25N/07E-21C01	08-05-91	1500	Qal	<1	<2	<1	<1	6
25N/07E-23Q01S	08-16-91	1530	Qvt	1	<2	<1	3	4
25N/07E-26F01S	08-07-91	1600	Qvr	<1	3	<1	1	<1
25N/07E-27D01	08-09-91	1240	Qvr	2	8	<1	<1	<1
25N/07E-28Q01	08-05-91	1425	Qal	<1	7	<1	2	10
25N/07E-29H02	08-07-91	1135	Q(A)c	9	19	<1	<1	3
25N/07E-30F01	08-03-91	1325	Q(A)c	1	4	<1	2	1
25N/07E-31D01	08-09-91	1045	Qal	2	6	<1	<1	<1
25N/07E-31J01	08-05-91	1800	Q(A)c	<1	14	<1	<1	3
25N/07E-33Q01	08-05-91	1320	Q(A)c	<1	4	<1	2	1
25N/07E-34E02	08-16-91	0930	Qvr	<1	2	<1	<1	<1
26N/06E-02M01	08-07-91	1300	Q(A)c	3	4	<1	<1	<1
26N/06E-04J02	08-08-91	1020	Br	2	24	<1	<1	35
26N/06E-09B02	08-08-91	0900	Qva	12	14	<1	<1	6
26N/06E-10A01	08-06-91	1000	Qva	<1	5	<1	2	15
26N/06E-13D03	08-05-91	1320	Q(A)c	37	23	<1	<1	2
26N/06E-13J01	08-16-91	1250	Qva	<1	2	<1	<1	3
	08-16-91	1255	Qva	<1	2	<1	<1	1
26N/06E-14D01	08-05-91	1145	Q(A)c	77	4	<1	<1	13
26N/06E-22K02	08-07-91	1525	Qva	<1	<2	<1	<1	3
26N/06E-24D01	08-06-91	0830	Q(A)c	33	10	<1	<1	3
26N/06E-25F01	08-07-91	1510	Qvt	19	12	<1	<1	3
26N/06E-26D03	08-14-91	1450	Qva	8	12	<1	<1	<1
26N/07E-03M01	08-06-91	1205	Br	<1	<2	<1	<1	1
26N/07E-04D01	08-06-91	1435	Br	<1	<2	<1	<1	3
	08-06-91	1440	Br	<1	<2	<1	<1	2
26N/07E-06K01	08-14-91	1320	Br	<1	<2	<1	<1	9
26N/07E-08A01	08-05-91	1620	Br	<1	<2	<1	<1	4
26N/07E-09F02	08-07-91	1100	Br	<1	<2	<1	<1	9
26N/07E-14G02	08-16-91	1115	Br	<1	<2	<1	2	180
26N/07E-16A01	08-06-91	1640	Br	<1	<2	<1	<1	1
26N/07E-16L02	08-08-91	1405	Qva	<1	<2	<1	<1	<1
26N/07E-17C01	08-07-91	1130	Q(A)f	14	8	<1	<1	1
26N/07E-18B01	08-07-91	1635	Qva	<1	<2	<1	1	2
26N/07E-18N01	08-07-91	1400	Q(A)c	<1	7	<1	<1	<1
26N/07E-19J02	08-08-91	1125	Q(A)f	29	7	<1	<1	1

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Lead, dissolved (µg/L as Pb)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Radon 222, total (pCi/L)
25N/07E-15C01	<1	<0.1	<1	<1	4	--
25N/07E-15R02	<1	<.1	<1	<1	55	--
25N/07E-17A01	<1	<.1	<1	<1	200	--
25N/07E-20P01	<1	<.1	<1	<1	14	--
25N/07E-21C01	<1	<.1	<1	<1	150	250
25N/07E-23Q01S	<1	<.1	<1	<1	6	--
25N/07E-26F01S	<1	<.1	<1	<1	15	--
25N/07E-27D01	<1	<.1	<1	<1	<3	--
25N/07E-28Q01	<1	<.1	<1	<1	61	--
25N/07E-29H02	<1	<.1	<1	<1	5	--
25N/07E-30F01	<1	.2	<1	<1	310	--
25N/07E-31D01	<1	<.1	<1	<1	3	--
25N/07E-31J01	<1	<.1	<1	<1	270	--
25N/07E-33Q01	<1	<.1	<1	<1	24	--
25N/07E-34E02	<1	<.1	<1	<1	550	--
26N/06E-02M01	<1	<.1	<1	<1	88	--
26N/06E-04J02	<1	<.1	<1	<1	45	--
26N/06E-09B02	<1	<.1	<1	<1	14	--
26N/06E-10A01	<1	<.1	<1	<1	57	--
26N/06E-13D03	<1	<.1	<1	<1	6	<80
26N/06E-13J01	<1	<.1	<1	<1	67	--
	<1	<.1	<1	<1	40	--
26N/06E-14D01	<1	<.1	<1	<1	10	--
26N/06E-22K02	<1	<.1	<1	<1	67	--
26N/06E-24D01	<1	<.1	<1	<1	10	--
26N/06E-25F01	2	<.1	<1	<1	37	--
26N/06E-26D03	<1	.2	<1	<1	140	--
26N/07E-03M01	<1	<.1	<1	<1	8	--
26N/07E-04D01	<1	<.1	<1	<1	17	320
	<1	<.1	<1	<1	20	320
26N/07E-06K01	1	<.1	<1	<1	<3	--
26N/07E-08A01	<1	<.1	<1	<1	210	--
26N/07E-09F02	<1	<.1	<1	<1	44	360
26N/07E-14G02	<1	<.1	<1	<1	29	--
26N/07E-16A01	<1	<.1	<1	<1	10	--
26N/07E-16L02	<1	<.1	<1	<1	5	--
26N/07E-17C01	<1	<.1	<1	<1	10	--
26N/07E-18B01	<1	<.1	<1	<1	28	--
26N/07E-18N01	<1	<.1	<1	<1	190	--
26N/07E-19J02	<1	<.1	<1	<1	22	--

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Cadmium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Copper, dis-solved (µg/L as Cu)
26N/07E-19P01	08-08-91	1240	Qva	18	7	<1	<1	<1
26N/07E-20E01	08-06-91	1530	Qva	6	4	<1	3	<1
26N/07E-22D01	08-07-91	0955	Qva	<1	<2	<1	<1	1
26N/07E-27F01	08-07-91	1230	Br	<1	26	<1	<1	<1
26N/07E-28E02	08-08-91	1130	Qva	2	<2	<1	<1	1
26N/07E-30A01	08-08-91	1600	Qva	9	3	<1	<1	8
26N/07E-30P01	08-06-91	1325	Qvt	<1	2	<1	<1	52
26N/07E-31B02	08-06-91	1145	Qva	1	5	<1	2	1
26N/07E-32K01	08-09-91	1200	Q(A)c	13	9	<1	<1	<1
26N/07E-32M01	08-08-91	1410	Q(A)f	10	9	<1	<1	13
26N/07E-33Q02	08-09-91	1220	Qvr	2	4	<1	<1	2
26N/07E-35D01	08-15-91	1335	Qva	<1	23	<1	<1	<1
BLANK - Deionized water	07-30-91	1530	--	<1	<2	<1	<1	<1
	08-03-91	1630	--	<1	<2	<1	<1	<1
	08-06-91	1505	--	<1	<2	<1	<1	<1
	08-07-91	1330	--	<1	<2	<1	2	<1
	08-07-91	1515	--	<1	<2	<1	<1	2
	08-08-91	1140	--	<1	<2	<1	<1	<1
	08-15-91	1455	--	<1	<2	<1	<1	<1
	08-16-91	1320	--	<1	<2	<1	<1	2

Table B2.--*Concentrations of selected trace elements--Continued*

Local well number	Lead, dissolved (µg/L as Pb)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)	Radon 222, total (pCi/L)
26N/07E-19P01	<1	<0.1	<1	<1	5	--
26N/07E-20E01	<1	<.1	<1	<1	130	--
26N/07E-22D01	<1	<.1	<1	<1	67	--
26N/07E-27F01	<1	<.1	<1	<1	11	--
26N/07E-28E02	<1	<.1	<1	<1	48	150
26N/07E-30A01	<1	<.1	<1	<1	15	--
26N/07E-30P01	<1	<.1	<1	<1	40	--
26N/07E-31B02	<1	<.1	<1	<1	76	--
26N/07E-32K01	<1	<.1	<1	<1	5	--
26N/07E-32M01	2	<.1	<1	<1	27	--
26N/07E-33Q02	<1	<.1	<1	<1	4	--
26N/07E-35D01	<1	<.1	<1	<1	5	--
BLANK - Deionized water	<1	<.1	<1	<1	<3	--
	<1	<.1	<1	<1	<3	--
	<1	<.1	<1	<1	11	110
	<1	<.1	<1	<1	7	--
	<1	<.1	<1	<1	<3	<80
	<1	<.1	<1	<1	5	100
	<1	<.1	<1	<1	<3	--
	<1	<.1	<1	<1	<3	--

Table B3.--*Concentrations of volatile organic compounds*

Local well number	Date (month/ day/ year)	Time	Geo-hydrologic unit	Chloromethane, total (µg/L)	Dichloro methane, total (µg/L)	Trichloromethane, total (µg/L)	Tetrachloromethane, total (µg/L)	Bromomethane, total (µg/L)	Dibromomethane, total (µg/L)	Tribromomethane, total (µg/L)
23N/08E-04L01	08-08-91	1215	Qal	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23N/08E-05K02	08-16-91	0900	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-10F03	08-15-91	1425	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-22A01	08-15-91	1015	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/06E-10H02	08-08-91	1110	Qva	<.2	<.2	<.2	<.2	<.2	<.2	<.2
	08-08-91	1115	Qva	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-10K01	08-09-91	0855	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-15D01	07-29-91	1435	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-21C01	08-05-91	1500	Qal	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-27D01	08-09-91	1240	Qvr	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/06E-13D03	08-05-91	1320	Q(A)c	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/07E-19P01	08-08-91	1240	Qva	<.2	<.2	<.2	<.2	<.2	<.2	<.2
BLANK - Deionized water	08-08-91	1140	--	<.2	.2	<.2	<.2	<.2	<.2	<.2

Local well number	Bromodichloromethane, total (µg/L)	Dibromochloromethane, total (µg/L)	Trichlorofluoromethane, total (µg/L)	Dichlorodifluoromethane, total (µg/L)	Chloroethane, total (µg/L)	1,1-Dichloroethane, total (µg/L)	1,2-Dichloroethane, total (µg/L)	1,1,1-Trichloroethane, total (µg/L)	1,1,2-Trichloroethane, total (µg/L)	1,1,1,2-Tetrachloroethane, total (µg/L)
23N/08E-04L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23N/08E-05K02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-10F03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-22A01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/06E-10H02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-10K01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-15D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-21C01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-27D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/06E-13D03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/07E-19P01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
BLANK - Deionized water	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

Table B3.--*Concentrations of volatile organic compounds--Continued*

Local well number	1,1,2,2-Tetrachloroethane, total (µg/L)	1,2-Dibromoethane, total (µg/L)	Chloroethene, total (µg/L)	1,1-Dichloroethene, total (µg/L)	1,2-Dichloroethene, total (µg/L)	Trichloroethene, total (µg/L)	Tetrachloroethene, total (µg/L)	1,2-Dichloropropane, total (µg/L)	1,3-Dichloropropane, total (µg/L)
23N/08E-04L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23N/08E-05K02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-10F03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-22A01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/06E-10H02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-10K01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-15D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-21C01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-27D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/06E-13D03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/07E-19P01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
BLANK - Deionized water	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

Local well number	2,2-Dichloropropane, total (µg/L)	1,2,3-Trichloropropane, total (µg/L)	1,1-Dichloropropene, total (µg/L)	cis 1,3-Dichloropropene, total (µg/L)	trans 1,3-Dichloropropene, total (µg/L)	Benzene, total (µg/L)	Chlorobenzene, total (µg/L)	1,2-Dichlorobenzene, total (µg/L)	1,3-Dichlorobenzene, total (µg/L)
23N/08E-04L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23N/08E-05K02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-10F03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-22A01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/06E-10H02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-10K01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-15D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-21C01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-27D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/06E-13D03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/07E-19P01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
BLANK - Deionized water	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

Table B3.--*Concentrations of volatile organic compounds--Continued*

Local well number	1,4-Dichloro-benzene, total (µg/L)	Bromo-benzene, total (µg/L)	Toluene, total (µg/L)	2-Chloro-toluene, total (µg/L)	4-Chloro-toluene, total (µg/L)	Di-methyl-benzene, total (µg/L)	Ethyl-benzene, total (µg/L)	Ethenyl-benzene, total (µg/L)
23N/08E-04L01	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23N/08E-05K02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-10F03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23N/08E-22A01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/06E-10H02	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-10K01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
24N/07E-15D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-21C01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
25N/07E-27D01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/06E-13D03	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
26N/07E-19P01	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
BLANK - Deionized water	<.2	<.2	.3	<.2	<.2	<.2	<.2	<.2

Table B4.--*Concentrations of selected pesticides*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	2,4-D, total (µg/L)	2,4-DP, total (µg/L)	2,4,5-T, total (µg/L)	Silvex, total (µg/L)	Dicamba, total (µg/L)
23N/08E-04L01	08-08-91	1215	Qal	<0.01	<0.01	<0.01	<0.01	<0.01
24N/06E-10H02	08-08-91	1110	Qva	<.01	<.01	<.01	<.01	<.01
	08-08-91	1115	Qva	--	--	--	--	--
24N/07E-04E01	08-09-91	1045	Qal	<.01	<.01	<.01	<.01	<.01
24N/07E-08A02	08-15-91	1025	Qvt	.02	<.01	<.01	<.01	<.01
24N/07E-10K01	08-09-91	0855	Qal	<.01	<.01	<.01	<.01	<.01
25N/07E-21C01	08-05-91	1500	Qal	<.01	<.01	<.01	<.01	.01
25N/07E-28Q01	08-05-91	1425	Qal	<.01	<.01	<.01	<.01	.01
25N/07E-29H02	08-07-91	1135	Q(A)c	<.01	<.01	<.01	<.01	<.01
25N/07E-31D01	08-09-91	1045	Qal	<.01	<.01	<.01	<.01	<.01
26N/06E-13D03	08-05-91	1320	Q(A)c	<.01	<.01	<.01	<.01	.01
26N/06E-25F01	08-07-91	1510	Qvt	<.01	<.01	<.01	<.01	<.01
26N/07E-06K01	08-14-91	1320	Br	<.01	<.01	<.01	<.01	<.01
BLANK- Deionized water	08-08-91	1140	--	<.01	<.01	<.01	<.01	<.01

Local well number	Piclo-ram, total (µg/L)	Ala-chlor, dis-solved (µg/L)	Ame-tryn, dis-solved (µg/L)	Atra-zine, dis-solved (µg/L)	Cyana-zine, dis-solved (µg/L)	De-ethyl atra-zine, dis-solved (µg/L)	De-iso-propyl atra-zine, dis-solved (µg/L)
23N/08E-04L01	<0.01	<0.05	<0.05	<0.05	<0.20	<0.05	<0.05
24N/06E-10H02	<.01	<.05	<.05	<.05	<.20	<.05	<.05
	--	<.05	<.05	<.05	<.20	<.05	<.05
24N/07E-04E01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
24N/07E-08A02	<.01	<.05	<.05	<.05	<.20	<.05	<.05
24N/07E-10K01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
25N/07E-21C01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
25N/07E-28Q01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
25N/07E-29H02	<.01	<.05	<.05	<.05	<.20	<.05	<.05
25N/07E-31D01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
26N/06E-13D03	<.01	<.05	<.05	<.05	<.20	<.05	<.05
26N/06E-25F01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
26N/07E-06K01	<.01	<.05	<.05	<.05	<.20	<.05	<.05
BLANK - Deionized water	<.01	<.05	<.05	<.05	<.20	<.05	<.05

Table B4.--*Concentrations of selected pesticides--Continued*

Local well number	Metolachlor, dissolved (µg/L)	Metribuzin sencor, dissolved (µg/L)	Prometon, dissolved (µg/L)	Prometryn, dissolved (µg/L)	Propazine, dissolved (µg/L)	Simazine, dissolved (µg/L)
23N/08E-04L01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
24N/06E-10H02	<.05	<.05	<.05	<.05	<.05	<.05
	<.05	<.05	<.05	<.05	<.05	<.05
24N/07E-04E01	<.05	<.05	<.05	<.05	<.05	<.05
24N/07E-08A02	<.05	<.05	<.05	<.05	<.05	<.05
24N/07E-10K01	<.05	<.05	<.05	<.05	<.05	<.05
25N/07E-21C01	<.05	<.05	<.05	<.05	<.05	<.05
25N/07E-28Q01	<.05	<.05	<.05	<.05	<.05	<.05
25N/07E-29H02	<.05	<.05	<.05	<.05	<.05	<.05
25N/07E-31D01	<.05	<.05	<.05	<.05	<.05	<.05
26N/06E-13D03	<.05	<.05	<.05	<.05	<.05	<.05
26N/06E-25F01	<.05	<.05	<.05	<.05	<.05	<.05
26N/07E-06K01	<.05	<.05	<.05	<.05	<.05	<.05
BLANK - Deionized water	<.05	<.05	<.05	<.05	<.05	<.05

Table B5.--*Concentrations of septage-related compounds*

Local well number	Date (month/ day/ year)	Time	Geo-hydro-logic unit	Nitrate plus nitrite, dis-solved (mg/L as N)	Boron, dis-solved (µg/L as B)	Carbon, organic, dis-solved (mg/L as C)	Methy-lene blue active sub-stances (mg/L)
23N/08E-05K02	08-16-91	0900	Qal	<0.05	20	1.6	<0.02
23N/08E-10F03	08-15-91	1425	Qal	.49	10	.2	<.02
23N/08E-22A01	08-15-91	1015	Qal	.30	10	.3	<.02
24N/06E-02E01	08-02-91	1540	Qvt	1.2	<10	.5	<.02
24N/06E-10H02	08-08-91	1110	Qva	1.4	<10	.5	<.02
	08-08-91	1115	Qva	1.5	<10	.4	<.02
24N/06E-10P02	08-08-91	1400	Qva	<.05	10	.6	<.02
24N/07E-15D01	07-29-91	1435	Qal	1.9	30	.6	<.02
24N/08E-20R02	07-29-91	1335	Qvr	<.05	<10	1.5	<.02
24N/08E-30N01	07-31-91	1150	Qal	.07	<10	1.4	<.02
25N/06E-34D01	08-02-91	1130	Qva	.53	<10	.4	<.02
25N/07E-15C01	08-07-91	1300	Q(A)c	<.05	120	.8	<.02
25N/07E-17A01	08-01-91	1255	Qva	.80	<10	.5	<.02
25N/07E-21C01	08-05-91	1500	Qal	.32	<10	.4	<.02
25N/07E-29H02	08-07-91	1135	Q(A)c	<.05	60	.8	<.02
26N/06E-04J02	08-08-91	1020	Br	.12	20	.5	<.02
26N/06E-10A01	08-06-91	1000	Qva	.28	20	.5	<.02
26N/07E-04D01	08-06-91	1435	Br	<.05	20	.7	<.02
	08-06-91	1440	Br	<.05	<10	.7	<.02
26N/07E-22D01	08-07-91	0955	Qva	.22	10	.4	<.02
26N/07E-28E02	08-08-91	1130	Qva	2.5	10	.4	<.02
BLANK - Deionized water	08-06-91	1505	--	<.05	<10	.5	<.02
	08-08-91	1140	--	<.05	<10	.5	<.02

APPENDIX C.--QUALITY-ASSURANCE ASSESSMENT OF WATER-QUALITY DATA

The quality-assurance plan for this study (G. L. Turney, U.S. Geological Survey, written commun., 1991) calls for quality-control procedures at all levels of data collection and analysis. Whereas many of the procedures address only methodology, some require the collection and analysis of quality-control samples. The resulting data are reviewed to determine the quality of the project data.

The water-quality data in this study appeared to be good by all measures. Errors associated with most standard and duplicate samples were within project criteria for most constituents. Exceptions were large percentage errors from constituent concentrations near detection limits with otherwise small absolute errors. Concentrations in blanks, various internal sample checks, and comparisons of field and laboratory determinations were within acceptable limits for most constituents and samples. The results of the quality-assurance analyses did not affect any interpretations of ground-water-quality data.

In the following sections, data from standard reference samples, sample duplicates, blanks, cation-anion balance, field alkalinity, and checks on field values are discussed. The data are included in the tables of Appendix B.

Standard Reference Samples

Standard reference samples of various concentrations for selected inorganic constituents were inserted as blind samples into the laboratory sample runs at the National Water Quality Laboratory (NWQL). Each standard sample was submitted several times to obtain enough data to be statistically meaningful. The results were summarized and are available through computer programs maintained by the U.S. Geological Survey's Branch of Quality Assurance (BQA). The summary provides the mean concentration determined by the NWQL for each standard during a given period, along with the standard deviation of the laboratory concentrations, coefficient of variation, and number of times the standard was submitted and analyzed. These data for standards submitted from July 15 to August 31, 1991, were used to assess the error in the analytical accuracy of samples collected from 124 east King County wells and springs during that period. The standards used in the assessment were only those that enclosed the range of the sample concentrations; that is, the range of standards just exceeded the range of samples. In cases where that was not possible, those standards that best represented the sample concentrations were used.

First, the standard deviation from the true standard concentration was determined for each standard using the following equation:

$$s_i = \sqrt{s_s{}^2 + (\bar{u}_s - MPV_s)^2} \qquad (1)$$

where

s_i = standard deviation of the estimated true standard concentration;

s_s = standard deviation of the mean concentration determined by the NWQL;

$\bar{u}_s$ = mean concentration of the standard as determined by the NWQL; and

MPV_s = most probable value of the standard. This is an estimate of the true standard concentration based on the average result from as many as 150 independent laboratories.

Equation 2 was used to determine the coefficient of variation (CV_i) for the analysis of each standard:

$$CV_i = \frac{s_i}{MPV_s} \qquad (2)$$

Then the overall coefficient of variation for a particular constituent was determined by averaging the squares of the coefficients of variation for all the standards that were in the range of concentrations found in east King County. This average was weighted by the number of times each standard was analyzed in the period as follows:

$$CV_o = \sqrt{\frac{\sum_{i=1}^{m} (n_i - 1) CV_i^2}{\sum_{i=1}^{m} (n_i - 1)}} \qquad (3)$$

where

CV_0 = overall coefficient of variation of all standards for a constituent;

n_i = number of times the standard was submitted and analyzed; and

m = number of standards.

Finally, the overall coefficient of variation was used to estimate the overall error of analysis of the standard reference samples for the constituent, at the 95-percent confidence level. The following equation was used:

$$E = (1.96 \times CV_0)\,100 \quad , \qquad (4)$$

where E = overall error of analysis, in percent.

This error is a representation of the average percent error in analytical accuracy of the samples from east King County and is shown in table C1 for each constituent. It also includes a degree of analytical precision. However, the accuracy and precision are difficult to separate in the given data, and, in the interest of conservation, the error is considered to be entirely in the accuracy.

The average absolute standard deviation (s_0) for each constituent, in units based on concentration, was calculated using equation 5 and is also shown in table C1.

$$s_0 = \sqrt{\frac{\sum_{i=1}^{m} (n_i - 1)\, s_s^2}{\sum_{i=1}^{m} (n_i - 1)}} \qquad (5)$$

The estimated errors for the cations and anions determined in this study were generally reasonable. Quality-assurance goals for this study called for an error of 10 percent or less for cations, anions, and nutrients. The errors for magnesium, sodium, alkalinity, and chloride met this goal. The errors for calcium, potassium, and silica, just barely exceeded the goal and ranged from 11 to 12 percent. The errors for sulfate and nitrate were 19 and 14 percent, respectively, and are probably representative. The largest error was 53 percent, for fluoride, and was a result of errors in small concentrations that were close to the detection limit. At these low concentrations, acceptable small absolute errors, as represented by the absolute standard deviation, produce large percent errors. For example, an absolute error of 0.2 mg/L is a 20-percent error for a concentration of 1.0 mg/L, but is only a 2-percent error for a concentration of 10 mg/L.

Errors for metals ranged from 11 to 111 percent. In a few instances, the error was within the goal of 20 percent. However, the generally large percent errors associated with metals were usually from concentrations that were at or near detection limits. Even though the percentages themselves were large at these low levels, the absolute errors were reasonable.

The average absolute error, as represented by the average absolute standard deviations, was generally reasonable. Even in instances where it seemed large, such as for sulfate or zinc, the absolute error was good when compared with the range of standards from which it was derived. Only for cadmium and chromium did the average absolute error seem large. Because cadmium and chromium were not present in significant quantities in east King County ground water, this is not considered a problem. Furthermore, the absolute standard deviation of the actual samples was probably smaller than that listed in table C1 for the standards. This is because the overall error as derived usually overemphasizes standards at larger concentrations when the concentration ranges over several standards. Although the standards were submitted in approximately equal numbers over the entire concentration range, the constituent concentrations in the ground-water samples were mostly near the smaller end of the range; only a small percentage of samples were near the larger end of the concentration range. In fact, in most cases the median ground-water concentration was smaller than the smallest standard, even though the sample concentration range covered several standards. In extreme cases, such as for cadmium and chromium, the smallest standard concentration was larger than the largest ground-water concentration. The standard deviation tends to increase with concentration, so the average standard deviation of the standards will be larger than the average standard deviation of the samples due to the difference in concentration distribution.

Internal surrogate standards were injected into each sample to be analyzed for concentrations of volatile organic compounds or pesticides. The standards were used to determine percent recoveries, and those that were not detected within a certain percentage of the known concentrations (variable, dependent upon the compound)

Table C1.--*Estimated error in analysis of inorganic constituents*

[Concentrations in milligrams per liter unless otherwise noted. All are dissolved concentrations; µg/L, micrograms per liter]

Constituent	Number of standards	Number of times standards submitted	Median concentration in ground-water samples	Range of concentrations in ground-water samples	Range of concentration of standards	Average absolute standard deviation of standards	Average[a] percent error in analysis
Calcium	6	34	15	0.79 - 55	8.31 - 63.2	1.6	11
Magnesium	6	34	5.0	.03 - 27	2.04 - 41.8	.82	7.2
Sodium	6	34	6.6	1.9 - 200	27.5 - 101	2.8	9.0
Potassium	5	22	1.3	.1 - 7	1.60 - 3.53	.12	12
Alkalinity	5	22	76	20 - 266	16.8 - 88.5	2.3	8.8
Sulfate	5	22	4.8	<.1 - 170	12.5 - 314	6.9	19
Chloride	5	22	3.0	.3 - 140	23.0 - 54.3	1.7	9.8
Fluoride	4	19	<.1	<.1 - 2.5	.33 - 1.05	.14	53
Silica	3	11	23	8.5 - 43	5.53 - 12.3	.59	11
Nitrate	2	73	.07	<.05 - 6.3	.41 - 1.42	.05	14
Iron (µg/L)	2	17	24	<3 - 14,000	38.2 - 122	6.7	14
Manganese (µg/L)	1	3	17	<1 - 920	46.3	2.6	11
Arsenic (µg/L)	2	18	2	<1 - 77	2.75 - 5.97	.80	53
Barium (µg/L)	3	20	5	<2 - 75	56.8 - 126	6.8	12
Boron (µg/L)	4	18	10	<10 - 120	11.0 - 66.2	5.9	47
Cadmium (µg/L)	2	7	<1	<1 - <1	3.99 - 11.5	4.0	74
Chromium (µg/L)	2	6	<1	<1 - 5	6.17 - 18.2	4.7	52
Copper (µg/L)	2	7	1	<1 - 180	5.45 - 7.06	1.3	39
Lead (µg/L)	2	7	<1	<1 - 5	9.40 - 11.5	1.3	25
Mercury (µg/L)	2	7	<.1	<.1 - .8	.11 - .16	.07	111
Selenium (µg/L)	1	12	<1	<1 - <1	3.95	1.1	56
Silver (µg/L)	2	6	<1	<1 - <1	.69 - 4.20	.47	65
Zinc (µg/L)	3	20	15	<3 - 550	68.2 - 198	9.6	19

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[a] At 95-percent confidence level. Computed using equations described in the text and data supplied by the U.S. Geological Survey's Branch of Quality Assurance. Error criterion is 10 percent for cations, anions, silica, dissolved solids, and nutrients. Error criterion is 20 percent for metals and trace elements.

were identified by the NWQL. No samples were reported to have substandard volatile organic compound or pesticide recoveries.

Duplicate Samples

Duplicate pairs of samples were collected for all types of analyses performed. Precision criteria were a 10-percent maximum difference for cations, anions, silica, dissolved solids, and nutrients and a 20-percent maximum difference for metals, trace elements, and organic compounds. A difference for each pair was computed as a percentage of the average concentration for the pair. The average difference of all pairs and the number of pairs exceeding the difference criteria are listed for each constituent in table C2.

For most constituents, the average percent difference was well within the criteria presented above. Only boron and copper had percent differences exceeding the criteria, although the differences for potassium, chloride, and zinc were relatively large also. In almost all cases, the larger percent errors were a result of small absolute differences in small concentrations near the detection limit, and were therefore considered acceptable. One exception was zinc, where a pair of samples from well 26N/06E-13J01 had concentrations of 67 and 40 µg/L, well above the detection limit of 3 µg/L. This disparity may reflect a sampling or analytical problem, but the overall difference for zinc is 19 percent (including these pairs) and the problem was probably isolated.

Blanks

Blanks of deionized water were processed in the same manner as water samples and sent to the NWQL for analysis. Although no criteria were set for constituent concentrations in blanks, the significance of any constituent present in a blank was based on how close the constituent concentration was to the detection limit and how small it was compared with the median sample concentration. Also important was the number of times the constituent was detected in blank samples. These data are presented in table C3 and, when compared with these criteria, concentrations in blanks were insignificant for all constituents except iron, zinc, and dissolved organic carbon. Even though iron was detected in four blanks, and the maximum concentration was 14 µg/L, the average blank concentration was 5 µg/L. Excluding the largest value, the average blank concentration was just over 3 µg/L, which was acceptable. Likewise, zinc was present in four blanks, and the average concentration in all blanks was 5 µg/L. Excluding the largest value of 11 µg/L, the average blank concentration was 4 µg/L, which was reasonable. For dissolved organic carbon, both blank concentrations were equal to the sample median concentration of 0.5 mg/L. However, the concentrations of concern in the study were 1.0 mg/L or larger, so interpretations were not affected.

Cation-Anion Balance

Various sums, differences, and ratios based on the principles of aquatic chemistry were computed for each sample. These computations check the consistency between constituent concentrations in a sample and provide a gross check in the accuracy and completeness of the analysis. One of the most useful computations is the cation-anion balance, which is discussed in the following paragraphs.

The cation-anion balance was calculated as a percent difference, using the following equation:

$$\frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} , \qquad (6)$$

where

$\sum$ cations = the sum of the concentrations of cations, in milliequivalents, and

$\sum$ anions = the sum of the concentrations of anions, in milliequivalents.

Ideally, this value is zero, but nonzero values are common and may be large when a cation or anion concentration is in error or when an ion present in large concentrations (often a metal) is not analyzed for. The acceptable percent difference varies with the total sum of cations and anions, as shown in figure C1. For most of the samples collected in east King County, the cation-anion balance was acceptable; only six analyses exceeded the allowable percent difference. Of these, five still had cation-anion balances of less than 3 percent, and four of the five exceeded the allowable percent difference by less than 1 percent. The error in these five analyses was therefore minimal. The remaining sample, from well 24N/07E-10K01, had a cation-anion balance of 8.6 percent, and it is likely that the error was in the alkalinity. This sample was one of the eight for which a field alkalinity was determined and for these eight, field alkalinities were used in calculating the cation-anion

Table C2.--*Average differences in constituent values and concentrations determined for duplicate samples*

Constituents	Number of duplicate pairs	Average difference in percent	Number[a] of pairs exceeding difference criteria
Calcium	8	0.4	0
Magnesium	8	1.3	0
Sodium	8	2.3	0
Potassium	8	9.0	3
Alkalinity	8	1.4	0
Sulfate	8	1.2	0
Chloride	8	8.5	1
Fluoride	8	.0	0
Silica	8	1.5	0
Dissolved solids	8	.3	0
Nitrate	8	1.2	0
Iron	8	5.5	1
Manganese	8	3.3	1
Arsenic	8	1.5	0
Barium	8	2.3	0
Boron	2	33	1
Cadmium	8	.0	0
Chromium	8	8.3	1
Copper	8	26	3
Lead	8	.0	0
Mercury	8	.0	0
Selenium	8	.0	0
Silver	8	.0	0
Zinc	8	19	2
Radon-222	3	13	1
Dissolved organic carbon	2	11	1
Methylene blue active substances	2	.0	0
All organic[b]	1	.0	0

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[a] Difference criterion is 10 percent for cations, anions, silica, dissolved solids, and nutrients. Percent-difference criterion is 20 percent for all metals, trace elements, radiochemicals, and organic compounds. No percent-difference criterion was established for bacteria.

[b] Organic compounds were not detected in any of the duplicate samples, therefore all differences for these compounds are zero. The duplicate analysis for the chlorophenoxy pesticides was lost during analysis.

Table C3.--*Summary of constituent values and concentrations determined for blank samples*

[Concentrations in milligrams per liter unless otherwise noted; µg/L, micrograms per liter; pCi/L, picocuries per liter; cols. per 100 mL, colonies per 100 milliliters]

Constituent	Number of blanks	Detection limit	Number of blanks equal to or exceeding detection limit	Maximum blank concentration	Median sample concentration
Calcium	8	0.02	5	0.07	15
Magnesium	8	.01	6	.07	5.0
Sodium	8	.2	0	<.2	6.6
Potassium	8	.1	0	<.1	1.3
Alkalinity	8	1	8	3.0	76
Sulfate	8	.1	4	.2	4.8
Chloride	8	.1	4	.8	3.0
Fluoride	8	.1	0	<.1	<.1
Silica	8	.1	6	.3	23
Nitrate	8	.05	0	<.05	.07
Iron (µg/L)	8	3	4	14	24
Manganese (µg/L)	8	1	1	1	17
Arsenic (µg/L)	8	1	0	<1	2
Barium (µg/L)	8	2	0	<2	5
Boron (µg/L)	2	10	0	<10	10
Cadmium (µg/L)	8	1	0	<1	<1
Chromium (µg/L)	8	1	1	2	<1
Copper (µg/L)	8	1	2	2	1
Lead (µg/L)	8	1	0	<1	<1
Mercury (µg/L)	8	.1	0	<.1	<.1
Selenium (µg/L)	8	1	0	<1	<1
Silver (µg/L)	8	1	0	<1	<1
Zinc (µg/L)	8	3	3	11	15
Radon-222 (pCi/L)	3	80	2	110	250
Dissolved organic carbon	2	.1	2	.5	.5
Methylene blue active substances	2	.02	0	<.02	<.02
Dichloromethane (µg/L)	1	.2	1	.2	<.2
Toluene (µg/L)	1	.2	1	.3	<.2
All other organics, by class [1]					
Volatiles (µg/L)	1	.2	0	<.2	<.2
Chlorophenoxy acid pesticides (µg/L)	1	.01	0	<.01	<.01
Triazine pesticides (µg/L)	1	.05	0	<.05	<.05
Fecal coliform (cols. per 100 mL)	38	1	0	0	<1
Fecal streptococci (cols. per 100 mL)	38	1	2	4	<1

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[1] Organic compounds other than those listed individually were not detected in the blanks.

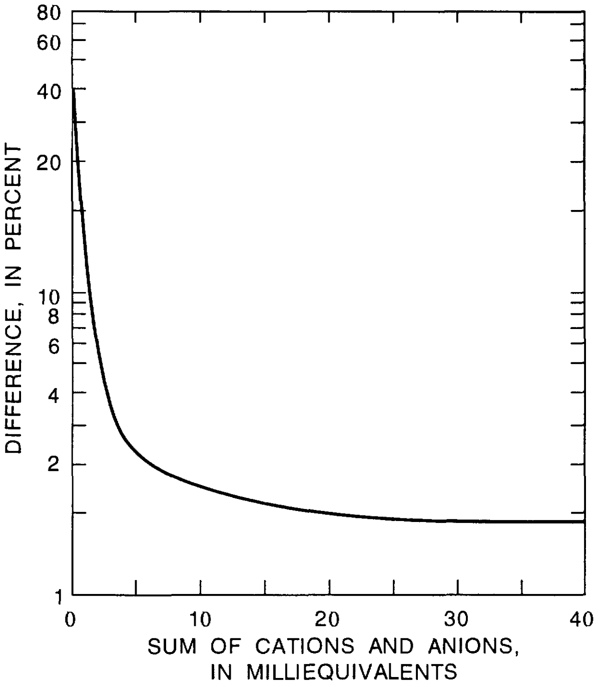


Figure C1.--Cation and anion percent difference curve.

balance because they provided a better balance. Nevertheless, the field alkalinity determined for this sample may have been low because some iron carbonate may have already precipitated, as discussed in the next section. All six analyses with excessive cation-anion balances were kept and used, because the indicated error was not large enough to affect any interpretations of the data. Also, when the error could be attributed to a likely constituent, such as the alkalinity, there was no way to determine the extent of error and the correct concentration.

Field Alkalinity

Alkalinity consists primarily of bicarbonate and a minor amount of carbonate and hydroxide in most natural ground-water systems. Alkalinity can be determined by titration either in the laboratory or in the field, but there are drawbacks with each. Field alkalinity analyses are time-consuming and are performed onsite in a field vehicle, often under less than ideal conditions. As a result, errors in analyses are more frequent than for laboratory analyses. The laboratory procedure is automated; however, the samples are not preserved, so any changes in sample chemistry, especially mineral precipitation or dissolution, can affect the alkalinity. One of the best indicators of the accuracy of an alkalinity value is the cation-anion balance. If field and laboratory alkalinity values differ greatly, the one that provides the better cation-anion balance is likely more accurate.

For this study, field alkalinities were determined only for samples that had a dissolved oxygen value of 1.0 mg/L or less and had an iron concentration of 800 µg/L or more, as determined with a field screening method. This approach was taken after making the following general observations during several other studies in Washington. First, in studies where field alkalinities were determined for every sample (Turney, 1986a, 1986b, 1986c, 1990) the difference in field and laboratory alkalinities was insignificant in most cases. Furthermore, when differences were significant, almost always the laboratory value was more accurate, as judged by the cation-anion balance. Most differences were therefore attributable to error in the field analysis. The most notable exceptions occurred when dissolved oxygen values were less than 0.5 mg/L and iron concentrations were larger than 1,000 µg/L. In these cases, the laboratory alkalinity was usually substantially smaller than the field alkalinity, probably because the unpreserved sample became oxygenated and iron carbonate precipitated out of solution, reducing the total alkalinity. The iron concentration was determined in the laboratory from an acid-preserved sample, so a corresponding drop in the iron concentration was not observed. This was evident during a study (Dion and others, 1994) where field alkalinities were not determined, and most of the samples with poor cation-anion balances had small dissolved-oxygen concentrations and large iron concentrations.

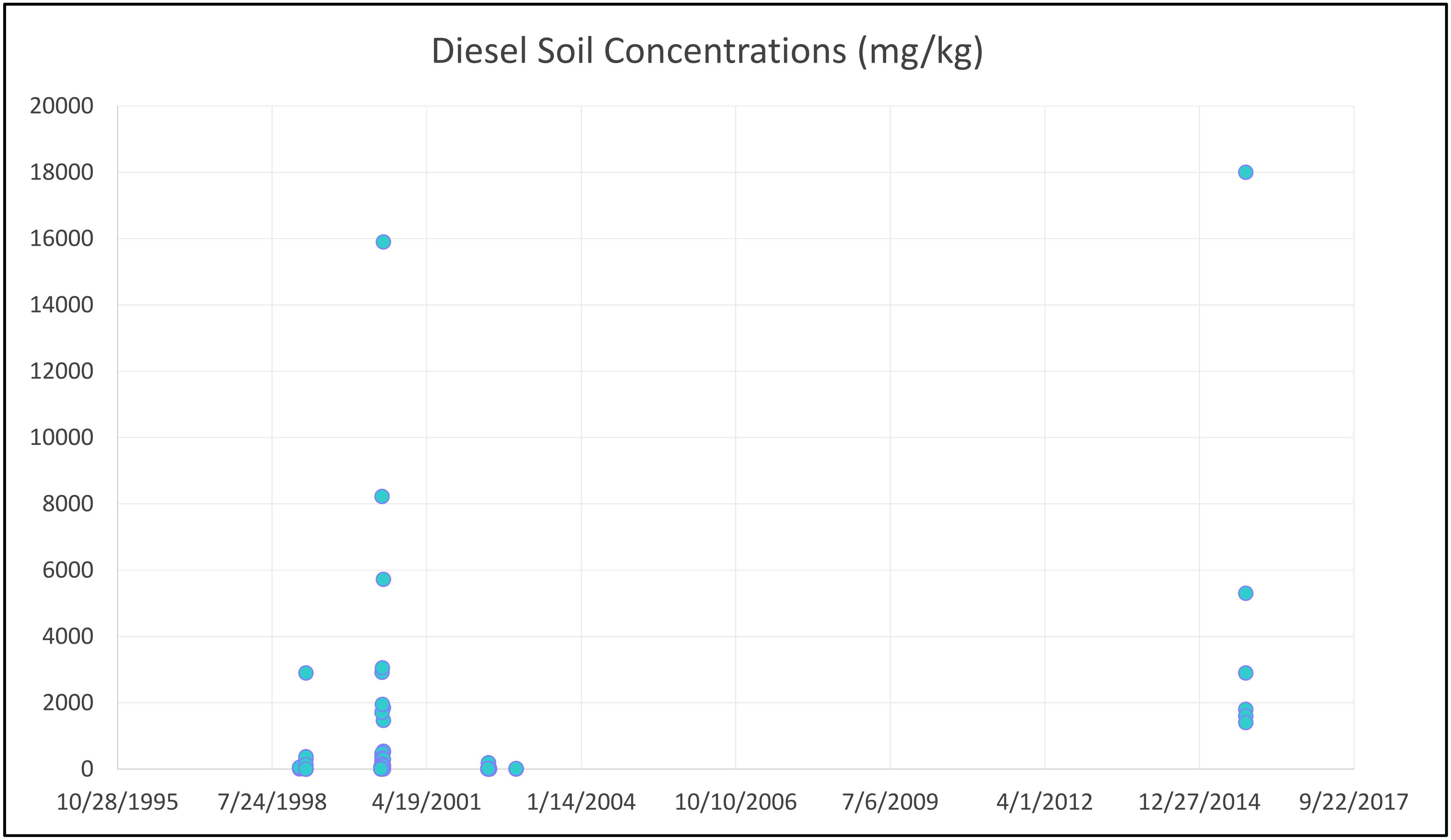
As mentioned in the report, only eight samples met the criteria for determining the alkalinity in the field. Of the eight samples, the field and laboratory alkalinities were identical for four of them. Of the remaining four, the laboratory alkalinity was lower than the field alkalinity by an average of 18 percent. Furthermore, these 4 samples had by far the 4 largest iron concentrations of all 124 samples, ranging from 5,700 to 14,000 µg/L. The cation-anion balance was acceptable in three of these four samples when calculated with the field alkalinity in place of the laboratory alkalinity. The sample with the unacceptable cation-anion balance, from well 24N/07E-10K01, was the only sample in the entire study with a cation-anion balance greatly exceeding that allowable (see previous section). In all four samples with the large iron concentrations, it is evident that iron carbonate was precipitating. For well 24N/07E-10K01, it simply appears that the precipitation began even before the field alkalinity could be determined. Given the overall good cation-anion balances observed for the east King County samples, and the results of the field alkalinities, the approach taken in this study for deciding when to determine field alkalinities seems reasonable.

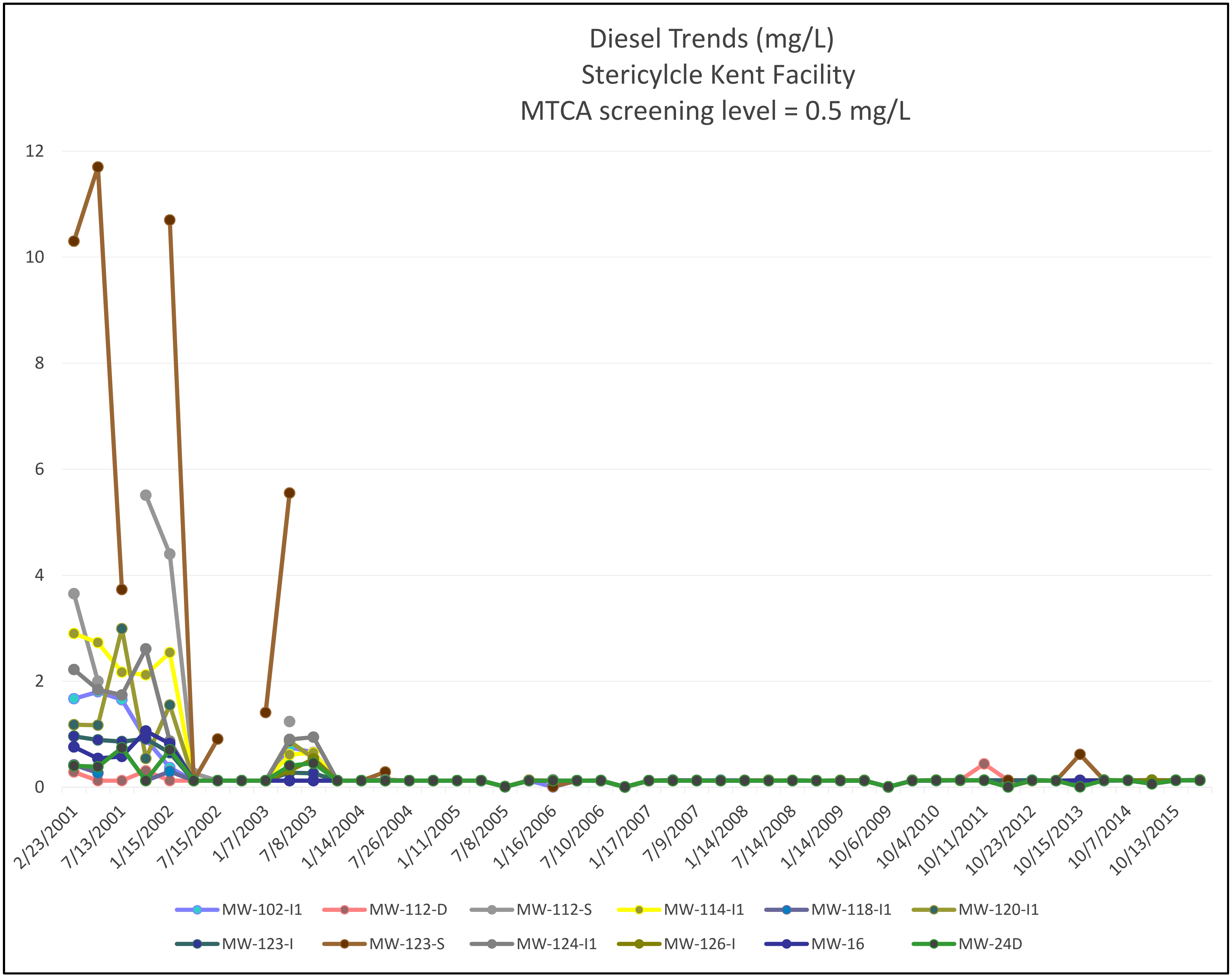
Checks on Field Values

The primary controls on the determinations of field values of pH, specific conductance, dissolved oxygen, and temperature are proper instrument calibration and field procedures. However, pH and specific conductance are also determined in the laboratory as standard procedure. Values of laboratory and field specific conductance differed by more than 5 percent for 31 of 124 samples, and of these 31, exceeded 10 percent for 19 samples. Field and laboratory pH differed by more than 0.3 units for 18 of 124 samples, but only 8 of these differed by more than 0.5 units; the maximum difference was 1.3 units. Because pH and specific conductance values can change during the time between the field and laboratory determinations, these comparisons must be considered approximations at best, but the good agreement generally serves to confirm the field values.

APPENDIX I

Historical TPH Data


Diesel Soil Concentrations (mg/kg)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
10/28/1995
7/24/1998
4/19/2001
1/14/2004
10/10/2006
7/6/2009
4/1/2012
12/27/2014
9/22/2017


Diesel Trends (mg/L)
Stericylcle Kent Facility
MTCA screening level = 0.5 mg/L
12
10
8
6
4
2
0
2/23/2001
7/13/2001
1/15/2002
7/15/2002
1/7/2003
7/8/2003
1/14/2004
7/26/2004
1/11/2005
7/8/2005
1/16/2006
7/10/2006
1/17/2007
7/9/2007
1/14/2008
7/14/2008
1/14/2009
10/6/2009
10/4/2010
10/11/2011
10/23/2012
10/15/2013
10/7/2014
10/13/2015
MW-102-I1
MW-112-D
MW-112-S
MW-114-I1
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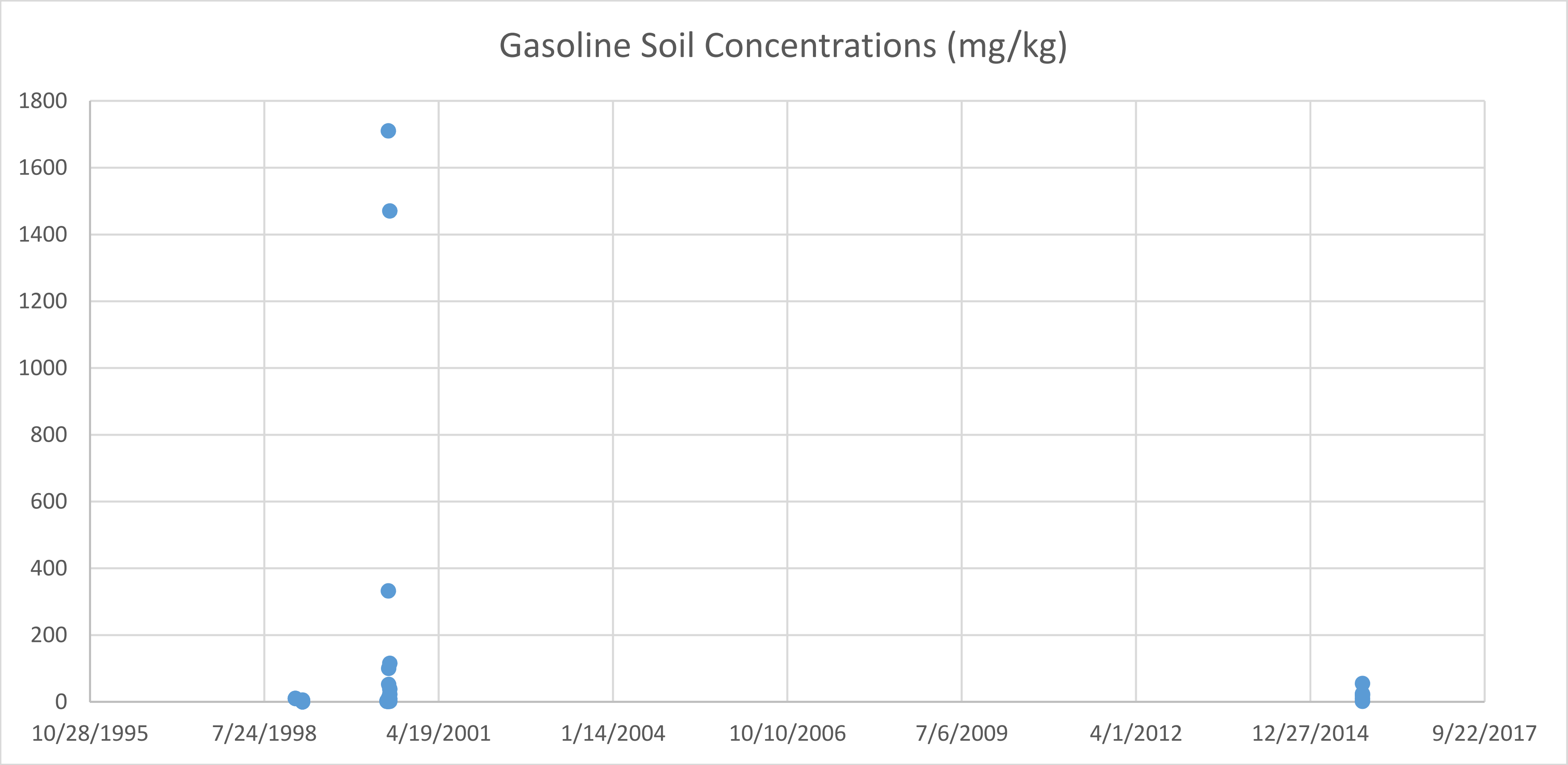
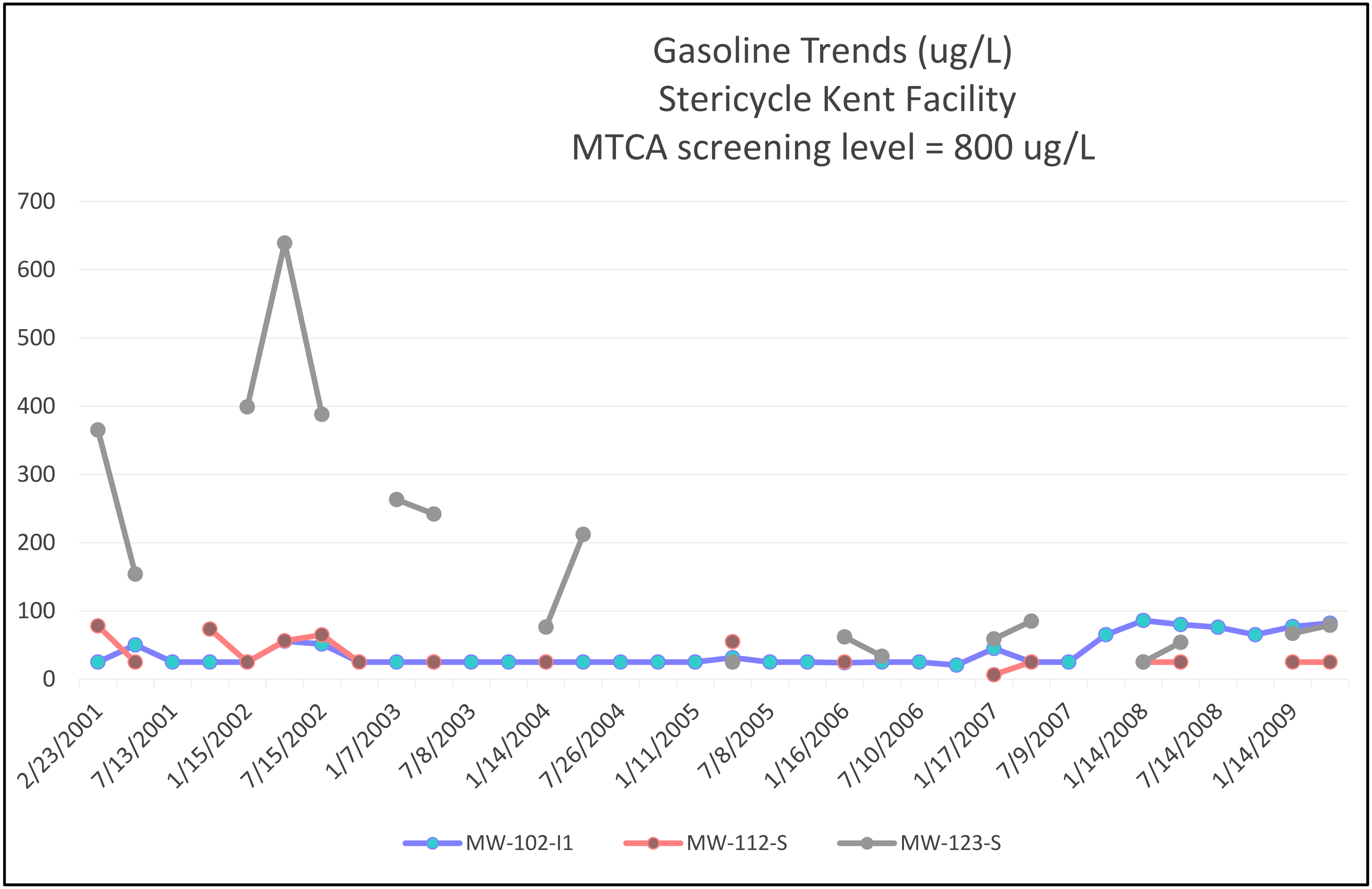
MW-126-I
MW-16
MW-24D


Gasoline Soil Concentrations (mg/kg)
1800
1600
1400
1200
1000
800
600
400
200
0
10/28/1995
7/24/1998
4/19/2001
1/14/2004
10/10/2006
7/6/2009
4/1/2012
12/27/2014
9/22/2017



Gasoline Trends (ug/L)
Stericycle Kent Facility
MTCA screening level = 800 ug/L