WHITE PAPER

1,4-Dioxane Detection, Occurrence, and Evaluation of Remedial Alternatives at the Landsburg Mine Site

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1.0 INTRODUCTION

The Landsburg Mine Site (Site) is a Washington State Model Toxics Control Act (MTCA) listed site, administered by the Washington State Department of Ecology (Ecology). The history of the Site, summary of the remedial investigation (RI), feasibility study (FS) and additional environmental investigations completed at the Site, and the remedial actions selected by Ecology are detailed in the Final Cleanup Action Plan (CAP; Ecology 2017a). Prior to the start of the selected remedial actions, low concentrations of 1,4-dioxane were detected in three Site groundwater monitoring wells located at the north end of the Site. 1,4-dioxane has not been detected in samples collected from any of the other 10 Site wells or in samples collected from groundwater monitoring wells installed downgradient of the north end of the Site.

In response to the 1,4-dioxane detection, several investigations, risk evaluations, and response actions were completed to determine the nature and extent of the 1,4-dioxane. These actions were completed under Ecology's approval, and the data that was collected and determinations made from the investigations were provided to Ecology in various reports. This White Paper summarizes the actions completed to evaluate the 1,4-dioxane detections, and presents Ecology with an evaluation of remedial alternatives to determine protective and appropriate remedial action(s) to address the 1,4-dioxane detected at the Site.

2.0 DETECTION AND OCCURRENCE OF 1,4-DIOXANE AT THE SITE

2.1 Initial Detection

Quarterly groundwater monitoring was conducted during the RI starting in 1994, and interim groundwater monitoring was conducted from 1995 to 2003, quarterly in 2004, and semiannually from 2005 to 2018. The interim groundwater monitoring was conducted to provide continued monitoring of the Site groundwater quality until the approved remedial actions and associated compliance monitoring were started as described in the CAP and Compliance Monitoring Plan (CMP; Ecology 2017b). The interim groundwater monitoring has included laboratory testing for a comprehensive list of analytes; including: petroleum compounds, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), pesticides, polychlorinated biphenyls (PCBs), and various metals. There were no detections of contaminants that are attributable to mine waste contaminants during the RI or during any of the interim groundwater monitoring events from 1994 to November 2017.

In response to public comments received on the draft CAP, Ecology added the compound 1,4-dioxane to the suite of analytes listed in the CMP for testing during protection and confirmation monitoring at the Site. 1,4-Dioxane was the only new compound added to the CMP. All other compounds included in the CMP have been tested at the Site during the RI and during the interim groundwater monitoring conducted since 2003. Prior to the start of remedial actions and the associated compliance monitoring required in the CAP, the Landsburg Potentially Liable Parties (PLP) Group elected to add 1,4-dioxane to the list of test analytes included in the interim groundwater monitoring.

Figure 1 shows the location of Site groundwater monitoring wells, and monitoring well construction details are provided in Table 1. Figure 2 provides a cross-section depiction the monitoring well locations and screen intervals. Figure 2 also shows the predominant groundwater flow direction. There is a groundwater divide located in the southern portion of the mine. Groundwater north of the divide flows towards the north and south of the divide flows towards the south. The location of the divide shifts seasonally, but groundwater beneath the waste disposal area always flows towards the north.

The November 2017 interim groundwater monitoring round included analysis for 1,4-dioxane for the first time. The analytical results for all test analytes during the November 2017 sampling event were consistent with results during the RI and with all the previous interim groundwater monitoring events conducted since 2003, except that 1,4-dioxane was detected in LMW-2 and LMW-4 at concentrations of 2.0 micrograms per liter (µg/L) and 2.3 µg/L, respectively. Since November 2017 was the first time 1,4-dioxane was tested for at the Site, its detection in LMW-2 and LMW-4 does not necessarily indicate a change in groundwater conditions. The compound 1,4-dioxane was not detected in any other groundwater monitoring wells or in either of the portal surface water samples, including monitoring well LMW-10 and the north portal, which are located upgradient of LMW-2 and LMW-4.

LMW-2 and LMW-4 were resampled in February 2018 to confirm the November 2017 1,4-dioxane detections. 1,4-Dioxane was detected during the resampling at 2.1 µg/L and 2.3 µg/L in LMW-2 and LMW-4, respectively, similar to the results detected in the November 2017 groundwater monitoring. The Landsburg PLP Group notified Ecology after the November 2017 results were received and validated and after the February 2018 resampling results were received and validated.

2.2 Initial Response Actions

In response to the detection of the 1,4-dioxane in LMW-2 and LMW-4, the Landsburg PLP Group, in cooperation with Ecology, completed the following actions:

- Expedited the installation of the four additional groundwater monitoring wells referred to as "sentinel wells" in the CAP. Sentinel wells are groundwater monitoring wells that are located between the waste disposal area and the compliance wells at the north and south ends of the Site.
- Increased the interim monitoring frequency to quarterly for the groundwater monitoring wells located at the north end of the Site. The increased monitoring frequency provided additional data to evaluate 1,4-dioxane concentration trends and to confirm that no other compounds were being detected above applicable action levels.
- Installed three additional groundwater monitoring wells north of the Site to provide empirical data on the groundwater quality downgradient of the Site.

Implementation of initial response actions to further address 1,4-dioxane did not delay implementation of the Site-wide remedial actions contained in the CAP (Ecology 2017a).

2.2.1 Expedited Installation of Four Additional Sentinel Wells

In March 2018, a sentinel well installation work plan (Golder 2018a) was submitted to Ecology describing the details for installing four additional sentinel wells. The wells are referred to as sentinel wells because they will provide early warning in the event of impacted groundwater migration. Ecology approved the work plan, and the two north sentinel wells were installed from March through May 2018. The northern sentinel wells were installed first to provide data to evaluate the potential source of the 1,4-dioxane detected in LMW-2 and LMW-4. As shown on Figure 2, the new shallow north sentinel well (LMW-12) was screened within the former mine workings from a depth of 15.5 to 25.5 feet below ground surface (ft bgs). The new deeper north sentinel well (LMW-13R) was screened within the former mine workings at a depth of 115 to 140 ft bgs. Existing north sentinel well LMW-10 was screened near the bottom of the coal seam at a depth of 267 to 287 ft bgs. LMW-10, LMW-12, and LMW-13R are located upgradient of northern compliance wells LMW-2 and LMW-4 and downgradient of the former waste disposal area, as shown on Figure 2. If the 1,4-dioxane detected in LMW-2 and LMW-4 is a mine waste contaminant, it would also be expected to be detected in LMW-12 and LMW-13R, because LMW-12 and LMW-13R are screened within the same general depth intervals as LMW-2 and LMW-4, respectively. LMW-10 is screened 50 feet deeper than LMW-4, so 1,4-dioxane would be detected in LMW-10 only if the vertical extent of 1,4-dioxane extended to the depth of the LMW-10 screen interval.

In October 2018 LMW-15 was installed, and in April 2019 LMW-14 was installed. Both LMW-14 and LMW-15 were installed south of the waste disposal area as shown on Figures 1 and 2. LMW-14 is located immediately south of the waste disposal area and is a dual-purpose sentinel well and effectiveness monitoring well used to monitor groundwater level changes resulting from trench backfilling and capping. LMW-15 is a south sentinel well located approximately 1000 feet south of LMW-14. With the installation of LMW-14 and LMW-15, there are seven sentinel wells located south of the waste disposal area included in the short-term and long-term compliance monitoring.

As each of the four additional sentinel wells were installed, they were included in the required groundwater monitoring program detailed in the CMP. In addition, the new north sentinel wells, LMW-12 and LMW-13R, were also included in the increased groundwater monitoring frequency for wells located at the north end of the Site to monitor 1,4-dioxane concentration trends.

2.2.2 Increased Groundwater Monitoring Frequency

Following the November 2017 detection of 1,4-dioxane in wells LMW-2 and LMW-4 the groundwater monitoring frequency for all wells located at the north end of the Site was increased to quarterly. Following the expedited installation of sentinel wells LMW-12 and LMW-13R, the quarterly north end monitoring wells included LMW-2, LMW-4, LMW-10, LMW-12, and LMW-13R. The increased quarterly monitoring included analysis for 1,4-dioxane, as well as other analyses required under the CMP short-term monitoring, i.e., VOCs and total petroleum hydrocarbon (TPH). The increased monitoring frequency provided data to evaluate 1,4-dioxane concentration trends, and to assess whether contaminants were being detected indicating mine waste contaminants were migrating from the mine. Semi-annual interim groundwater monitoring continued at all other Site groundwater monitoring wells, until compliance monitoring as described in the CMP started in June 2019. Results of all groundwater monitoring events were provided to Ecology in groundwater monitoring reports (Golder 2018b, c; 2019b, c, d, e; and 2020).

1,4-Dioxane has been detected only in wells LMW-2, LMW-4, and LMW-12. Table 2 presents the concentrations of 1,4-dioxane detected in the north end groundwater monitoring wells. Figure 3 provides a concentration trend graph of the 1,4-dioxane detections in LMW-2, LMW-4, and LMW-12. The trend graph indicates from 2017 through 2019 concentrations of 1,4-dioxane detected in the north end wells have been steady to slightly decreasing. The one exception is that 1,4-dioxane was not detected in LMW-12 during the December 2019 sampling round. As provided in the quarterly monitoring reports submitted to Ecology, there have been no detections of other analytes in any of the Site groundwater monitoring wells that indicate mine waste contaminants are migrating from the mine.

2.2.3 Installation of Groundwater Monitoring Wells North of the Site

On the Site, groundwater within the northern portion of the mine flows horizontally to the north/northeast, along the strike through the highly permeable Rogers seam. North of the Site, groundwater from the Rogers seam discharges to the Cedar River through the highly permeable glacial sands and gravels that overlie the coal seam and underlie the Cedar River. The Cedar River is located approximately 600 feet north of LMW-2 and LMW-4. Figures 2 and 4 conceptually depict the coal seams, the low permeability Puget Group sandstone and siltstones located on either side of the coal seams, and the recessional outwash sands and gravel deposits overlying the bedrock and beneath the Cedar River. To provide empirical data on the groundwater quality to the north, between the Site and the Cedar River, three additional groundwater monitoring wells were installed from November 27 to 29, 2018:

- LMW-20 – Installed along the strike of the Rogers coal seam and screened in the glacial soils overlying the Rogers coal seam. The monitoring well provides groundwater quality data on groundwater discharging from the Rogers coal seam to the glacial soils at a location approximately 400 feet downgradient of LMW-2 and LMW-4, and prior to discharge to the Cedar River.
- LMW-21 – Installed east of LMW-20. LMW-21 provides groundwater quality data at a location that is upgradient of the Rogers seam and within the same glacial soils that LMW-20 and LMW-22 are installed. This upgradient well was installed to evaluate anthropogenic background of 1,4-dioxane in the Cedar River glacial deposits. The anthropogenic background detections of 1,4-dioxane are related to its use as a stabilizer in chlorinated solvents and in common commercial and household products, which has resulted in detections of 1,4-dioxane in groundwater throughout the United States.
- LMW-22 – Installed west/northwest of LMW-20, between the Rogers coal seam and the closest private wells located to the northwest of the Site. Based on the geology noted in the private Water Well Reports filed with Ecology at the time of drilling, the nearest private wells located northwest of the Site are screened within the glacial soils overlying the bedrock. LMW-22 provides empirical data on the presence or absence of 1,4-dioxane in groundwater between the Rogers coal seam and the closest private wells.

The wells were drilled and installed in accordance with Golder Technical Guidelines TG-1.2-12 *Monitoring Well Drilling and Installation* and TG-1.2 6 *Soil Description System*. Details of the drilling and well installations were provided to Ecology in the 1,4-Dioxane Alternative Source Evaluation Report (Golder 2019a).

Groundwater levels for the newly completed and existing monitoring wells were measured using an electric water level tape on December 3, 2018. Water level measurements obtained in December 2018 indicated groundwater at the north end of the Site flows to the north/northeast towards Cedar River. The groundwater elevations in LMW-20, LMW-21, and LMW-22 confirm that the dominant groundwater flow within the glacial gravels is towards the Cedar River. The groundwater elevation in LMW-20, which is the well installed along the strike of the Rogers coal seam is lower than the groundwater elevations in LMW-22. This gradient confirms that groundwater discharging from the Rogers seam would not flow towards the nearest private wells located northwest of the Site. Groundwater discharging from the Rogers seam flows within the glacial gravels towards the Cedar River. Figure 5 depicts the groundwater elevations at the north end of the Site.

Wells LMW-20, LMW-21, and LMW-22 were sampled in accordance with the procedures detailed in the approved CMP (Ecology 2017b) on December 6, 2018. The samples were analyzed for 1,4-dioxane by US Environmental Protection Agency (EPA) Method 8270D and for VOCs by EPA Method 8260C in accordance with the Quality Assurance Project Plan (QAPP).

The December 2018 sampling indicated no VOC analytes or 1,4-dioxane were detected above the reporting limit in the three wells installed north of the Site. Complete analytical results from LMW-20, LMW-21, and LMW-22 sampling were presented to Ecology in the 1,4-Dioxane Alternative Source Evaluation Report (Golder 2019a).

2.3 1,4-Dioxane Alternative Source Evaluation Report

Results of the investigations described above were presented to Ecology in the report "*1,4-Dioxane Alternative Source Evaluation*" (Golder 2019a). This report concluded: "The low-level detections of 1,4-dioxane in three Site monitoring wells downgradient of the waste disposal area, indicates that the 1,4-dioxane could possibly be a mine waste contaminant. However, the absence of 1,4-dioxane in LMW-13R, which is downgradient of the waste disposal area and is screened at a depth that is shallower than LMW-4 does not support this determination." Assessment of the 1,4-dioxane detection within the report indicated the following:

- Quarterly groundwater monitoring since the initial detection of 1,4-dioxane indicated overall the concentrations of 1,4-dioxane had decreased compared to the initial detection.
- Analyses of groundwater samples collected during quarterly monitoring did not detect any other contaminants that would indicate mine waste contaminants were migrating from the mine.
- 1,4-Dioxane was not detected in groundwater samples from the three groundwater monitoring wells installed north of the Site and downgradient of LMW-2 and LMW-4. Groundwater elevation data from the three new wells confirm that groundwater discharging from the Rogers seam flows towards the Cedar River, and 1,4-dioxane does not reach the Cedar River.
- The horizontal and vertical extent of the 1,4-dioxane have been delineated. There are no current downgradient drinking water receptors located between the Site and the Cedar River, and installation of private groundwater wells within the area where 1,4-dioxane is detected above MTCA cleanup levels is prohibited. The 1,4-dioxane does not present a threat to human health or the environment.

3.0 NATURE AND EXTENT OF 1,4-DIOXANE AT THE SITE

3.1 Characteristics of 1,4-Dioxane

1,4-Dioxane was used as a stabilizer in chlorinated solvents (particularly 1,1,1-trichloroethane [TCA]) starting in the 1970s until its use as a stabilizer was phased out in 1995. 1,4-Dioxane is also present as a by-product (meaning it is not added during production of a product, but instead results from various reactions during the production of the product) of various surfactants, resins, aircraft de-icing fluids, polyethylene terephthalate (PET) plastics, chemical food additives, and other compounds that are used in common commercial and household products. Some common household products like laundry detergents, shampoos, and dish soaps have measured concentrations of 1,4-dioxane exceeding 10,000 micrograms per kilogram (µg/kg; Mohr 2017). The state of New Hampshire detected 1,4-dioxane in car wash soap at a concentration of 760,000 µg/kg. 1,4-Dioxane is released to the environment at sites where TCA or other commercial products containing 1,4-dioxane were released. 1,4-Dioxane is also released to the environment where consumer products like detergents, soaps, and shampoos that contain 1,4-dioxane infiltrate to the soil and potentially to the underlying groundwater through private homeowner's septic system drainage fields. Because public wastewater treatment systems are often unable to remove 1,4-dioxane from the treated effluent, discharges of 1,4-dioxane to surface water from public wastewater treatment plants commonly occurs (Mohr 2017). The wide-spread use 1,4-dioxane as a stabilizer in TCA and in various consumer and commercial products combined with the release of these products to the environment has resulted in 1,4-dioxane being found in groundwater at sites throughout the United States (EPA 2017).

1,4-Dioxane is a synthetic chemical that is completely miscible in water (i.e., it mixes easily with water). Unlike many organic compounds, 1,4-dioxane does not readily adsorb to carbon that is present in most soils. The high solubility and weak retardation of the compound in soil results in migration of 1,4-dioxane from soil to groundwater. It is relatively resistant to biodegradation in groundwater compared to chlorinated solvents. Its resistance to degradation and high mobility in groundwater often result in 1,4-dioxane migrating greater distances from the source area than most other organic compounds.

Based on laboratory studies on animals, the US Department of Health and Human Services (HHS), considers 1,4-dioxane as reasonably anticipated to be a human carcinogen. HHS indicates in the April 2012 Agency for Toxic Substances and Disease Registry (ATSDR), that the effects of 1,4-dioxane on human health depends on how much 1,4-dioxane a person is exposed to and the length of exposure (ATSDR 2012). The ATSDR document indicates the EPA has determined that exposure to 400 µg/L of 1,4-dioxane in drinking water for 10 days is not expected to cause any adverse effect in a child. The National Academy of Science (NAS) and the US Food and Drug Administration have established a maximum concentration of 10,000 µg/kg in food additives, products used in dietary supplements, and cosmetics (ATSDR 2012).

There are currently no drinking water levels established by EPA or in Washington State for 1,4-dioxane. The World Health Organization suggests a 50 µg/L drinking water threshold for 1,4-dioxane, whereas the EPA National Center for Environmental Assessment proposed a health-based advisory level of 3 µg/L in tap water (Water Research Foundation 2014). Under MTCA, Ecology has set a groundwater cleanup level for 1,4-dioxane of 0.44 µg/L. This value assumes that a person is drinking 2 liters of the impacted water every day for 30 years, which could result in an excess cancer risk of less than one in one million. Seventeen other states have established drinking water and groundwater guidelines with acceptable groundwater concentrations ranging from 77 µg/L to 0.25 µg/L. Twelve states have standards that are higher than 3 µg/L for 1,4-dioxane, and six states (including Washington) have cleanup levels for 1,4-dioxane that are lower than 3 µg/L. Groundwater samples collected from the Landsburg Site were analyzed for 1,4-dioxane using EPA Method 8270D with a detection limit of 0.2 µg/L, which is lower than all the drinking water criteria discussed above and lower than the MTCA cleanup level of 0.44 µg/L.

1,4-Dioxane easily breaks down in the atmosphere due to photo-oxidation (EPA 2017). 1,4-Dioxane has low aquatic toxicity as it does not bioaccumulate, biomagnify, or bioconcentrate in the food chain (ATSDR 2012; Mohr 2001). There are no surface water cleanup levels established for 1,4-dioxane in Washington state. At the PSC Georgetown Facility in Seattle, Washington, Ecology established a protection of surface water criteria for 1,4-dioxane, based on human consumption of fish, of 78.5 µg/L (Ecology 2010). The lowest No Observable Effects Concentration (NOEL) for aquatic organisms listed in the EPA EcoTox Database for 1,4-dioxane is 100,000 µg/L (EPA 2018). A MTCA Method B surface water value, calculated using a bioconcentration factor of 0.5 liters per kilogram (Oak Ridge National Laboratory's Risk Assessment Information System [RAIS 2018]) and the oral cancer potency factor listed in Cleanup Levels and Risk Calculation (CLARC) of 0.1 kilograms per day per milligram (kg-day/mg), results in a MTCA Method B surface water value of 130 µg/L.

3.2 Extent of 1,4-Dioxane at the Site

Low concentrations of 1,4-dioxane are detected in groundwater monitoring wells LMW-2, LMW-4, and LMW-12, all located at the northern end of the Landsburg Site. The concentrations detected in these wells has been steady to decreasing and 1,4-dioxane was not detected in LMW-12 during the December 2019 sampling round. The northern portal (Portal #2), LMW-10, and LMW-13R are also located at the north end of the Site, but 1,4-dioxane was not detected in any of these locations. 1,4-Dioxane has not been detected in any other Site wells or portal surface water samples. Groundwater in the three new monitoring wells installed north of the Site, including LMW-20 installed directly downgradient of LMW-2 and LMW-4 along the strike of the Rogers coal seam, has been tested and does not contain 1,4-dioxane.

In the northern portion of the Site where 1,4-dioxane was detected, the lateral extent of the 1,4-dioxane is limited to the width of the former Rogers seam. The coal seam itself is approximately 10 to 12 feet wide, but the collapsed width of the Rogers mine is about 15 feet. The geology and hydrogeology of the Site are described within the CAP (Ecology 2017a). On the northern end of the Site the coal seam and associated mine workings are oriented nearly vertically. The mined/backfilled Rogers seam is a relatively highly conductive zone for groundwater flow. The fine-grained, vertically bedded Puget Group bedrock strata located to either side of the seam are several orders of magnitude less permeable than the mined-out seam and are confining units for the groundwater present within the mine workings and coal seam. Groundwater flow within the mine flows horizontally to the north to northeast, along the strike through the highly permeable Rogers seam.

Groundwater beneath the waste disposal area within the former Rogers mine seam flows to the north to northeast along the strike of the Rogers coal seam and within the mine workings. The new sentinel wells LMW-12 and LMW-13R are screened in the Rogers seam, hydrologically downgradient of the former waste disposal area and upgradient of the compliance wells LMW-2 and LMW-4, also screened in the Rogers seam. If the source of the 1,4-dioxane detected in LMW-2 and LMW-4 is the former waste disposal area, one would expect to see higher concentrations of 1,4-dioxane in LMW-12 and detectable concentrations in LMW-13R. 1,4-Dioxane has not been detected in LMW-13R during any of the quarterly sampling conducted in 2018 and 2019. The absence of 1,4-dioxane in LMW-13R, which is screened at a depth shallower than LMW-4, is inconsistent with 1,4-dioxane being a mine waste contaminant.

3.3 Evaluation of Current and Potential Future Potential Exposure Pathways

During the period of November 2017 through 2019, the concentrations of 1,4-dioxane detected in groundwater samples collected from LMW-2, LMW-4, and LMW-12 range from non-detect (detection limit of 0.2 µg/L) to 2.3 µg/L. The highest concentrations were detected during the November 2017 sampling round, which was the first sampling round that included testing for 1,4-dioxane. Concentrations of 1,4-dioxane detected in LMW-2, LMW-4, and LMW-12 since the initial detections have decreased, with overall steady to decreasing trends. There have been no other contaminants detected that would indicate mine waste contaminants are migrating in groundwater within the mine.

The Ecology MTCA Method B cleanup value of 0.44 µg/L is based on a person drinking 2 liters of impacted water every day for 30 years. This cleanup level is based on an upper bound on the estimated excess cancer risk of less than one in one million. Evaluation of the potential groundwater exposure pathways includes the following:

- There are no drinking water wells located on the Site, and the environmental covenants required under the CAP will prevent future groundwater use from the Site for any non-remedial purpose.
- There are also no groundwater wells located downgradient of the Site between LMW-2/LMW-4 and the Cedar River. The properties north (downgradient) of LMW-2 and LMW-4 are owned by Palmer Coking Coal, King County Parks, Seattle City Light, and Seattle Public Utilities. Installation of private wells is prohibited on the public parcels. The nearest private well is located approximately 1,300 feet west of the Rogers coal seam (Figures 1 and 4) and is not along the downgradient groundwater flow path between the Rogers seam and the Cedar River.
- 1,4-Dioxane was not detected in the three new groundwater monitoring wells installed downgradient of the site between LMW-2/LMW-4 and the Cedar River. This confirms that the low-level concentrations of 1,4-

dioxane detected in the three northern Site wells attenuates rapidly and does not reach any off-site receptors.

- The concentrations of 1,4-dioxane detected in LMW-2, LMW-4, and LMW-12 since 2017 is steady to slightly decreasing and was not detected in LMW-12 during the December 2019 sampling round.

The combination of these factors – prohibition of drinking water wells on Site and immediately downgradient of LMW-2 and LMW-4, distance/cross-gradient location of nearest private wells, and the rapid attenuation to non-detectable concentrations downgradient of the Site - indicates that the low-level detection of 1,4-dioxane in LMW-2, LMW-4, and LMW-12 does not present a current or likely future risk to human health or the environment.

1,4-Dioxane was not detected in any of the three monitoring wells installed downgradient of the site before the Cedar River, so there is no risk to surface water. Even if a pathway to the Cedar River were identified, the concentrations of 1,4-dioxane detected in the three Site wells are significantly below surface water values that are protective of human health from consumption of organisms (130 µg/L calculated MTCA Method B cleanup level) and significantly lower than concentrations for the protection of aquatic Ecological receptors (100,000 µg/L; EPA 2018).

4.0 REMEDIAL ALTERNATIVES

This section describes treatment technologies used at other sites impacted by 1,4-dioxane, summarizes the existing remedial actions that will be completed at the Landsburg Site under the CAP, and evaluates reasonable remedial alternatives to address the 1,4-dioxane detections at the Landsburg Site.

4.1 1,4-Dioxane Treatment Technologies

1,4-Dioxane readily dissolves in groundwater, and its movement is not retarded significantly by sorption to soil particles. It is highly mobile, recalcitrant to microbial degradation, and has a low tendency to volatilize from water. Conventional water treatment practices, such as aeration, granular activated carbon (GAC) adsorptions, ozone, ultraviolet light degradation (UV), barrier walls, and biofiltration, have proven to be ineffective at removing 1,4-dioxane from water (Water Research Foundation 2014). More aggressive advanced oxidation process that require the addition of caustic chemicals like hydrogen peroxide and sodium hydroxide, or chlorine is required to increase effective removal of 1,4-dioxane from water. By-products, like carcinogenic bromates, trihalomethanes, and hexavalent chromium that can result from processes like advanced oxidation and chlorination of 1,4-dioxane are significantly more toxic that 1,4-dioxane itself (California Water Resource Control Board 2017).

At sites where treatment technologies are implemented for 1,4-dioxane remediation, they are usually implemented in conjunction with the remediation of other contaminants (e.g. chlorinated VOCs) or are used to reduce the mass of 1,4-dioxane from high concentration source areas. These technologies are seldom used at sites like the Landsburg Site where 1,4-dioxane is the only compound and is present at very low concentrations (i.e., less than 2.0 µg/L). This is because these treatment technologies become significantly less effective or not effective at all when concentrations of 1,4-dioxane are extremely low. For example, bench scale studies at the University of California Los Angeles determined that biodegradation is only effective down to a concentration of approximately 13 µg/L (SERDP and ESTCP 2017). Other in-situ remedial technologies like chemical oxidation are also not used to remediate dispersed, low concentration 1,4-dioxane in groundwater, because it would require the injection of large quantities chemical oxidants (e.g., hydrogen peroxide with ferrous iron, persulfate, or ozone) into the subsurface. Extremely large quantities of oxidant would be consumed by the natural oxidant demand (NOD) naturally present in groundwater and soil matrix significantly reducing the potential reduction on the actual contaminant. The coal bedrock at the Site would be expected to have an extremely high NOD, making chemical oxidation completely infeasible. These caustic chemical injectants and their potential byproducts like hexavalent chromium and bromate would result in greater impacts to groundwater and potential threats to human health and the environment than the low concentration 1,4-dioxane (California Water Resource Control Board 2017).

The most commonly used *in-situ* remedial approach for the low concentration impacted groundwater areas is monitored natural attenuation (MNA). Monitored natural attenuation is a well-established and accepted remedial approach for numerous compounds, but it is imperative to demonstrate that human health and the environment are protected during the MNA process.

Ex-situ treatment technologies all have common components of groundwater extraction followed by application of a process to reduce the concentration of 1,4-dioxane in the extracted groundwater to below an acceptable level. This treatment process is typically referred to as “pump-and-treat.” The treatment process relies on either chemical destruction using strong oxidizers or sorption. As discussed previously, the advanced oxidation processes typically include hydrogen peroxide and UV or hydrogen peroxide and ozone. Because the oxidation process is not specific to only 1,4-dioxane, all compounds including naturally occurring organic compounds and metals will be oxidized. The byproducts like hexavalent chromium and bromate from the oxidation can be more toxic than the original 1,4-dioxane. Sorption using GAC is one of the most commonly applied treatment technologies for removal of organic contaminants. However, the high solubility and low partitioning coefficient of 1,4-dioxane has been shown to result in only partial absorption of 1,4-dioxane on GAC. A carbonaceous synthetic resin called AMBERSORB™ developed by the Dow Chemical Company has been found effective in adsorption of 1,4-dioxane. The AMBERSORB™ process requires construction of an onsite regeneration process using steam heating and condensation of the extracted 1,4-dioxane, which then requires offsite disposal.

Because 1,4-dioxane is highly mobile in groundwater, pump-and-treat can be an effective process to limit the mass flux of 1,4-dioxane at sites where migration offsite could reach a receptor at unacceptable concentrations. However, back diffusion from low permeability subsurface material makes pump-and-treat a long-term proposition and it should not be implemented without first considering the life cycle cost of prolonged pumping and treating compared to the net environmental benefits.

4.2 Remedial Actions Under the Approved CAP

4.2.1 Backfilling and Capping

The remedial actions selected for the Site are detailed in the CAP (Ecology 2017a). The remedial actions were selected to meet Remedial Action Objectives (RAOs) based on acceptable exposure levels that are protective of human health and the environment and consider applicable or relevant and appropriate requirements (ARARs). The RAOs for the Site are:

- Minimize the potential for future direct exposure of human or ecological receptors to any waste constituents that may remain at the Site.
- Reduce the potential for migration of any waste constituents from the trenches in groundwater, surface water, or airborne dust.

The remedy selected in the CAP for the Site was Alternative 5 (low permeability soil cap). This alternative provides a low-permeability soil cap over the backfill of the trenches. The permeability of this soil will be less than 1×10^{-6} centimeters per sec (cm/sec), and the cap will thus meet the minimum functional standards (MFS) specified in Washington Administrative Code (WAC) 173-304. The major steps in this alternative are:

1) Backfill the trenches with clean soil to the same elevation as the adjacent ground surface, as required for capping.

2) Allow the backfill to consolidate between construction seasons and add additional backfill as necessary to re-establish the previous fill surface.

3) Place a low-permeability soil cap over the backfill of the trenches, and grade the adjacent areas to collect and divert surface water away from the cap.

4) Cap maintenance will continue until residual hazardous substance concentrations no longer exceed cleanup or remediation levels as described in the CAP resulting from either (1) the application of new remediation technologies currently unavailable or (2) other circumstances or conditions that affect residual concentrations such that they no longer pose a risk to human health or the environment.

5) Implement and maintain institutional controls, groundwater monitoring, and any instituted contingency plan until residual hazardous substance concentrations no longer exceed cleanup or remediation levels as described in the CAP resulting from either (1) the application of new remediation technologies currently unavailable, or (2) other circumstances or conditions that affect residual concentrations such that they no longer pose a risk to human health or the environment.

During 2019, the trench was backfilled with clean soil and allowed to settle. During 2020, final grading will be conducted to prepare the backfilled area for installation of the low-permeability cap and to grade the adjacent areas for stormwater management.

4.2.2 Contingent Groundwater Extraction and Treatment System

In addition to the remedial actions described above, the CAP contains provisions for a contingent groundwater extraction and treatment system. The requirements for the Contingent Groundwater Extraction and Treatment Plan (Contingency Plan) are detailed with Exhibit D, Part C of the CD (Ecology 2017b). The primary purpose of the Contingency Plan is to prevent migration of mine waste contaminants beyond the compliance boundary if detected in Site groundwater wells above trigger levels established in the CAP (Ecology 2017a). “Mine waste contaminants” are defined in the CAP as “chemical compounds potentially posing a human or environmental health risk and/or that exceed potential regulatory criteria, and that are directly attributable to, and the result of, the prior waste disposal activities within the Rogers coal mine (Rogers seam) at the Site.”

To allow for prompt implementation of the Contingency Plan if warranted in the future, some of the components of the treatment system infrastructure that have long lead times have already been installed. Infrastructure was installed in 2008 near the north portal (Portal #2), while infrastructure for the south portal (Portal #3) was completed in 2019 and early 2020. The completed infrastructure consists of:

North End - Completed in 2008:

- A gravel pad for the treatment equipment
- Underground electrical service to a panel to provide power for the treatment equipment
- Light poles and fixtures at several locations around the pad to provide adequate illumination for night work
- A chain-link fence around the perimeter of the pad for security
- A gravel road from the Summit Landsburg road to provide vehicle access

- A 3-inch diameter high density polyethylene (HDPE) discharge pipe was installed extending from the treatment pad, west towards the nearest municipal sewer line. The line was extended up to the Palmer Coking Coal property boundary and flanged to allow further extension and connection to the nearest sewer line if ever required. The nearest sewer line is the Soos Creek Sewer District line located approximately 1,000 feet west of the location where the 3-inch discharge line was terminated.

South End - Completed in 2019 and 2020:

- A gravel pad for the treatment equipment
- Underground electrical service to a panel to provide power for the treatment equipment
- Improvement of the gravel road from the Kent-Kangley road to the south treatment pad

4.3 Evaluation of 1,4-Dioxane Remedial Actions

As detailed in this White Paper, the 1,4-dioxane detected at the Site does not present a current or potential future threat to human health or the environment. The detected concentrations are limited to three wells located at the north end of the Site, and concentrations detected in those wells since November 2017 are steady to slightly decreasing. Monitoring wells installed downgradient of the Site confirmed that 1,4-dioxane does not extend to the nearest downgradient well, which is located less than 400 feet downgradient, and there are no current or likely future receptors in this area downgradient of the Site. Groundwater monitoring started at the Site in 1994, and there have been no compounds detected in groundwater that indicate mine waste contaminants are migrating in groundwater within the mine workings. As concluded in the Alternative Source Evaluation Report (Golder 2019a), the 1,4-dioxane could possibly be a mine waste contaminant. However, the absence of 1,4-dioxane in LMW-13R, which is downgradient of the waste disposal area and is screened at a depth that is shallower than LMW-4 does not support this possibility. This section evaluates remedial actions, both current actions and potential additional actions, associated with the 1,4-dioxane detected at the Site.

4.3.1 Trench Backfilling and Capping

Trench backfilling and installation of the low permeability soil cap will significantly reduce the volume of rainwater that infiltrates through the portions of the trench where wastes were disposed. Additionally, the total volume of groundwater flowing through the Rogers seam will also be reduced. If the 1,4-dioxane is a mine waste contaminant, these actions would be expected to reduce the concentrations of 1,4-dioxane detected. As the current concentrations of 1,4-dioxane detected are around 1.5 µg/L, minimal reductions are needed to achieve concentrations below MTCA cleanup level of 0.44 µg/L.

To further reduce the potential for rainwater to infiltrate through the trench cover and backfill, a geomembrane (thick plastic) layer will be proposed to Ecology as an upgrade to the low-permeability soil layer currently required in the CAP. The low-permeability soil cover specifications in the CAP requires a permeability of no greater than 1×10^{-6} cm/sec. The upgrade to the geomembrane will nominally achieve a permeability of 1×10^{-11} cm/sec or less, which is 10,000 times less permeable than the low permeability soil layer. The geomembrane cover system will include a drainage layer and a vegetated soil layer. The drainage layer is an additional measure to reduce infiltration through the cover because it minimizes hydraulic head on the geomembrane. If the 1,4 -dioxane is a mine waste contaminant, the geomembrane will further reduce the concentration of 1,4-dioxane in groundwater.

4.3.2 Activation of the Contingent Groundwater Extraction and Treatment System Plan

Implementation of a pump-and-treat system as described in the Contingency Plan could effectively inhibit the migration of mine waste contaminants beyond the point of compliance. There are significant environmental impacts and financial costs associated with implementing the Contingency Plan to address 1,4-dioxane at the Site. Considering the unique nature of the 1,4-dioxane detected at the north end of the site, specifically, the low levels detected and limited extent of detections, the net benefit of implementing the Contingency Plan must be measured against the potential environmental and financial costs. The Contingency Plan in general terms would include the following:

- An extraction well would be installed between the north sentinel wells and the compliance wells LMW-2 and LMW-4. Groundwater extraction would occur at a pumping rate that creates a hydraulic capture of groundwater across the entire horizontal and vertical depth of the impacted groundwater within the Rogers seam. Pumping would be required to continuously sustain the hydraulic capture.
- Performance wells would be installed between the extraction well and the compliance wells to measure hydraulic gradients that would demonstrate inward gradients towards the extraction well.
- Settling/surge tanks would be constructed within the treatment system pad. Extracted groundwater would be pumped to the tanks for settling of suspended solids and other pretreatment if necessary. Communications with Mr. Bruce Tiffany, an engineer with the King County – Industrial Waste Program, confirmed that water containing 1,4-dioxane concentrations detected at the Site (i.e., approximately 1 to 2.5 µg/L) would be acceptable for discharge to the King County sanitary sewer system. Mr. Tiffany indicated that King County – Industrial Waste Program had accepted a discharge limit of 2,000 µg/L for another project.
- Booster pumps would push water from the tanks through the 3-inch discharge line to the Soos Creek sewage line. From there the effluent is piped to the South Plant, commonly known as the Renton wastewater treatment plant. The South Plant treatment system is part of the King County – Industrial Waste Program, which is responsible for wastewater treatment and permit compliance.

The above described pump-and-treat system would inhibit off-site migration but would result in expending a tremendous amount of energy to transfer the water to the South Plant (i.e. Renton wastewater treatment plant). It would require approximately 15 kilowatts per hour (kWh) to continuously operate the pumps associated with the system. That is 130,647 kWh of electricity per year. Puget Sound Energy's (PSE's) calculated greenhouse gas emissions per kWh of electricity produced is 1.2 pounds (PSE 2019). Therefore, the pump-and-treat system would generate over 156,000 pounds of greenhouse gases (carbon dioxide, methane, nitrous oxide, and sulfur hexafluoride) per year. This energy usage estimate does not include the energy associated with the South Plant treatment system. If an on-Site treatment system and water disposal option were feasible, even greater energy usage would occur than under direct discharge to the sewer line. The estimated cost to build the pump-and-treat system as described above is $900,000 without any on-Site treatment. If on-Site treatment is added the estimated cost is $2.15 million. The estimated annual cost for operation and maintenance is $147,000 if no on-Site treatment is required and $200,000 if on-Site treatment is required prior to discharging water to the sewage line.

MTCA includes a provision under WAC 173-340-360(3)(e) to conduct a disproportionate cost analysis when evaluating the remedial actions. The provision generally states that "costs are disproportionate to benefits if the incremental costs of the alternative over that of a lower cost alternative exceed the incremental degree of benefits achieved by the alternative over that of the other lower cost alternative."

For the 1,4-dioxane detected at the Landsburg Site, the evaluation of disproportionate cost analysis related to activation of the Contingency Plan involves comparing the sustainability and financial costs described above to the net environmental benefits. As detailed in this White Paper, the 1,4-dioxane detected at the Site does not present a current or potential future threat to human health or the environment. This is based on the following:

- The extent of 1,4-dioxane has been delineated at the Site. 1,4-Dioxane is only detected in the north end of the Site and it does not extend to the nearest off-Site downgradient monitoring well, which is located less than 400 feet from the Site. The downgradient properties are owned by Palmer Coking Coal, King County Parks, and Seattle City Light, and Seattle Public Utilities. Installation of private wells is prohibited on the public properties. The Environmental Covenants required under the CAP prohibit use of groundwater on the Site for other than remedial purposes.
- Concentrations detected since 2017 are steady to decreasing, and the concentrations detected on Site are significantly below the most stringent surface water criteria for protection of organisms and protection of human health.
- No other compounds have been detected which would indicate that mine waste contaminants are migrating through the Rogers seam.

In consideration of the nature and extent of the 1,4-dioxane detected at the Site, the Contingency Plan system would provide minimal to no reduction in risks but would result in significant costs and the imposition of other environmental costs in the form of carbon emissions. The costs of implementing the Contingency Plan to address the 1,4-dioxane detected at the Site is disproportionate to the extremely limited potential benefits. As discussed above, other remedial technologies employed at 1,4-dioxane sites are not applicable for use at the Landsburg Site, could result in more significant adverse effects, or would have equal or greater disproportionate costs as determined for the Contingency Plan.

4.3.3 Increased Groundwater Monitoring Frequency

Following the initial detection of 1,4-dioxane in LMW-2 and LMW-4, the Landsburg PLP Group increased the groundwater monitoring frequency of all wells located on the north end of the site to quarterly. The increased quarterly monitoring included 1,4-dioxane, VOCs, and TPH. In continued response to the 1,4-dioxane detection, quarterly monitoring of the groundwater monitoring wells located at the north end of the Site (LMW-2, LMW-4, LMW-10, LMW-12, and LMW-13) for 1,4-dioxane, VOCs, and TPH will continue through completion of the remedial actions. During remedial actions, this increased monitoring will augment the short-term groundwater monitoring detailed in Table A-2 of the CMP (Ecology 2017b). At the completion of remedial actions, the increased groundwater monitoring frequency required under the CMP (Table A-3) will continue and will include analyzing for 1,4-dioxane, VOCs, and TPH every 4 months until the concentrations of 1,4-dioxane attenuate to 0.25 of the MTCA cleanup level. This increased monitoring frequency will provide a higher level of confidence that concentrations of 1,4-dioxane continue to attenuate, continue to confirm that other compounds are not detected that would indicate mine waste contaminants are migrating through the Rogers seam, and allow for continued monitoring of the migration pathway to ensure that off-site receptors remain unaffected.

4.3.4 Addition of LMW-20 to the Groundwater Monitoring Plan

Groundwater monitoring well LMW-20 was installed downgradient of the Site and along the strike of the Rogers seam. The well location is shown on Figures 4 and 5. Groundwater monitoring data from LMW-20 established that 1,4-dixoane is not detected at that location indicating that 1,4-dioxane quickly attenuates to non-detectable levels north of the Site. Although the steady to decreasing concentration trends observed in on-Site wells would indicate that the plume has reached steady-state, continued sampling of LMW-20 will provide empirical data to confirm off-site migration is extremely limited. As mentioned previously, the 1,4-dioxane concentrations detected on Site are well below surface water criteria, so the proposed additional monitoring in LMW-20 will also provide additional data that the Cedar River is protected. Annual sampling of LMW-20 with analysis for 1,4-dioxane is proposed to be added to the Site groundwater monitoring plan. The annual sampling would continue until 1,4-dioxane in Site wells no longer exceeds cleanup levels.

4.3.5 Connecting the Discharge Line to the Soos Creek Sewer Line

Components of the Contingency Plan that have long lead times are already installed, apart from completing the extension of the 3-inch diameter discharge line and connecting it to the Soos Creek sewer line located west of the Site. Various permits and access agreements will be required in association with extending the buried discharge pipe across King County park land and connecting to the Soos Creek sewer line. Ms. Karen Wolf, Senior Executive Policy Advisor for King County (King County 2006) provided preliminary agreement for completing these activities to Ecology during the early planning stages of the CAP. Having this line installed and ready for discharge, would increase the ability to rapidly respond if conditions ever changed at the Site and implementation of the Contingency Plan were required. All other components of the Contingency Plan are on-Site actions (e.g., design and installation of extraction wells, pumps, and surge tanks), and completion of those items if ever needed can be implemented in a timely fashion.

4.4 Summary of 1,4-Dioxane Remedial Alternative

Implementation of the Contingency Plan to address the 1,4-dioxane detected at the Site is disproportionate to the benefits. The 1,4-dioxane detected at the Site does not present a threat to human health or the environment. Installation and activation of the contingent groundwater extraction and treatment system described in the CAP would produce no measurable net environmental protection benefits but would result in significant financial costs and significant sustainability impacts in the form of energy usage and carbon emissions. The alternative remedial actions proposed to ensure that human health and the environment continue to be protected at the Site include the following:

- Continue with the remedial actions of capping the portions of the trench required in the CAP but upgrade the cover to a geomembrane cover system. The upgrade will nominally achieve a permeability of 1×10^{-11} cm/sec or less, which is 10,000 times less permeable than the low permeability soil layer. This will significantly reduce the flow of rainwater through the former waste disposal area, and if the 1,4-dioxane is a mine waste contaminant, will further reduce the concentration of 1,4 -dioxane in groundwater.

- Continue the increased groundwater monitoring frequency of the north end wells to provide a high level of confidence that concentrations of 1,4-dioxane continue to attenuate and that other compounds are not detected that would indicate mine waste contaminants are migrating through the Rogers seam.

- Add routine monitoring of the off-Site groundwater monitoring well that is located directly downgradient of the north end of the Site along the strike of the Rogers seam. Groundwater monitoring data from this well will continue to confirm that 1,4-dioxane is not detected at that location indicating that 1,4-dioxane quickly attenuates to non-detectable levels north of the Site and that the Cedar River is protected.

- Complete the extension of the Contingency Plan discharge pipe from the north contingent treatment pad to connect to the nearest municipal sewer line, Soos Creek sewer line located west of the Site. Having this line installed and ready for discharge, would increase the ability to rapidly respond if conditions ever changed at the Site and implementation of the Contingency Plan were required.

5.0 CONCLUSIONS

1,4-Dioxane was the only new compound added to the CMP by Ecology to respond to comments received during the public comment period in 2017 and was added to the interim groundwater monitoring program starting in November 2017. The initial detection of low concentrations of 1,4-dioxane in two groundwater monitoring wells located at the north end of the Site prompted several initial response actions to characterize the nature and extent of the 1,4-dioxane. The actions included increasing the groundwater monitoring frequency, installing four additional sentinel wells at the Site, and installing three groundwater monitoring wells downgradient of the north end of the Site. Assessments from these actions determined that the 1,4-dioxane detections were limited to three Site monitoring wells located at the north end of the Site and the concentrations attenuated quickly to non-detectable levels downgradient of the Site. The concentrations detected in the Site wells were significantly below surface water criteria that are protective of aquatic organisms and human health. Installation of domestic wells on Site and immediately downgradient of the Site are prohibited. The low-level concentrations of 1,4-dioxane detected at the Site do not present a current or potential future threat to human health or the environment.

The increased groundwater sampling conducted from November 2017 through 2019 indicated that the concentrations of 1,4-dioxane detected in the three north end wells are steady to decreasing. Additionally, there were no detections of other analytes in any of the Site groundwater monitoring wells that indicate mine waste contaminants are coming from the mine.

Installation and operation of the Contingency Plan to address the 1,4-dioxane detections would provide minimal to no benefits but would result in significant sustainability and financial costs. The costs of implementing the Contingency Plan to address the 1,4-dioxane detected at the Site is disproportionate to the benefits. Several alternative remedial measures are presented in this White Paper that have the potential to reduce the concentration of 1,4-dioxane in groundwater and ensure human health and the environment continue to be protected.

Signature Page

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Tables

Table 1: Landsburg Mine Site Groundwater Monitoring Wells Construction Summary

Well ID	Northing	Easting	Installation Date	Date Last Surveyed	Datum	Measuring Point Elevation (ft AMSL)	Measuring Point	Borehole Depth (ft bgs)	Borehole Diameter (inches)	Well Casing Diameter (inches)	Well Materials	Depth to Top of Screen (ft bgs)	Depth to Bottom of Screen (ft bgs)	Elevation Top of Screen (ft amsl)	Elevation Bottom of Screen (ft amsl)	Screen Slot Size (inches)	Depth to Top of Filter Pack (ft bgs)	Comments
LMW-1	138279.52	1354991.57	1/23/1994	8/14/2018	NAVD88	765.36	Top of PVC Casing	180	8	4	Stainless/PVC	162	177	603	588	0.02	158	In area of gangway that connects mine fault off-set
LMW-2	139077.61	1355972.91	2/11/1994	8/14/2018	NAVD88	617.79	Top of PVC Casing	46	8	4	Stainless/PVC	28	38	590	580	0.02	25	Shallow north compliance
LMW-3	135192.23	1353220.37	11/22/2004	11/3/2004	NAVD88	656.75	Top of PVC Casing	76	8	4	Stainless/PVC	50	65	607	592	0.02	47	Shallow south compliance
LMW-4*	139122.67	1355865.52	2/19/1994	8/14/2018	NAVD88	619.27	Top of PVC Casing	233	8	4	Stainless/PVC	195	210	424	410	0.02	210	Deep north compliance
LMW-5	135206.05	1353141.36	12/8/2004	11/3/2004	NAVD88	658.27	Top of PVC Casing	247	8	4	Stainless/PVC	232	242	426	416	0.02	232	Deep south compliance
LMW-6	138714.14	1354126.78	1/13/1994	11/3/2004	NAVD88	632.33	Top of PVC Casing	106	8	4	Stainless/PVC	91	106	541	526	0.02	83	Frasier Coal Seam
LMW-7*	138055.10	1355483.61	1/10/1994	11/3/2004	NAVD88	771.51	Top of PVC Casing	254	8	4	Stainless/PVC	240	254	532	518	0.02	n/a	Landsburg Coal Seam
LMW-8	135074.90	1353229.41	4/7/2004	11/3/2004	NAVD88	646.97	Top of PVC Casing	15	9	2	PVC	7.5	13	639	634	0.02	6	Representative of Portal #3 discharge
LMW-9	135727.33	1353324.04	4/14/2004	11/3/2004	NAVD88	743.99	Top of PVC Casing	160	9	2	PVC	149	159	595	585	0.02	144	Southern Sentinel Well mid-depth
LMW-10	139054.56	1355787.97	5/11/2004	8/14/2018	NAVD88	618.98	Top of PVC Casing	450	9	4	PVC	267	287	352	332	0.02	258	Deep, near bottom of mine, northern end
LMW-11	136159.27	1353317.36	8/24/2005	4/19/2019	NAVD88	802.19	Top of PVC Casing	707	9	4	Stainless/PVC	697	707	105	95	0.02	688	Deep, near bottom of mine, south end
LMW-12	138923.92	1355721.80	3/14/2018	8/14/2018	NAVD88	625.35	Top of PVC Casing	30	8	4	PVC	15.5	25.5	610	600	0.02	11	North Portal Sentinel Shallow Sentinel Well
LMW-13	138937.17	1355707.45	3/22/2018	8/14/2018	NAVD88	625.62	Top of PVC Casing	150	8	4	PVC	125.5	145.5	500	480	0.02	121	Dry Well
LMW-13R	138932.43	1355728.92	5/15/2018	8/14/2018	NAVD88	625.86	Top of PVC Casing	151	8	4	PVC	115	140	511	486	0.02	110	North Portal Sentinel Deep Sentinel Well
LMW-14*	137188.61	1353967.91	4/15/2019	4/19/2019	NAVD88	805.12	Top of PVC Casing	176	6	2	PVC	156.5	172.3	649	633	0.01	152.6	15° Incline. Vertical depths reported
LMW-15	136245.07	1353517.07	11/5/2018	4/19/2019	NAVD88	796.46	Top of PVC Casing	248	6	2	PVC	238	248	558	548	0.01	233	South cap effectiveness well
LMW-20	139352.05	1356317.06	11/27/2018	12/26/2018	NAVD88	546.80	Top of PVC Casing	24.5	6	2	PVC	14	24	533	523	0.01	11	Cedar River Valley Rogers Seam
LMW-21	139209.99	1356404.12	11/29/2018	12/26/2018	NAVD88	544.09	Top of PVC Casing	15	6	2	PVC	10	15	534	529	0.01	7	Cedar River Valley East Well
LMW-22	139493.44	1355909.73	11/28/2018	12/26/2018	NAVD88	542.86	Top of PVC Casing	27.5	6	2	PVC	17	27	526	516	0.01	14	Cedar River Valley West Well

Notes:
* LMW-4 and LMW-7 were drilled at a 20° incline; LMW-14 was drilled at 15° incline.
** No filter pack was installed in P-2 due to the open mine shaft at 39 feet to 44 feet. The casing was removed, and the native material collapsed around the well to 15 feet below ground surface.
ft AMSL - feet above mean sea level
ft bgs - feet below ground surface

Table 2: Summary of 1,4-Dioxane Detections in Groundwater Monitoring Wells Located on the North End of the Site

Sample Date	LMW-2	LMW-4	LMW-10	LMW-12	LMW-13R
	µg/L	µg/L	µg/L	µg/L	µg/L
11/30/2017	**2.0**	**2.3**	0.4 U	NA	NA
2/9/2018	**2.1**	**2.3**	NA	NA	NA
5/24/2018	**1.8**	**1.5**	0.4 U	**1.5**	0.4 U
8/15/2018	**1.6**	**1.5**	0.4 U	**1.6**	0.4 U
12/4/2018	**1.7**	**1.6**	0.4 U	**1.2**	0.4 U
3/5/2019	**1.5**	**1.7**	0.4 U	**1.1**	0.4 U
5/22/2019	**1.5**	**2 (1.5)**	0.4 U	**1.4**	0.4 U
8/14/2019	**1.8**	**1.5**	0.4 U	**1.6**	0.4 U
12/10/2019	**1.5**	**1.6 (1.6)**	0.4 U	0.4 U	0.4 U

Notes:

U - The analyte was not detected above the level of the method detection limit.

µg/L = micrograms per liter

Analyses performed by EPA Method 8270

NA = Not Analyzed

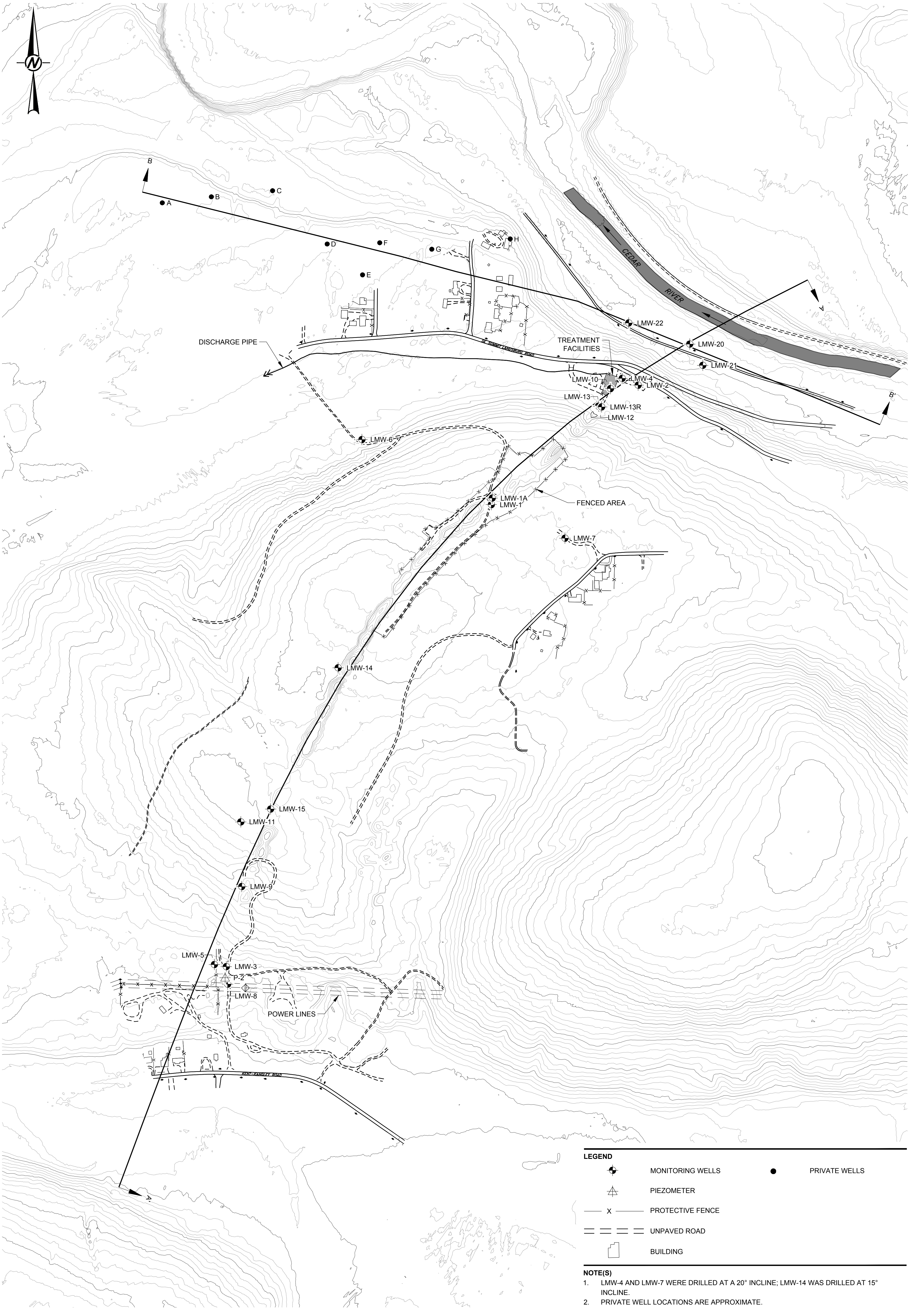
Duplicate results are included in parentheses

MTCA Method B Cleanup Level of 1,4-Dioxane is 0.44 µg/L

1,4-dioxane was not detected in any other Site groundwater monitorng wells

Figures

Path: \\redmond.golder.gds\data\geomatics\PalmerCokingCoalCo\LandsburgMineWA\99_PROJECTS\9231000005_RemedialAction\1019_DioxaneReport\02_PRODUCTION\DWG\ | File Name: 9231000005_1019_001.dwg | Last Edited By: trybar Date: 2019-05-03 Time:2:21:57 PM | Printed By: TRybar Date: 2019-05-03 Time:2:22:44 PM



LEGEND

MONITORING WELLS	PRIVATE WELLS
PIEZOMETER	
PROTECTIVE FENCE	
UNPAVED ROAD	
BUILDING	

NOTE(S)

1. LMW-4 AND LMW-7 WERE DRILLED AT A 20° INCLINE; LMW-14 WAS DRILLED AT 15° INCLINE.
2. PRIVATE WELL LOCATIONS ARE APPROXIMATE.

0 300 600
1" = 300' FEET

CLIENT
LANDSBURG MINE SITE PLP GROUP

PROJECT
LANDSBURG MINE SITE
MTCA REMEDIAL ACTION

CONSULTANT

GOLDER

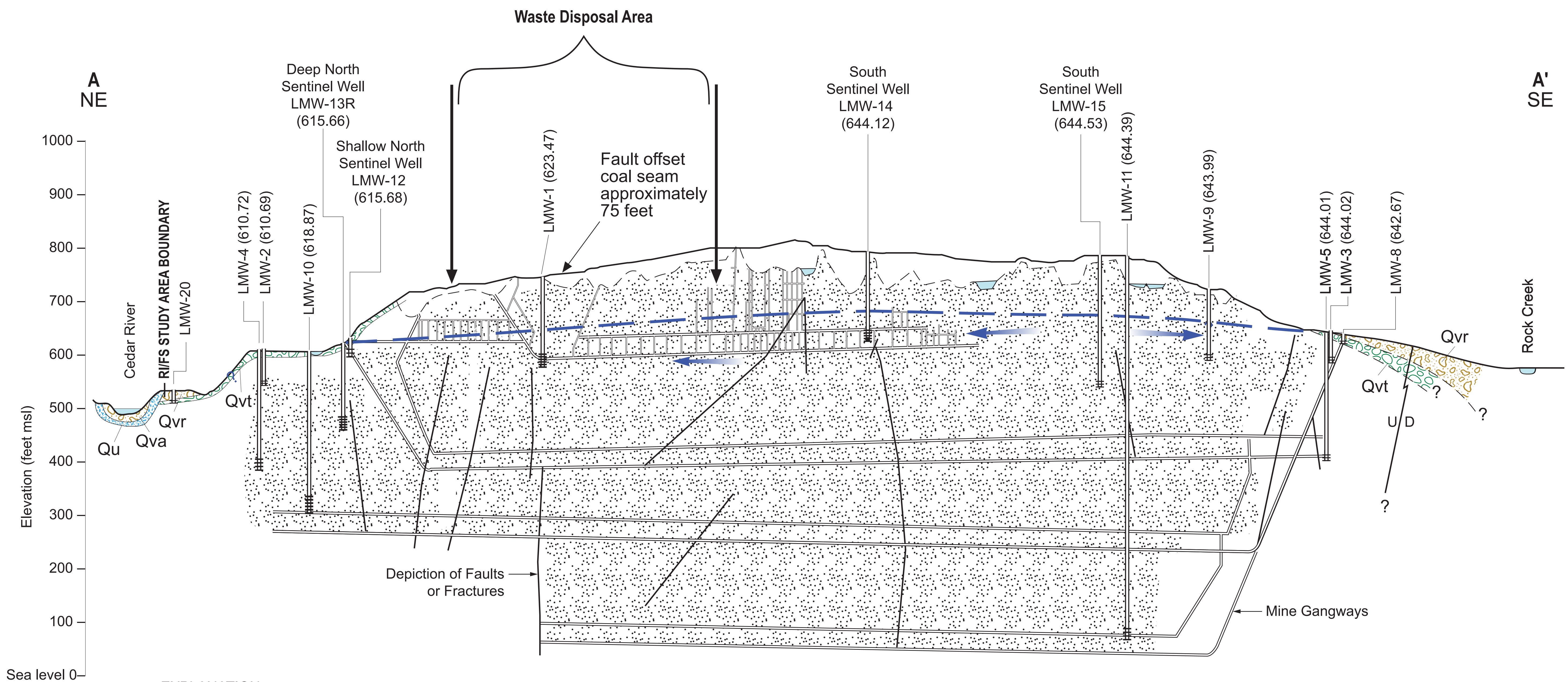
YYYY-MM-DD	2019-04-25
DESIGNED	XXX
PREPARED	XXX
REVIEWED	XXX
APPROVED	XXX

TITLE
SITE MAP

PROJECT NO.	PHASE	REV.	SHEET
9231000005	1019	A	1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D

0 1 in



EXPLANATION

- Potentiometric surface
- Outline of trench bottom
- LMW-2 (610.69) Well ID (water level in ft. amsl)
- Qvt Till, compact mixture of gravel occasional boulders in clayey silty sand matrix
- Sandstone
- Surface water feature
- Anticipated collapsed zone within mine
- Qu Drift, till, fluvial sand and gravel, lacustrine sand, silt, clay and peat
- Qvr Recessional outwash, well sorted sand and pebble-cobble
- Qva Advanced outwash pebble-cobble gravel may include very fine sand
- Monitoring Interval
- Groundwater Flow Direction

0 500
FEET

Sources for the Geology and Mine Information:
J.E. Luzier 1969; surficial geology
State of Washington, Water Well reports
Mine Superintendant's Records
Landsburg Well Logs

NOTE: Vertical to horizontal scale ratio is 2.5:1
Wells are project normal into the strike of the Cross-Section A-A'

Groundwater elevation obtained 12/10/2019

CLIENT LANDSBURG PLP GROUP		PROJECT LANDSBURG MINE SITE	
CONSULTANT GOLDER	YYYY-MM-DD: 2020-03-16 PREPARED: REDMOND DESIGN REVIEW APPROVED	TITLE CROSS-SECTION ALONG STRIKE AT COAL SEAM CROSS-SECTION A-A'	
		PROJECT No. 923-1000	PHASE 1200 / FIGURE 2

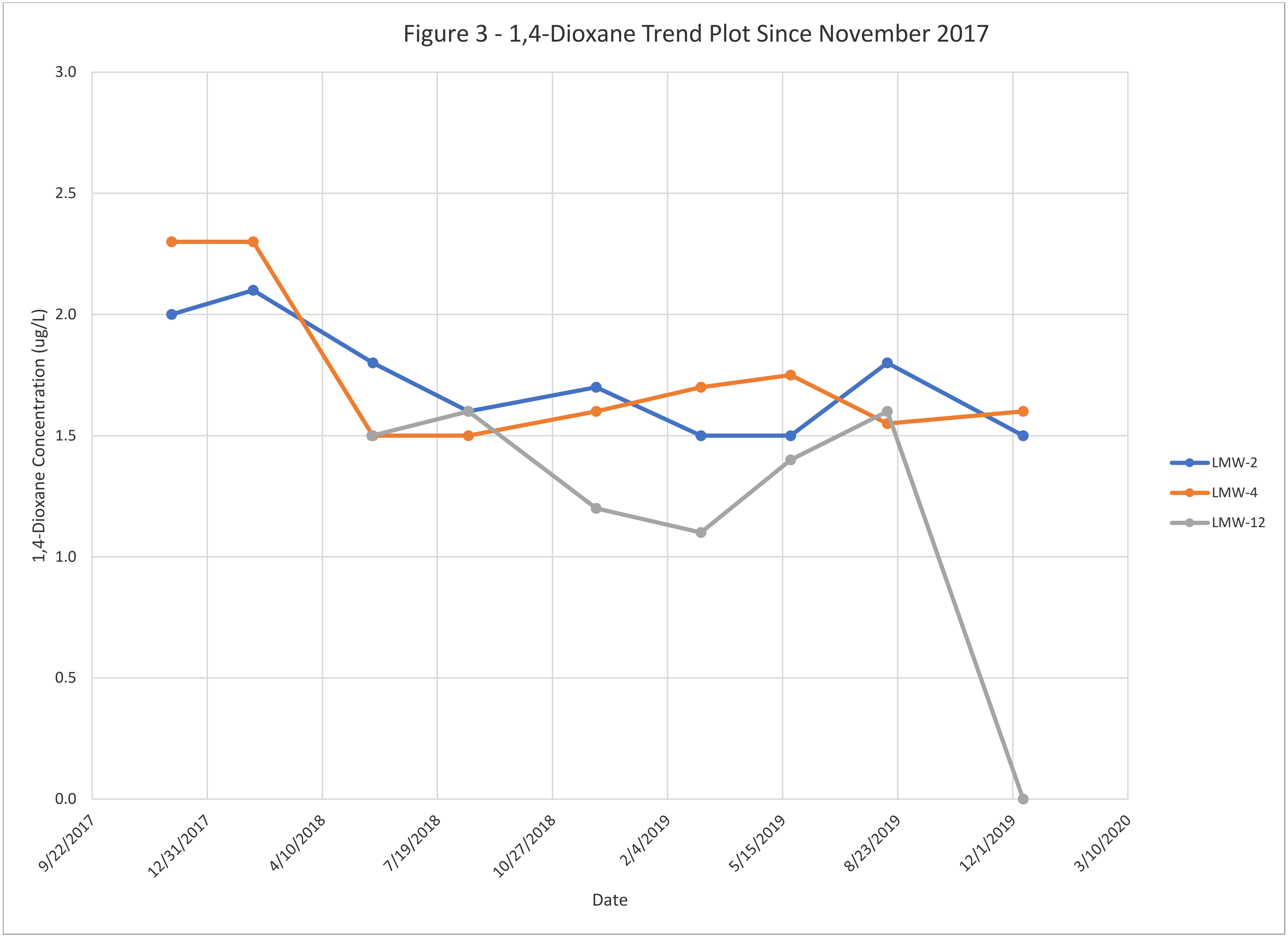
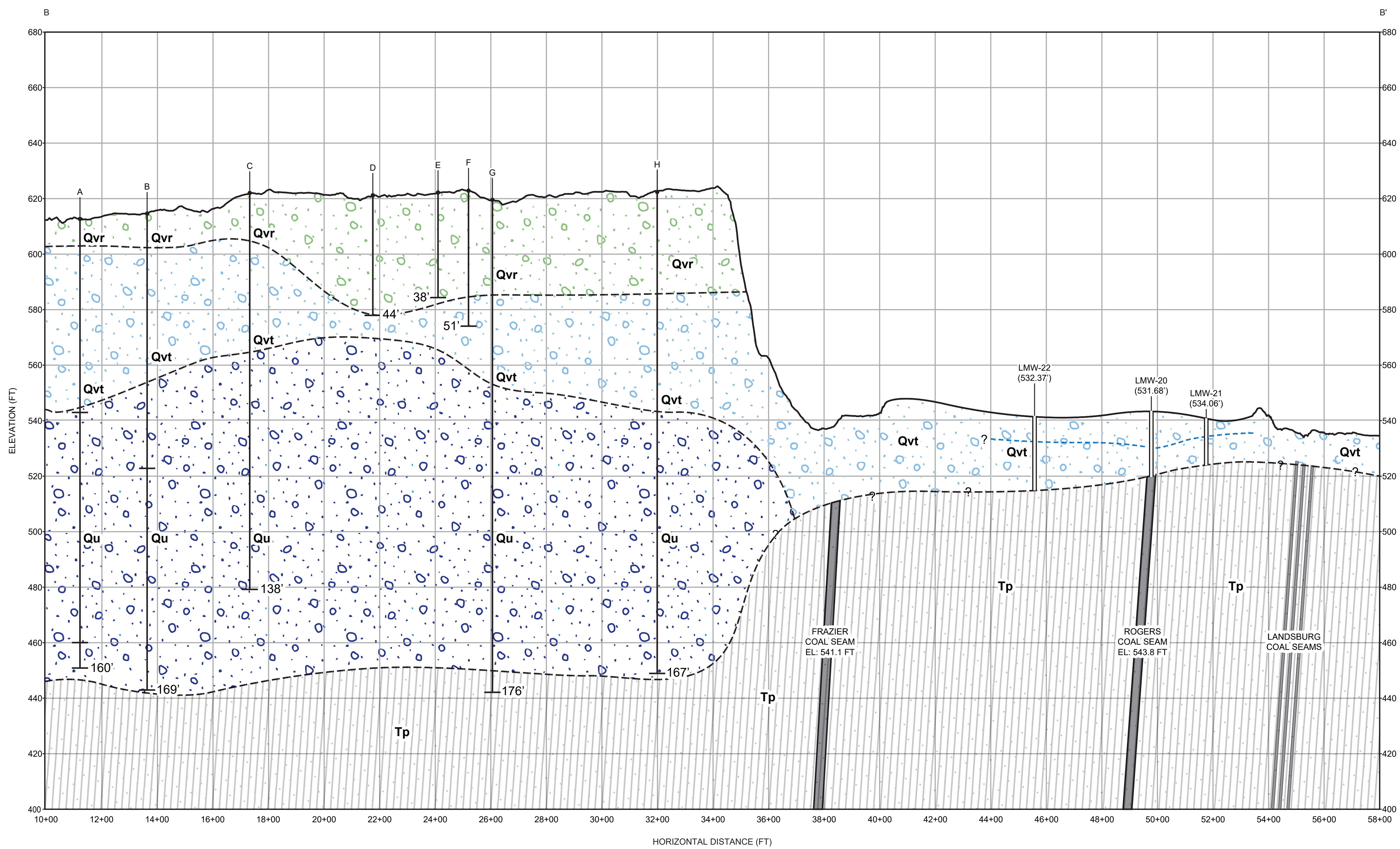


Figure 3 - 1,4-Dioxane Trend Plot Since November 2017
1,4-Dioxane Concentration (ug/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
9/22/2017
12/31/2017
4/10/2018
7/19/2018
10/27/2018
2/4/2019
5/15/2019
8/23/2019
12/1/2019
3/10/2020
Date
LMW-2
LMW-4
LMW-12



VERTICAL SCALE: 1" = 20' — 0, 20, 40 FEET

HORIZONTAL SCALE: 1" = 200' — 0, 200, 400 FEET

EXPLANATION

- Tp (UNDIFFERENTIATED PUGET GROUP) - SANDSTONE INTERBEDDED SHALE AND COAL
- Qu (PRE-VASHON DRIFT) - TILL, FLUVIAL SAND AND GRAVEL, LACUSTRINE SAND, SILT, CLAY, AND PEAT
- Qvt (TILL) - COMPACT MIXTURE OF GRAVEL, OCCASIONAL BOULDERS IN CLAYEY SILTY SAND MATRIX
- Qvr (RECESSIONAL OUTWASH) - WELL SORTED SAND AND PEBBLE-COBBLE
- A — PRIVATE WELL LOCATION AND DEPTH FROM DRILLERS BOREHOLE LOGS
- LMW-20 (531.68') — WELL ID (WATER LEVEL IN FT. AMSL)
- POTENTIOMETRIC SURFACE

NOTE: Groundwater elevation obtained 4/22/2019

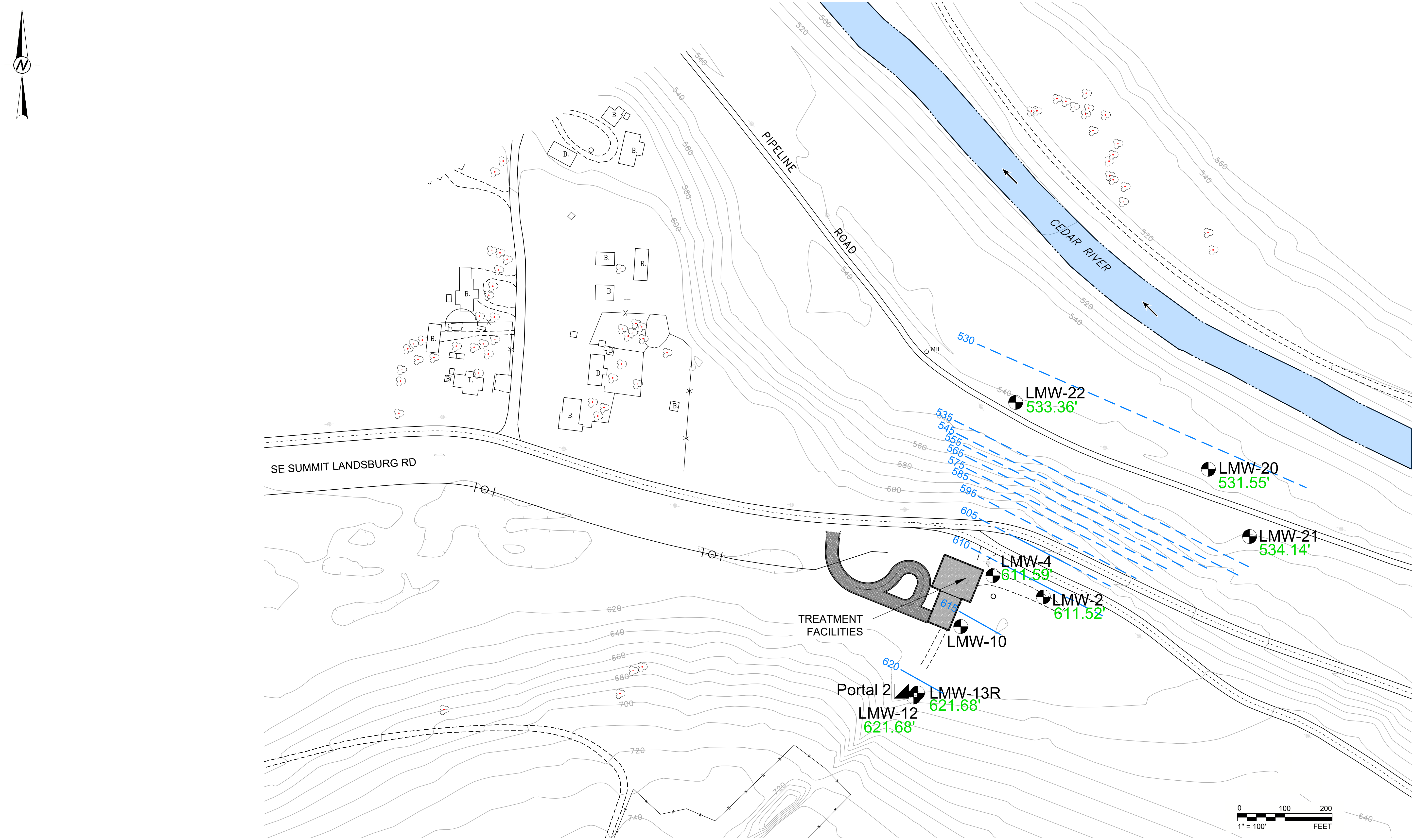
Private well locations are approximate

Sources for the Geology and Mine Information:

- J.E. Luzier 1969; surficial geology
- State of Washington, Water Well reports
- Landsburg Well Logs

NOTE:
Wells are projected normal into the strike of the Cross-Section C-C'.
Cross-sections are inferred from limited data and should be considered approximate.

CLIENT	LANDSBURG MINE SITE PLP GROUP	PROJECT	LANDSBURG MINE SITE
CONSULTANT	GOLDER	YYYY-MM-DD	2019-04-29
		PREPARED	REDMOND
		DESIGN	
		REVIEW	
		APPROVED	
TITLE	CROSS-SECTION B-B`		
PROJECT No.	923-1000.005	PHASE	1019
FIGURE	4		



LEGEND

(monitoring well symbol)	MONITORING WELL
615.88'	GROUNDWATER ELEVATION (FEET AMSL)
(blue line)	APPROXIMATE GROUNDWATER ELEVATIONS (FEET AMSL)

NOTE(S)

1. LMW - 10 MEASURES A DEEPER FORMATION AND ITS GROUNDWATER ELEVATION WAS NOT USED IN THE DEVELOPMENT OF THE APPROXIMATE GROUNDWATER ELEVATION CONTOURS.
2. GROUNDWATER ELEVATIONS OBTAINED 4/22/2019.

CLIENT
LANDSBURG MINE SITE PLP GROUP

CONSULTANT
GOLDER

YYYY-MM-DD	2019-04-12
DESIGNED	JX
PREPARED	REDMOND
REVIEWED	JX
APPROVED	GZ

PROJECT
LANDSBURG MINE SITE
MTCA REMEDIAL ACTION

TITLE
GROUNDWATER POTENTIOMETERIC SURFACE

PROJECT NO.	PHASE	REV.	SHEET
9231000005	1250	A	5

GOLDER

golder.com