Natural Attenuation Assessment Report
Boeing Auburn Facility
Auburn, Washington

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Prepared for

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1.0 INTRODUCTION

This report documents an assessment of natural attenuation of volatile organic compound (VOC) trichloroethene (TCE) and its breakdown products in the groundwater aquifer northwest of The Boeing Company's (Boeing's) Auburn Fabrication Division facility (facility). Boeing is currently undergoing corrective action at the facility, located at 700 15th Street Southwest in Auburn, Washington. Corrective action requirements are documented in an Agreed Order (Order; No. DE 01HWTRNR-3345) dated August 14, 2002 and the First Amended Agreed Order dated February 21, 2006, both with the Washington State Department of Ecology. The Order includes a requirement to conduct a remedial investigation (RI) of facility contamination impacts both on Boeing property and at downgradient properties (off Boeing property). This report assesses natural attenuation in groundwater and surface water on Boeing property and off Boeing property in Algona, Washington; northwest of the facility. The Boeing property[1] location and vicinity map, including Algona, are shown on Figure 1.

1.1 ASSESSMENT SCOPE AND OBJECTIVE

The scope and objective of the Algona natural attenuation assessment are presented in the Algona Natural Attenuation Assessment Work Plan (Work Plan; Landau Associates 2014a). The assessment was conducted in accordance with the Work Plan. The primary objective of the natural attenuation assessment was to provide information to be used in conjunction with the Algona bioremediation pilot test conducted in August and September 2015.

The scope of the assessment consisted of collecting additional geochemical and degradation end product data in groundwater and surface water and evaluating those data for evidence of natural attenuation of TCE and its breakdown products. Groundwater samples were collected at 27 locations, with a few locations at the facility (near Building 17-07), and the majority of locations downgradient along the groundwater flow path to the northwest. The locations along the downgradient flow path included commercial and residential Algona. A surface water sample was also collected from one location at the Chicago Avenue ditch in Algona. Data were evaluated for indicators of aquifer conditions conducive to biological (biotic) and chemical (abiotic) degradation and for breakdown products and end products that demonstrate TCE degradation.

The objective of this natural attenuation assessment is to understand the effects of natural aquifer conditions and resulting biotic and abiotic processes on the attenuation of low levels of TCE and breakdown product within the northeast Algona residential area and at locations nearby and hydraulically upgradient.

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[1] The facility as defined in the First Amended Agreed Order consists of the Boeing property and the Prologis property directly north of the Boeing property.

Results will assist in understanding data collected during and following the Algona pilot test and inform future remedy selection which could consist of source control, other active treatment, institutional controls, and monitored natural attenuation (MNA).

1.2 BACKGROUND

Boeing has been implementing RI activities to characterize the nature and extent of two groundwater plumes: the Area 1 plume (Plume 1) and the western plume (Plume 2), which occur beneath the northern portion of the facility and extend off Boeing property to the north and northwest. These plumes consist of TCE and its reductive dechlorination breakdown products cis-1,2-dichloroethene (cis-1,2-DCE) and vinyl chloride (VC). RI activities conducted to date are described in a series of RI reports (Landau Associates 2009a,b; 2010; 2012a,b; 2014b,c).

The uppermost aquifer near the Auburn site consists of saturated portions of modern alluvium and recent alluvium deposited by the Green River and White River. The Osceola Mudflow serves as a regional aquitard between the uppermost aquifer and deeper aquifers. Locally, beneath the Boeing property and off Boeing property to the north, the uppermost aquifer is about 90 feet (ft) thick. For the purpose of the RI, the uppermost aquifer has been subdivided into three groundwater zones based on depth beneath ground surface (BGS):

- A shallow zone from approximately the ground surface (or top of water table) to 30 ft BGS. Some monitoring wells within this zone are screened at or near the water table and resulting water table data is considered a subset of the shallow zone data
- An intermediate zone from approximately 40 to 60 ft BGS
- A deep zone from approximately 80 to 100 ft BGS. The bottom of the deep zone is defined by the contact with the Osceola Mudflow, the depth of which may vary based on location.

Detections of TCE and breakdown products in these three zones are used to define the shallow, intermediate, and deep zone extent of the two groundwater plumes.

In December 2012, new wells were installed which indicated that the western plume extended into the northeastern portion of residential Algona. Additional investigations occurred in this area to delineate the extent of the groundwater plumes in northeastern residential Algona (Landau Associates 2014c,d). Breakdown products cis-1,2-DCE and VC are common in the groundwater in this area and are evidence of anaerobic biodegradation of TCE. Organic content in aquifer soils and peaty deposits were observed, indicating an abundance of natural organic carbon that would support a reduced aquifer environment. The observed high organic content in aquifer soils reflects the lowland stream/wetland depositional environment that existed historically in this area. Chemical (abiotic) degradation is also likely occurring due to reduced minerals within the naturally anaerobic aquifer in this area. Additional background information about these natural attenuation degradation processes is provided in Section 2.0.

2.0 NATURAL ATTENUATION DEGRADATION PROCESSES

Natural attenuation describes a reduction of contaminant toxicity, volume, concentration, mobility, and/or bioavailability through natural physical, chemical, or biological processes that occur without human intervention. For the VOCs that occur in groundwater, the physical attenuation processes include dispersion, dilution, sorption, and volatilization; these VOCs are also susceptible to chemical and biological degradation. Chemical and biological attenuation processes that destroy or degrade contaminants are preferred over some of the non-destructive physical processes (EPA 1999). Synonyms for natural attenuation include intrinsic remediation, natural recovery, and natural assimilation.

MNA is a groundwater treatment technology that involves periodic groundwater monitoring to evaluate the progress of natural attenuation in achieving remediation objectives. MNA is not a “no action” approach, but requires performance monitoring, demonstration that attenuation is occurring, and an understanding of site-specific and contaminant-specific attenuation mechanisms. MNA is typically appropriate for sites with a low potential for continued contaminant migration (i.e., stable plumes) and relatively low concentrations, and where natural attenuation processes will achieve cleanup levels in a reasonable timeframe compared to more active treatment. MNA is typically performed in conjunction with some active remedial measures (e.g., source control) and/or institutional controls (EPA 1999).

This section describes the biological (biotic) and chemical (abiotic) degradation processes that can result in natural attenuation of the VOCs of concern in the groundwater plumes, required aquifer conditions, and evaluation of parent and degradation products. These degradation processes are described in various peer-reviewed publications (SERDP-ESTCP 2010, AFCEE 2004, Wiedemeier 2004). The VOCs of concern are TCE (parent) and biodegradation breakdown products cis-1,2-DCE[2] and VC. Biotic and abiotic degradation end products (ethene, ethane, and acetylene) are non-toxic. Although end products are further degraded to carbon dioxide and water (a process known as mineralization), detection of end products indicates complete degradation of chlorinated parent and breakdown products (e.g., cis-1,2-DCE and VC) that are subject to environmental regulation.

It should be noted that favorable aquifer conditions for biotic/abiotic degradation and the presence of degradation breakdown and end products may not result in the absence of parent and breakdown products at a particular location. Although degradation is occurring, ongoing flux of contaminants from hydraulically upgradient areas of the plume may result in continued detections of contaminants over some period of time.

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[2] Although dichloroethene (DCE) has three isomers, the predominant breakdown product of TCE reductive dechlorination is cis-1,2-DCE; 1,1-dichloroethene (1,1-DCE), and trans-1,2-dichloroethene (trans-1,2-DCE), if detected, are typically at much lower concentrations than the cis-1,2-DCE isomer (AFCEE 2007). Therefore, cis-1,2-DCE is the breakdown product of concern out of these three possible isomers.

The shifting balance between contaminant flux and attenuation processes determines the assemblage of TCE and degradation breakdown and end products present at a given location.

2.1 REQUIRED AQUIFER CONDITIONS

Anaerobic aquifer conditions are required for biotic and abiotic degradation of TCE and breakdown products. The presence of dissolved oxygen (DO) indicates aerobic, or oxidative, aquifer conditions. In the absence of DO, conditions are anaerobic, or reducing.

Aerobic and anaerobic conditions are characterized by sequential redox reactions, whereby aquifer microorganisms (including bacteria and archaea) obtain energy. These redox reactions require an electron donor (i.e., a source of organic carbon, which ferments to volatile fatty acids and hydrogen) and an electron acceptor (e.g., oxygen, nitrate, iron, sulfate, carbon dioxide). These redox reactions can be compared to the process whereby humans obtain energy through consumption of food (electron donor) and oxygen (electron acceptor).

Microorganisms obtain the greatest energy yield by using oxygen as an acceptor as it is highly oxidized and therefore, can be reduced easily and to a large degree. Less oxidized acceptors provide less energy yield and are utilized after available oxygen has been consumed. When oxygen is largely depleted, anaerobic bacteria use the less oxidized electron acceptors present in the aquifer in sequential order: nitrate, manganese (IV), iron (III), sulfate, and carbon dioxide. The redox state of the aquifer is defined by which natural electron acceptors are being used (i.e., reduced) at a given time. Understanding the redox state of the aquifer is important, as biotic and abiotic degradation of TCE and breakdown products requires specific redox conditions, as described below.

2.2 BIOTIC DEGRADATION

TCE can be biotically degraded in an anaerobic aquifer through either reduction or oxidation processes. TCE and breakdown products are utilized as electron acceptors by specific micro-organisms to obtain energy. The most common process is reductive dechlorination, whereby bacteria sequentially reduce TCE to breakdown products cis-1,2-DCE and VC, and finally to non-toxic end products ethene/ethane. Although anaerobic aquifer conditions are required for metabolic degradation of TCE, breakdown products VC and cis-1,2-DCE can also be degraded under aerobic conditions (AFCEE 2004; EPA 2000). Cis-1,2-DCE and VC can also be oxidized under anaerobic conditions to carbon dioxide although this is typically a minor pathway compared to reductive dechlorination. Anaerobic reductive dechlorination and anaerobic oxidation are described below.

TCE and breakdown products are reductively dechlorinated under different redox conditions. At each step of reductive dechlorination, a chlorine ion present on the chlorinated hydrocarbon molecule (e.g., TCE) is replaced with hydrogen resulting in the formation of successively less chlorinated (less oxidized) molecules, as follows:

TCE→cis-1,2-DCE→VC→Ethene/Ethane

Because TCE is highly oxidized, it can be reduced under moderately reducing (iron-reducing conditions; Chapelle 1996). Less oxidized cis-1,2-DCE and VC require successively more reduced aquifer conditions for anaerobic degradation; cis-1.2-DCE is reduced to VC under sulfate-reducing or methanogenic conditions (Chapelle 1996; Vogel et al. 1987) and VC to ethene/ethane under highly reducing, methanogenic conditions (Ballapragada et al. 1997; Freedman and Gosset 1989; Maymó-Gatell et al. 1995; Vogel and McCarthy 1985).

It is not uncommon for biotic degradation of TCE to result in accumulation of cis-1,2-DCE without further sequential dechlorination to VC and end products. This is known as cis-stall and can results from inadequately reduced aquifer redox conditions, as described above, and/or from inadequate presence of *Dehalococcoides* bacteria (AFCEE 2004; Major et al. 2003a). Various strains of *Dehalococcoides* are the only bacteria that have been identified as responsible for dechlorination of cis-1,2-DCE to VC, while the remaining dechlorination steps are performed by a much wider range of various micro-organisms. The occurrence of VC in groundwater indicates adequate reducing conditions and presence of *Dehalococcoides.*

Biotic anaerobic oxidation is a less-well understood degradation pathway and is a minor pathway compared to reductive dechlorination (SERDP-ESTCP 2010). VC and cis-1,2-DCE are more reduced than TCE and therefore, can be anaerobically oxidized to carbon dioxide. The precise mechanism for anaerobic oxidation of cis-1,2-DCE and VC is not fully understood. It likely involves either a redox reaction or conversion to acetate (i.e., acetogenesis), with further oxidation of acetate through either acetotrophic methanogenesis to methane and carbon dioxide (Bradley and Chapelle 1999a,b; 2000), or through anaerobic oxidation directly to carbon dioxide (Bradley and Chapelle 2000). Due to the common occurrence of the anaerobic oxidation breakdown products, it is not feasible to document degradation by this pathway.

2.3 ABIOTIC DEGRADATION

TCE and cis-1,2-DCE can also be degraded abiotically through chemical reaction with iron sulfide minerals. This abiotic destruction is complimentary and occurs concurrently with biological reductive dechlorination. This is the same abiotic degradation that occurs in zero valent iron permeable reactive barriers. Although the destruction of TCE and cis-1,2-DCE by this mechanism is abiotic, the formation of iron sulfide minerals requires biological reduction of iron and sulfate under iron- and sulfate-reducing redox conditions. Iron-sulfides form microscopic coatings on aquifer soil grains. Iron- and sulfate-reducing aquifer redox conditions commonly occur naturally in wetland dispositional environments where natural electron donor in the form of higher soil organic carbon content and/or peaty deposits (such as the northeastern portion of residential Algona, see Section 1.2) causes reduction of oxygen and other natural electron acceptors (AFCEE 2004; Brown et al. 2007). These naturally reducing environments are referred to as Type 2 geochemical environments. Iron-sulfides will form in any aquifer environment where iron, sulfate, and adequate electron donor are present; the iron- and sulfate-reducing bacteria responsible are ubiquitous (Wiedemeier 2004).

The predominant abiotic reaction is known as reductive elimination (or beta-elimination), whereby iron chemically reduces TCE or cis-1,2-DCE, replacing two chlorine atoms with hydrogen atoms. This reaction does not occur with VC. The reduction results in short-lived, non-toxic intermediaries chloroacetylene and acetylene; these compounds are highly reactive and break down quickly to ethene and/or ethane and then to carbon dioxide and water (Shen and Wilson 2007). If detected, acetylene indicates reductive elimination of TCE/cis-1,2-DCE is occurring; however, due to its high reactivity, acetylene is detected infrequently or at low concentrations even when reductive elimination is actively occurring. Even if acetylene is not detected, the occurrence of iron- and sulfate-reducing conditions is evidence that iron sulfides are formed in the aquifer, resulting in abiotic degradation of TCE and cis-1,2-DCE.

Hydrogenolysis is a minor abiotic degradation pathway whereby TCE chemically reacts with iron, sequentially replacing one chlorine atom at a time with a hydrogen atom. This sequential reduction produces the same breakdown products as biotic reductive dechlorination (cis-1,2-DCE and VC), which can be degraded further to ethene. This pathway cannot be distinguished from biotic reductive dechlorination.

2.4 EVALUATION OF MOLAR FRACTIONS

Conversion of groundwater concentrations [unit micrograms per liter (µg/L)] to molar equivalents (unit micromoles per liter) allows evaluation of molar fractions. Converting groundwater concentrations to molar equivalents allows a direct comparison of the number of moles (i.e., number of molecules) of TCE and breakdown products in a given sample. Because TCE and breakdown products have different molecular weights, with the molecular weight decreasing at each dechlorination step (i.e., removal of chloride ion), groundwater concentrations in units of µg/L do not allow a comparison of the relative percentages of TCE, breakdown products, and end products in a given sample. For example, full dechlorination of a given concentration of TCE (100 µg/L) results in lower concentrations of cis-1,2-DCE (79 µg/L), VC (48 µg/L), and ethene (21 µg/L) due to their lower molecular weights. However, conversion to molar equivalents allows direct comparison of the percentage of each compound since 1 mole of TCE would convert sequentially to 1 mole of cis-1,2-DCE, 1 mole of VC, then 1 mole of end products ethene /ethane.

Molar fractions presented in this assessment indicate the relative percentages of TCE, total DCE[3], VC, and ethene/ethane in a given sample. The molar equivalent of each compound is divided by the sum of molar equivalent for chlorinated volatile organic compounds (CVOCs)+ethene+ethane to calculate the compound's total ethene molar fractions (i.e., the percentage of total ethenes comprised by the given compound). The compound with the highest molar fraction is considered predominant in that sample. Predominance of TCE, DCE, VC, or ethene/ethane indicates the progression of reductive dechlorination at the sample location.

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[3] Although cis-1,2-DCE is known to be the primary isomer resulting from reductive dechlorination, total DCE, consisting of the sum of cis-1,2-DCE, trans-1,2-DCE, and 1,1-DCE isomers, is used as a conservatism in calculating the DCE molar fraction.

3.0 SAMPLING AND ANALYSIS

The scope of the natural attenuation assessment sampling and analysis program is presented in the Work Plan (Landau Associates 2014a). Field activities included collection of groundwater samples for the natural attenuation assessment from 27 selected monitoring wells and the collection of a surface water sample from one location at the Chicago Avenue ditch. Locations of the monitoring wells and surface water sampling location are shown on Figure 2.

Monitoring for assessment of natural attenuation included analysis of TCE, biotic and abiotic degradation products, organic carbon, and aquifer redox parameters. TCE biotic and abiotic degradation products include cis-1,2-DCE, VC, ethene, ethane, and acetylene. Total organic carbon (TOC) results indicate the availability of electron donor within the aquifer. Aquifer redox parameters include oxygen, nitrate, ferrous iron, sulfate/sulfide, and methane [produced by carbon dioxide ($C0_2$) reduction], which are used to assess the redox state of the aquifer. Parameters measured in the field consist of pH, ferrous iron, DO, and oxidation-reduction potential (ORP). Parameters requiring laboratory analysis are nitrate, sulfate, sulfide, TOC, and the dissolved gases acetylene, methane, ethene, and ethane. Table 1 describes the information provided by each field and laboratory parameter for evaluation of natural attenuation.

3.1 GROUNDWATER AND SURFACE WATER SAMPLING

Groundwater and surface water sampling for natural attenuation assessment were performed in conjunction with the regularly scheduled semiannual VOC sampling in December 2014. Groundwater sampling occurred between December 1 and December 11, 2014, using a peristaltic pump and dedicated tubing in accordance with low-flow sampling techniques.

Surface water sampling took place on December 2, 2014, after a period of no measureable precipitation over a 48-hour period to minimize stormwater runoff dilution of the sample. The surface water sample was collected from the approximate mid-point of the water column using a peristaltic pump, with dedicated sample tubing attached to a rigid pole to control the sampling location and depth; less than 4 inches of water were present at the time of sampling.

Field parameters were measured at the time of sampling for both groundwater and surface water. A multi-parameter probe (YSI 556 MPS) and flow-through cell was used to measure pH, conductivity, DO, temperature, and ORP. Ferrous iron was analyzed using a Hach® Model 1R-18C field test kit. Turbidity of groundwater samples was measured using a turbidity meter. Field parameters used for natural attenuation assessment are listed in Table 1 and discussed in Section 4.0.

3.2 LABORATORY ANALYSES

Nine or eleven[4] VOA containers and one 250-milliliter glass bottle were collected at each sample location. All sample containers were stored in coolers with ice and shipped using proper chain-of-custody procedures. A trip blank accompanied each cooler of samples. One set of duplicate samples was collected for each 20 samples.

Samples were analyzed by Eurofins Lancaster Laboratories, Inc of Lancaster, Pennsylvania, within the required holding time. Analytical methods, sample bottles, preservatives, and holding times are indicated in Table 1. Laboratory analytical results are presented in Appendix A. The information provided by each laboratory groundwater parameter for evaluation of natural attenuation is listed in Table 1 and discussed in Section 4.0.

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[4] Only nine volatile organic analyte (VOA) containers were collected at locations where selected ion monitoring analysis was not completed.

4.0 NATURAL ATTENUATION ASSESSMENT

Natural attenuation evaluation requires a "weight of evidence" approach, as there is often some disagreement between individual parameters. Aquifer conditions and evidence of reductive dechlorination were evaluated at each well. VOC and end product concentrations were converted to molar equivalents for each well to evaluate the molar fractions of TCE, breakdown products, and end products. Natural attenuation sampling results are summarized on Table 2.

4.1 AQUIFER CONDITIONS

Aquifer conditions at each sampling location were evaluated based on electron donor availability (presence of TOC), pH, and the redox conditions of the aquifer. Aquifer redox conditions are determined by evaluating the concentrations of DO, ORP, nitrate, iron, sulfate, sulfide and methane. Aquifer redox conditions and donor availability are presented in Figure 3.

Data were generally indicative of a Type 2 aquifer environment, defined as an aquifer that is anaerobic due to naturally occurring organic carbon (Weidemeier 2004). This is consistent with the observed organic soils and peaty deposits, and the historic lowland stream/wetland depositional environment in this area (Section 1.2). The natural occurrence of organic carbon and reduced aquifer conditions are conducive to biotic and abiotic degradation of TCE and breakdown products. It is understood that TOC and aquifer redox conditions will vary spatially and with depth in the aquifer due to aquifer heterogeneities caused by spatial and temporal variations in the depositional environment (e.g., meandering stream channels, overbank deposits, wetlands, etc).

4.1.1 ELECTRON DONOR AVAILABILITY

Electron donor availability is determined by the presence of TOC. TOC greater than 10 milligrams per liter (mg/L) is considered adequate for substantial reductive dechlorination (Major et al. 2003b) at sites where reductive dechlorination is stimulated through injection of electron donor. Relatively low concentrations, less than 5 mg/L, may be adequate for somewhat slower natural attenuation sustained over a longer period.

TOC results generally indicated adequate electron donor for sustained natural attenuation. TOC was detected at all of the sampling locations, except for five (AGW145, AGW146, AGW166, AGW167, and AGW191). Where detected, TOC concentrations ranged from 1.1 to 57.4 mg/L and averaged approximately 16 mg/L. TOC was greater than 10 mg/L at 11 of 28 sampling locations. The lowest TOC concentrations (less than 2.0 mg/L), including the non-detect results, were all at intermediate and deep zone wells; other intermediate and deep zone wells had higher concentrations, ranging from 2.8 to 37.3 mg/L. TOC in the Chicago Avenue ditch sample was 9.1 mg/L.

4.1.2 PH

Measured pH values between 6 and 8 and are generally considered optimal for biodegradation (EPA 1998). With the exception of one location, pH results were within this optimal range, from 6.04 to 7.09. At AGW242-1, pH was slightly below the optimal range at 5.87; however, other evidence indicates biodegradation at this location.

4.1.3 AQUIFER REDOX

Aquifer redox conditions were found to be anaerobic and generally highly reducing (i.e., sulfate-reducing to methanogenic). These conditions are beneficial to TCE degradation and consistent with observed TCE degradation breakdown products and end products, as discussed in Section 4.2. With the exception of well AGW146, conditions are also consistent with the formation of iron sulfides responsible for abiotic reductive elimination. Aquifer redox conditions at each sample location are indicated in Table 2 and in the groupings below. Redox conditions occur sequentially, but with some overlap or transition between redox states. The bacteria for these redox conditions are ubiquitous. Where data indicated a transitional condition (e.g., partial sulfate reduction or lower relative methane concentrations) a redox range is indicated.

- **Nitrate-reducing:** AGW146
- **Iron-reducing to Sulfate-reducing:** SW-CD13, AGW145, AGW167, AGW193, AGW225, and AGW248-5
- **Sulfate-reducing to Methanogenic:** AGW155, AGW200-6, AGW227, AGW228, AGW242-1, AGW245, AGW247-1, AGW248-1, AGW251-1, AGW251-2, AGW251-4, and AGW251-6
- **Methanogenic:** AGW032, AGW079, AGW166, AGW191, AGW192, AGW240-1, AGW240-5, AGW247-5, and AGW251-3.

The evidence provided by each redox parameter is discussed below. As discussed in Section 2.1, the redox state of the aquifer is indicated by which electron acceptors are reduced, with reduction occurring in sequential order: oxygen, nitrate, manganese (IV), iron (III), sulfate, and CO_2.

4.1.3.1 Dissolved Oxygen and Oxidation-Reduction Potential

Where measured, DO values were generally less than 1 mg/L indicating anaerobic conditions. DO was not measured at four well locations and was greater than 1 mg/L at 6 of the 23 well locations where it was measured. ORP values were negative indicating reducing conditions, except at five well locations.

However, DO and ORP are considered much less reliable than the parameters discussed below. The Chicago Avenue ditch surface water sample had a DO value of 5.4 mg/L indicating aerobic conditions, but the ORP value was negative, indicating reducing conditions. The ditch water is most likely a mixture of reduced groundwater and aerobic surface water.

4.1.3.2 Nitrate

Nitrate was not detected at any of the 27 well locations indicating conditions that are anaerobic and at least nitrate-reducing at all wells; more highly reduced conditions (i.e., iron-reducing, sulfate-reducing, or methanogenic conditions) existed at most wells, as described in subsequent sections. Nitrate was detected at a low concentration (0.61 µg/L) at the surface water sampling location. Concentrations above 1.0 mg/L are indicative of aerobic conditions; low to depleted nitrate concentrations indicate nitrate-reducing conditions.

4.1.3.3 Ferrous Iron

Ferrous iron was detected at all of the sampling locations[5] except for one (AGW146). Detected ferrous iron concentrations ranging from 0.4 to 6.0 mg/L, indicate iron-reducing conditions. Lack of ferrous iron at AGW146 indicates a nitrate-reducing condition.

4.1.3.4 Sulfate and Sulfide

Sulfate-reducing conditions are indicated by low or depleted sulfate and by the presence of methane. Methane presence indicates the occurrence of methanogenesis (CO_2 reduction) which is the next, more reduced redox state after sulfate reduction. Where substantial methane is present, sulfate reduction has occurred or is occurring concurrently. Sulfate was not detected at 9 of the 28 sampling locations, indicating complete sulfate reduction. Detected sulfate concentrations ranged from 1.1 to 194 mg/L. A sulfate-reducing condition was also clearly indicated at 11 additional wells (Table 2) where detected sulfate was accompanied by elevated methane (greater than 500 µg/L). At these wells, sulfate is not completely reduced despite clearly methanogenic conditions, likely due to higher upgradient sulfate conditions. Where sulfate and ferrous iron are both detected and methane is relatively low (less than 500 µg/L), conditions are iron- to sulfate-reducing. Sulfide, the product of sulfate reduction, was not detected at any of the 28 sampling locations. However, sulfide is commonly not detected where sulfate-reducing conditions occur, because it complexes with ferrous iron to precipitate on the aquifer matrix as iron sulfide (Weidemeier et al. 2004); these iron-sulfides are responsible for abiotic reductive elimination (Section 2.3). Iron sulfides

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[5] Iron was not measured at AGW248-1.

on aquifer soil are microscopic and well distributed; generally, this means they are not observable with the naked eye.

4.1.3.5 Methane

Methane was detected at all sampling locations indicating methanogenic aquifer redox conditions (i.e., CO_2 reduction). However, methane can also be transported with groundwater flow, so the presence of methane indicates that methanogenic conditions exist in the vicinity, but not necessarily at the sampling location (Weidemeier et al., 2004). Methane concentrations ranged from 29 to 16,000 µg/L. Aquifer redox conditions are described as methanogenic when sulfate was not detected and methane concentrations were detected at greater than 500 µg/L. Locations with detected sulfate and methane greater than 500 µg/L are described as sulfate-reducing to methanogenic.

4.2 EVIDENCE OF TRICHLOROETHENE DEGRADATION

Evidence of TCE degradation consists of the presence of biotic and abiotic degradation products, non-toxic end products, and the relative molar mass of breakdown and end products to TCE. As described in Sections 2.2 and 2.3, biotic reductive dechlorination and hydrogenolysis (a minor abiotic degradation pathway) both result in the breakdown products, cis-1,2-DCE and VC, and in end products ethene and ethane. Reductive elimination (the primary abiotic degradation pathway described in Section 2.3) results in the short-lived, non-toxic intermediaries chloroacetylene and acetylene, which further degrade to ethene and/or ethane. Ethene and ethane further degrade to carbon dioxide and water in a process known as mineralization. Groundwater concentrations of CVOCs and non-toxic end products are shown at each well on Figure 4.

Low-levels of tetrachloroethene (PCE) are occasionally detected at the facility and in the groundwater plumes; however, PCE was only detected at two locations (AGW193 and AGW248-5) and at concentrations less than 0.2 µg/L. Due to minor occurrence, PCE is not discussed further.

4.2.1 PRESENCE OF BREAKDOWN PRODUCTS AND END PRODUCTS

Breakdown products cis-1,2-DCE and VC were widely detected indicating widespread reductive dechlorination. For comparison, TCE was detected at 9 of the 28 sampling locations and ranged from 1.2 to 14 µg/L. Cis-1,2-DCE was detected at a greater number of sampling locations (20 of 28) and ranged from 0.4 to 8.7 µg/L. Final breakdown product VC was detected at even more locations (25 of 28) and ranged from 0.10 to 4.7 µg/L. It should be noted that VC was detected at all wells where TCE or cis-1,2-

DCE were detected and was the only CVOC detected at four of the sampling locations (AGW032, AGW242-1, AGW245, and AGW251-1).

Three locations (AGW191, AGW192, and AGW248-1) did not have detections of CVOCs. Aquifer redox conditions were sulfate-reducing to methanogenic or methanogenic at all these locations, indicating conditions conducive to complete reductive dechlorination of TCE to non-toxic end products. At AGW192 where cis-1,2-DCE and VC have not been detected since 2013, ethene (7.9 µg/L) was the only constituent detected, indicating ongoing and complete reductive dechlorination.

Ethene and/or ethane were detected at 11 of the 28 sampling locations, indicating complete reductive dechlorination through to these non-toxic end products. Ethene and/or ethane were detected at AGW192, AGW240-1, AGW240-5, AGW242-1, AGW247-1, AGW247-5, and all five channels sampled from AGW251.

Acetylene, the short-lived intermediary of abiotic reductive elimination, was not detected. However, acetylene is highly reactive and is detected infrequently even when reductive elimination is actively occurring (Weidemeier et al. 2004). As described in Sections 2.3 and 4.1.3, the observed redox conditions are conducive to formation of the iron-sulfides responsible for reductive elimination, providing evidence that this abiotic degradation pathway is occurring in the aquifer.

4.2.2 MOLAR FRACTIONS

Molar fractions were calculated to better understand the progression of sequential reductive dechlorination from the TCE parent product to non-toxic end products at each sampling location. Molar fractions were calculated for each of the 26 sample locations with CVOC detections; calculations are as described in Section 2.4. Molar fractions indicate the relative percentages of TCE, total DCE, VC, and ethene+ethane in a given sample. The compound with the highest molar fraction is considered predominant in that sample. Molar fractions are presented in Table 2 (predominant fractions highlighted) and on Figure 5. Figure 6 presents a plot of molar fractions for each sample location. Sampling locations are grouped by predominance as follows:

- **TCE Predominant:** AGW145, AGW146, AGW167, AGW193, and AGW248-5
- **DCE Predominant:** AGW200-6, AGW166, SW-CD13, AGW225, AGW247-5, AGW227, and AGW228
- **VC Predominant:** AGW032, AGW079, AGW155, AGW251-3, AGW240-5, and AGW245
- **Ethene/Ethane Predominant:** AGW192, AGW240-1, AGW242-1, AGW247-1, AGW251-1, AGW251-2, AGW251-4, and AGW251-6.

It is apparent from the data set and the distribution of predominance shown on Figure 5 that reductive dechlorination is further progressed beneath the northeast residential Algona neighborhood compared to the northern part of commercial Algona. On Figure 5, a northwest-trending line extended from the facility marks the division of wells with TCE or DCE predominance (east of the line) from wells with VC or ethene/ethane predominance (west of the line). Two exceptions are AGW247-5 (shallow zone neighborhood well) where DCE is predominant to the west of the line and AGW032 (water table/shallow zone well on the Facility) where VC is predominant east of the line. This division is consistent with VOC distribution data that show the fringe of the western VOC plume passing beneath the northeast corner of the Algona neighborhood, with the highest TCE concentrations located to the east and north of the neighborhood. This division is also consistent with the higher organics content (including peat) observed in aquifer soils beneath the neighborhood, which results from the wetlands depositional environment in this area. The higher organic content leads to the potential for greater reductive dechlorination as is evidenced by the predominance of VC or ethene/ethane west of the dividing line.

Non-toxic ethene/ethane is predominant at all sampled water table wells, with the exception of AGW225 and AGW245, which are located on the east and north edges of the neighborhood. Predominance of ethene/ethane in water table wells beneath the neighborhood is significant because this is the zone of greatest potential exposure to neighborhood residents. As indicated in Figure 6, ethene/ethane predominance also occurs at shallow, intermediate, and deep zone wells.

5.0 SUMMARY AND CONCLUSIONS

The weight of evidence indicates that substantial natural attenuation of VOCs in groundwater is occurring within the study area through biotic and abiotic degradation. Assessment findings discussed in prior sections are summarized below.

- Total organic carbon (TOC) was generally detected at concentrations adequate for ongoing natural attenuation.
- Aquifer redox conditions were anaerobic and generally highly reducing (i.e., sulfate-reducing to methanogenic). These highly reducing conditions are conducive to complete reductive dechlorination of PCE, TCE, and breakdown products cis-1,2-DCE and VC to non-toxic end products ethene/ethane. These conditions are also conducive to complementary and concurrent abiotic degradation.
- The surface water sampling location at the Chicago Avenue ditch indicates a mixture of aerobic surface water conditions with anaerobic groundwater.
- Reductive dechlorination breakdown products and non-toxic end products were more widely detected than parent product TCE. TCE was detected at 9 of the 28 locations. Final breakdown product VC was detected at more locations (25 of 28) than cis-1,2-DCE (20 of 28 locations). End products ethene/ethane were detected at 11 of the 28 locations. Presence of ethene/ethane indicates complete reductive dechlorination is occurring.
- Breakdown and end products were predominant on a molar basis at 21 of 26 locations with detected CVOCs, compared to only five locations where TCE was predominant. End product ethene/ethane was predominant over TCE, DCE, or VC at eight locations.
- Reductive dechlorination is further progressed beneath the residential neighborhood than beneath northern commercial Algona, with VC or ethene/ethane being generally predominant beneath the neighborhood. This is a function of further distance along the flow path from the Boeing facility, the presence of the neighborhood at the western fringe of the plume, and organic carbon naturally occurring in the aquifer beneath the neighborhood.
- Non-toxic ethene/ethane is predominant at all but two of the sampled water table wells which represent the zone of greatest potential exposure to neighborhood residents. Ethene/ethane predominance also occurs at shallow, intermediate, and deep zone wells.

This assessment indicates that the study area is an appropriate location for an enhanced natural attenuation pilot test. An enhanced natural attenuation pilot test will begin in 2015 as described in the pilot test work plan (Landau Associates 2015).

Based on work completed to date, MNA is expected to be a primary component of the remedy for the groundwater plumes. It is anticipated that additional natural attenuation assessment may be completed in other areas of the groundwater plumes to support MNA evaluation in the feasibility study.

6.0 USE OF THIS REPORT

This work plan has been prepared for the exclusive use of The Boeing Company for specific application to the Auburn Fabrication Division facility remedial investigation. No other party is entitled to rely on the information, conclusions, and recommendations included in this document without the express written consent of Landau Associates. Further, the reuse of information, conclusions, and recommendations provided herein for extensions of the project of for any other project, without review and authorization by Landau Associates, shall be at the user's sole risk. Landau Associates warrants that within the limitations of the scope, schedule, and budget, our services have been provided in a manner consistent with that level of care and skill ordinarily exercised by members of the profession currently practicing in the same locality under similar conditions at this project. We make no other warranty, either express or implied.

This document has been prepared under the supervision and direction of the following key staff.

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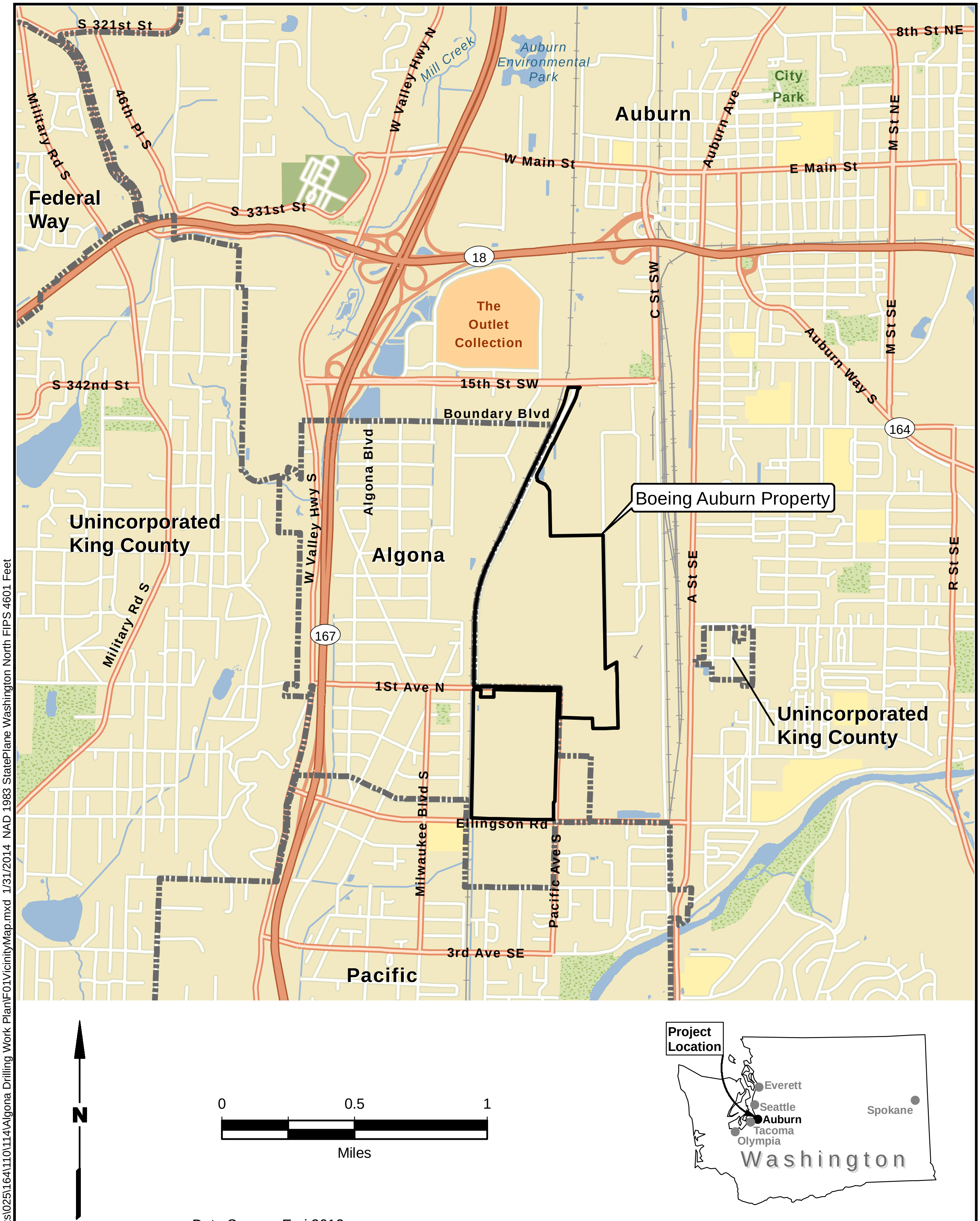

Data Source: Esri 2012

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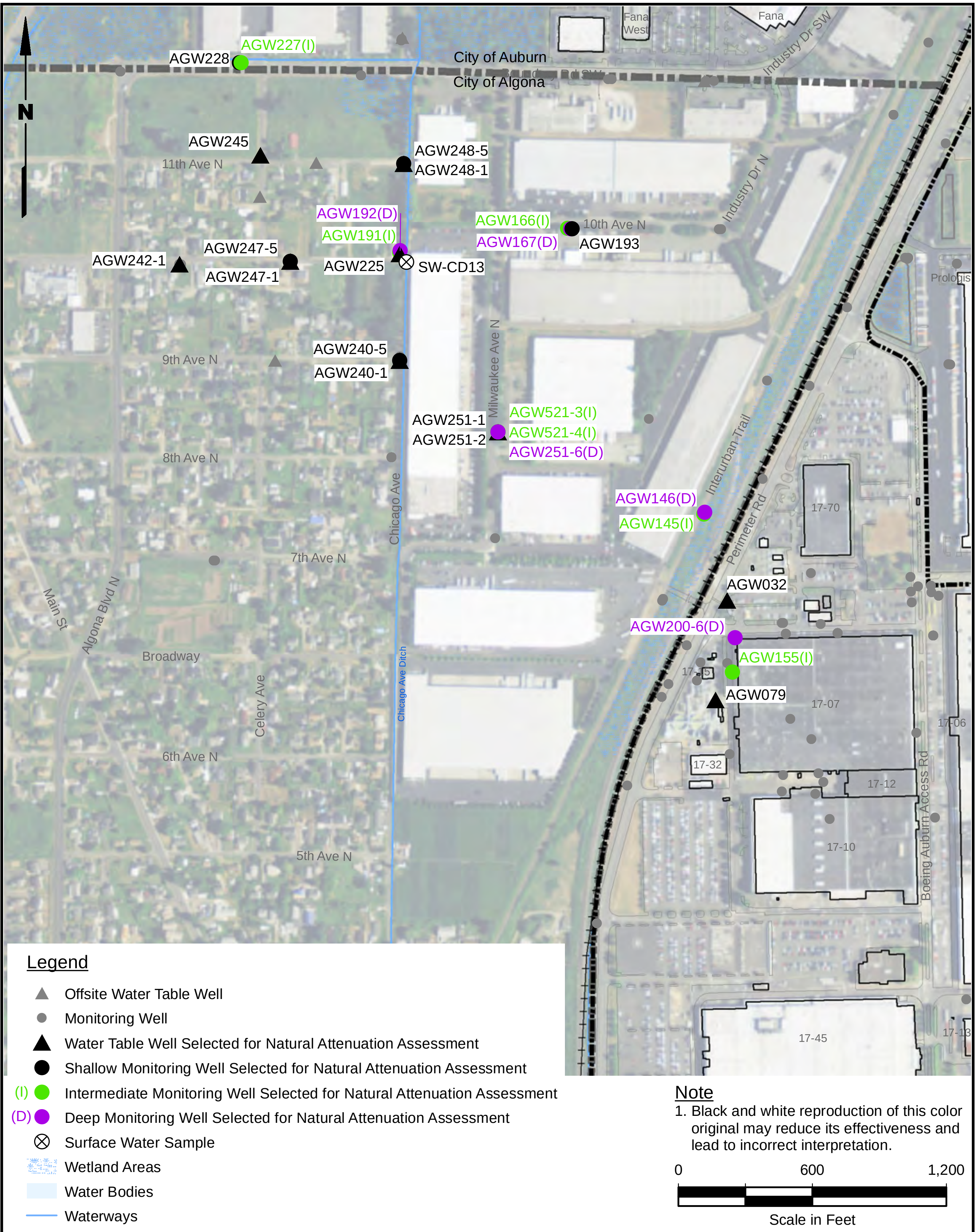
Landau Associates

Boeing Auburn Auburn, Washington	**Vicinity Map**	Figure 1



Note
1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

Base map source: Geometrix 2003; Aerial Photo Source: ESRI World Imagery; Parcel Data Source: King County GIS 2012

G:\Projects\025\164\110\110\Molar Most RecentNoBoreholes\8x11\F02SelectedWellsNAA.mxd 7/28/2015 NAD 1983 StatePlane Washington North FIPS 4601 Feet

Landau Associates

Boeing Auburn
Auburn, Washington

Selected Wells for Natural Attenuation Assessment

Figure
2

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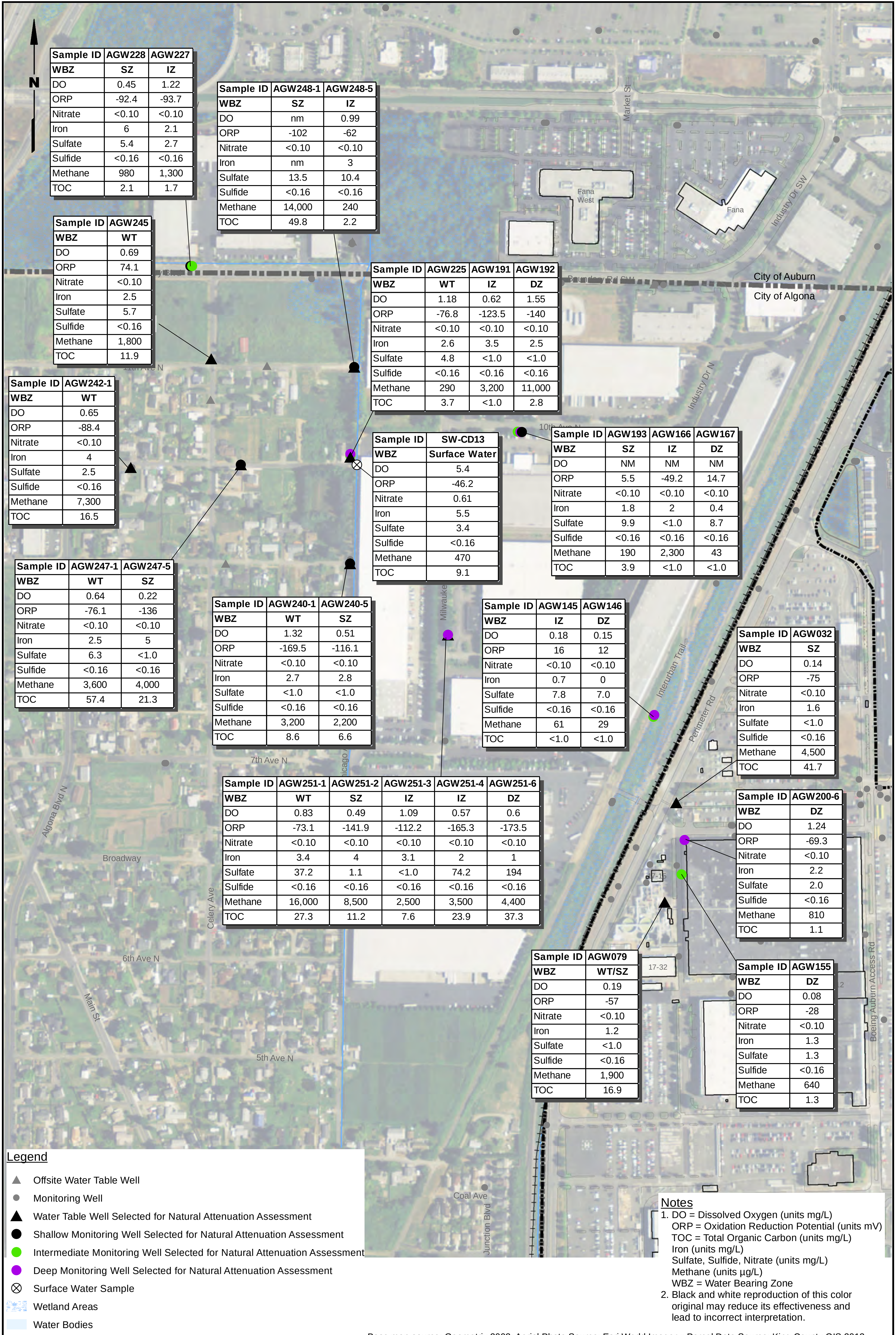

Sample ID	AGW228	AGW227
WBZ	SZ	IZ
DO	0.45	1.22
ORP	-92.4	-93.7
Nitrate	<0.10	<0.10
Iron	6	2.1
Sulfate	5.4	2.7
Sulfide	<0.16	<0.16
Methane	980	1,300
TOC	2.1	1.7

Sample ID	AGW248-1	AGW248-5
WBZ	SZ	IZ
DO	nm	0.99
ORP	-102	-62
Nitrate	<0.10	<0.10
Iron	nm	3
Sulfate	13.5	10.4
Sulfide	<0.16	<0.16
Methane	14,000	240
TOC	49.8	2.2

Sample ID	AGW245
WBZ	WT
DO	0.69
ORP	74.1
Nitrate	<0.10
Iron	2.5
Sulfate	5.7
Sulfide	<0.16
Methane	1,800
TOC	11.9

Sample ID	AGW225	AGW191	AGW192
WBZ	WT	IZ	DZ
DO	1.18	0.62	1.55
ORP	-76.8	-123.5	-140
Nitrate	<0.10	<0.10	<0.10
Iron	2.6	3.5	2.5
Sulfate	4.8	<1.0	<1.0
Sulfide	<0.16	<0.16	<0.16
Methane	290	3,200	11,000
TOC	3.7	<1.0	2.8

Sample ID	AGW242-1
WBZ	WT
DO	0.65
ORP	-88.4
Nitrate	<0.10
Iron	4
Sulfate	2.5
Sulfide	<0.16
Methane	7,300
TOC	16.5

Sample ID	SW-CD13
WBZ	Surface Water
DO	5.4
ORP	-46.2
Nitrate	0.61
Iron	5.5
Sulfate	3.4
Sulfide	<0.16
Methane	470
TOC	9.1

Sample ID	AGW193	AGW166	AGW167
WBZ	SZ	IZ	DZ
DO	NM	NM	NM
ORP	5.5	-49.2	14.7
Nitrate	<0.10	<0.10	<0.10
Iron	1.8	2	0.4
Sulfate	9.9	<1.0	8.7
Sulfide	<0.16	<0.16	<0.16
Methane	190	2,300	43
TOC	3.9	<1.0	<1.0

Sample ID	AGW247-1	AGW247-5
WBZ	WT	SZ
DO	0.64	0.22
ORP	-76.1	-136
Nitrate	<0.10	<0.10
Iron	2.5	5
Sulfate	6.3	<1.0
Sulfide	<0.16	<0.16
Methane	3,600	4,000
TOC	57.4	21.3

Sample ID	AGW240-1	AGW240-5
WBZ	WT	SZ
DO	1.32	0.51
ORP	-169.5	-116.1
Nitrate	<0.10	<0.10
Iron	2.7	2.8
Sulfate	<1.0	<1.0
Sulfide	<0.16	<0.16
Methane	3,200	2,200
TOC	8.6	6.6

Sample ID	AGW145	AGW146
WBZ	IZ	DZ
DO	0.18	0.15
ORP	16	12
Nitrate	<0.10	<0.10
Iron	0.7	0
Sulfate	7.8	7.0
Sulfide	<0.16	<0.16
Methane	61	29
TOC	<1.0	<1.0

Sample ID	AGW032
WBZ	SZ
DO	0.14
ORP	-75
Nitrate	<0.10
Iron	1.6
Sulfate	<1.0
Sulfide	<0.16
Methane	4,500
TOC	41.7

Sample ID	AGW251-1	AGW251-2	AGW251-3	AGW251-4	AGW251-6
WBZ	WT	SZ	IZ	IZ	DZ
DO	0.83	0.49	1.09	0.57	0.6
ORP	-73.1	-141.9	-112.2	-165.3	-173.5
Nitrate	<0.10	<0.10	<0.10	<0.10	<0.10
Iron	3.4	4	3.1	2	1
Sulfate	37.2	1.1	<1.0	74.2	194
Sulfide	<0.16	<0.16	<0.16	<0.16	<0.16
Methane	16,000	8,500	2,500	3,500	4,400
TOC	27.3	11.2	7.6	23.9	37.3

Sample ID	AGW200-6
WBZ	DZ
DO	1.24
ORP	-69.3
Nitrate	<0.10
Iron	2.2
Sulfate	2.0
Sulfide	<0.16
Methane	810
TOC	1.1

Sample ID	AGW079
WBZ	WT/SZ
DO	0.19
ORP	-57
Nitrate	<0.10
Iron	1.2
Sulfate	<1.0
Sulfide	<0.16
Methane	1,900
TOC	16.9

Sample ID	AGW155
WBZ	DZ
DO	0.08
ORP	-28
Nitrate	<0.10
Iron	1.3
Sulfate	1.3
Sulfide	<0.16
Methane	640
TOC	1.3

Legend

- ▲ Offsite Water Table Well
- ● Monitoring Well
- ▲ Water Table Well Selected for Natural Attenuation Assessment
- ● Shallow Monitoring Well Selected for Natural Attenuation Assessment
- ● Intermediate Monitoring Well Selected for Natural Attenuation Assessment
- ● Deep Monitoring Well Selected for Natural Attenuation Assessment
- ⊗ Surface Water Sample
- ▨ Wetland Areas
- ▭ Water Bodies
- — Waterways
- ▬ City Limits

Notes

1. DO = Dissolved Oxygen (units mg/L)
   ORP = Oxidation Reduction Potential (units mV)
   TOC = Total Organic Carbon (units mg/L)
   Iron (units mg/L)
   Sulfate, Sulfide, Nitrate (units mg/L)
   Methane (units µg/L)
   WBZ = Water Bearing Zone
2. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

Base map source: Geometrix 2003; Aerial Photo Source: Esri World Imagery; Parcel Data Source: King County GIS 2013

0 400 800
Scale in Feet

LANDAU ASSOCIATES

Boeing Auburn
Auburn, Washington

Aquifer Redox Concentration Data

Figure
3

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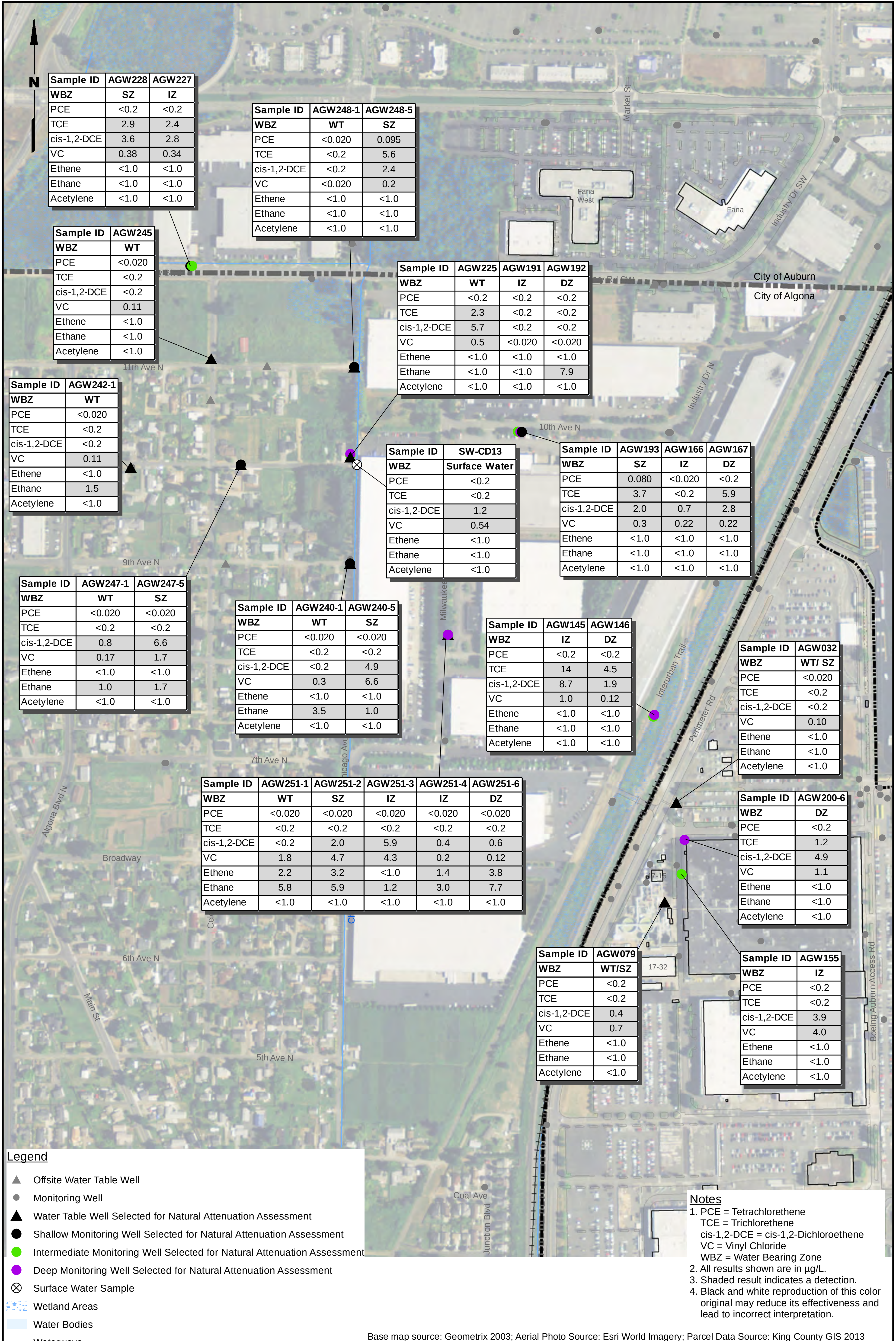


Sample ID	AGW228	AGW227
WBZ	SZ	IZ
PCE	<0.2	<0.2
TCE	2.9	2.4
cis-1,2-DCE	3.6	2.8
VC	0.38	0.34
Ethene	<1.0	<1.0
Ethane	<1.0	<1.0
Acetylene	<1.0	<1.0

Sample ID	AGW248-1	AGW248-5
WBZ	WT	SZ
PCE	<0.020	0.095
TCE	<0.2	5.6
cis-1,2-DCE	<0.2	2.4
VC	<0.020	0.2
Ethene	<1.0	<1.0
Ethane	<1.0	<1.0
Acetylene	<1.0	<1.0

Sample ID	AGW245
WBZ	WT
PCE	<0.020
TCE	<0.2
cis-1,2-DCE	<0.2
VC	0.11
Ethene	<1.0
Ethane	<1.0
Acetylene	<1.0

Sample ID	AGW225	AGW191	AGW192
WBZ	WT	IZ	DZ
PCE	<0.2	<0.2	<0.2
TCE	2.3	<0.2	<0.2
cis-1,2-DCE	5.7	<0.2	<0.2
VC	0.5	<0.020	<0.020
Ethene	<1.0	<1.0	<1.0
Ethane	<1.0	<1.0	7.9
Acetylene	<1.0	<1.0	<1.0

Sample ID	AGW242-1
WBZ	WT
PCE	<0.020
TCE	<0.2
cis-1,2-DCE	<0.2
VC	0.11
Ethene	<1.0
Ethane	1.5
Acetylene	<1.0

Sample ID	SW-CD13
WBZ	Surface Water
PCE	<0.2
TCE	<0.2
cis-1,2-DCE	1.2
VC	0.54
Ethene	<1.0
Ethane	<1.0
Acetylene	<1.0

Sample ID	AGW193	AGW166	AGW167
WBZ	SZ	IZ	DZ
PCE	0.080	<0.020	<0.2
TCE	3.7	<0.2	5.9
cis-1,2-DCE	2.0	0.7	2.8
VC	0.3	0.22	0.22
Ethene	<1.0	<1.0	<1.0
Ethane	<1.0	<1.0	<1.0
Acetylene	<1.0	<1.0	<1.0

Sample ID	AGW247-1	AGW247-5
WBZ	WT	SZ
PCE	<0.020	<0.020
TCE	<0.2	<0.2
cis-1,2-DCE	0.8	6.6
VC	0.17	1.7
Ethene	<1.0	<1.0
Ethane	1.0	1.7
Acetylene	<1.0	<1.0

Sample ID	AGW240-1	AGW240-5
WBZ	WT	SZ
PCE	<0.020	<0.020
TCE	<0.2	<0.2
cis-1,2-DCE	<0.2	4.9
VC	0.3	6.6
Ethene	<1.0	<1.0
Ethane	3.5	1.0
Acetylene	<1.0	<1.0

Sample ID	AGW145	AGW146
WBZ	IZ	DZ
PCE	<0.2	<0.2
TCE	14	4.5
cis-1,2-DCE	8.7	1.9
VC	1.0	0.12
Ethene	<1.0	<1.0
Ethane	<1.0	<1.0
Acetylene	<1.0	<1.0

Sample ID	AGW032
WBZ	WT/ SZ
PCE	<0.020
TCE	<0.2
cis-1,2-DCE	<0.2
VC	0.10
Ethene	<1.0
Ethane	<1.0
Acetylene	<1.0

Sample ID	AGW251-1	AGW251-2	AGW251-3	AGW251-4	AGW251-6
WBZ	WT	SZ	IZ	IZ	DZ
PCE	<0.020	<0.020	<0.020	<0.020	<0.020
TCE	<0.2	<0.2	<0.2	<0.2	<0.2
cis-1,2-DCE	<0.2	2.0	5.9	0.4	0.6
VC	1.8	4.7	4.3	0.2	0.12
Ethene	2.2	3.2	<1.0	1.4	3.8
Ethane	5.8	5.9	1.2	3.0	7.7
Acetylene	<1.0	<1.0	<1.0	<1.0	<1.0

Sample ID	AGW200-6
WBZ	DZ
PCE	<0.2
TCE	1.2
cis-1,2-DCE	4.9
VC	1.1
Ethene	<1.0
Ethane	<1.0
Acetylene	<1.0

Sample ID	AGW079
WBZ	WT/SZ
PCE	<0.2
TCE	<0.2
cis-1,2-DCE	0.4
VC	0.7
Ethene	<1.0
Ethane	<1.0
Acetylene	<1.0

Sample ID	AGW155
WBZ	IZ
PCE	<0.2
TCE	<0.2
cis-1,2-DCE	3.9
VC	4.0
Ethene	<1.0
Ethane	<1.0
Acetylene	<1.0

Legend

- ▲ Offsite Water Table Well
- ● Monitoring Well
- ▲ Water Table Well Selected for Natural Attenuation Assessment
- ● Shallow Monitoring Well Selected for Natural Attenuation Assessment
- ● Intermediate Monitoring Well Selected for Natural Attenuation Assessment
- ● Deep Monitoring Well Selected for Natural Attenuation Assessment
- ⊗ Surface Water Sample
- ▨ Wetland Areas
- ▭ Water Bodies
- — Waterways
- ▬ City Limits

Notes
1. PCE = Tetrachlorethene
   TCE = Trichlorethene
   cis-1,2-DCE = cis-1,2-Dichloroethene
   VC = Vinyl Chloride
   WBZ = Water Bearing Zone
2. All results shown are in µg/L.
3. Shaded result indicates a detection.
4. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

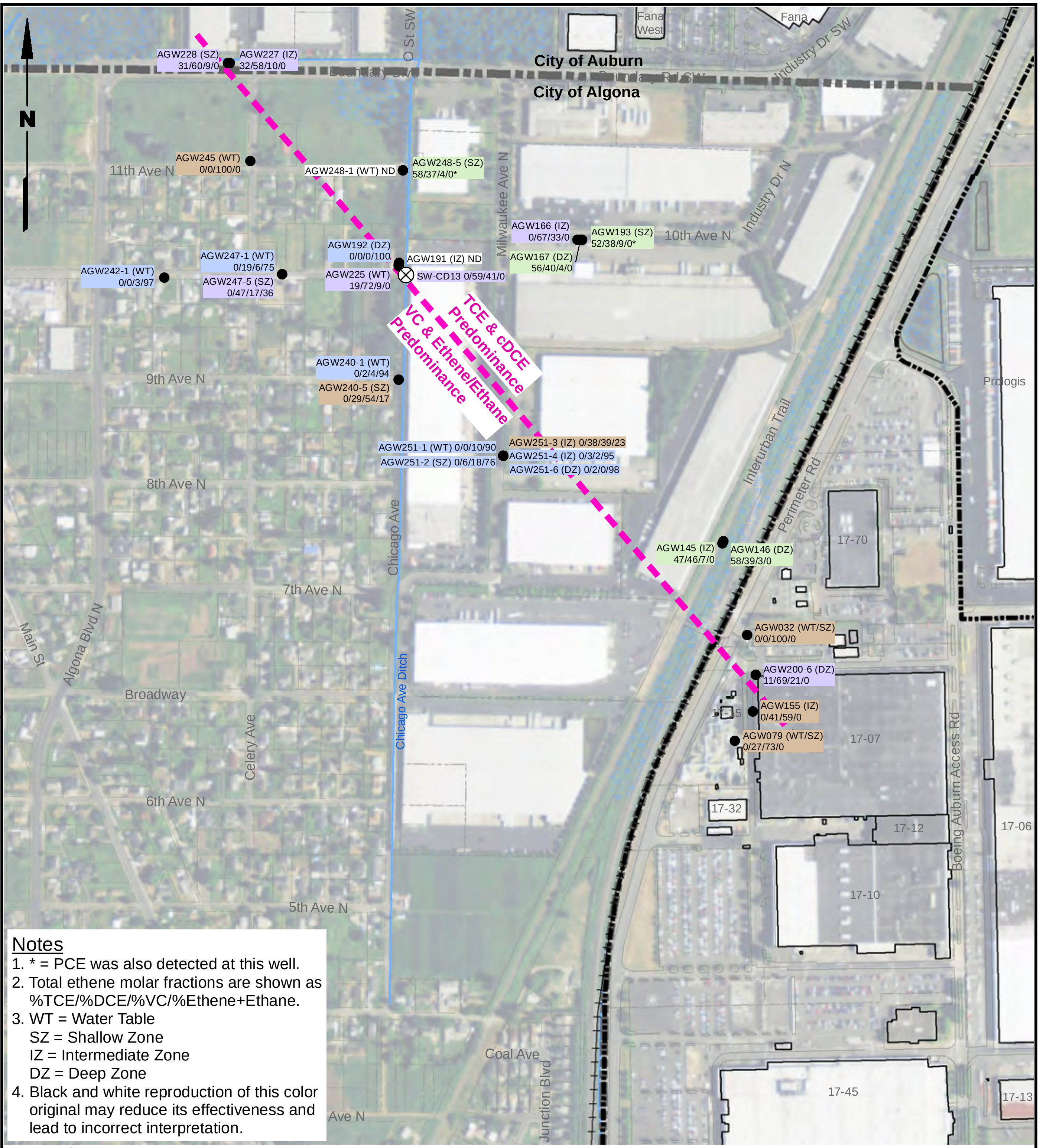
Base map source: Geometrix 2003; Aerial Photo Source: Esri World Imagery; Parcel Data Source: King County GIS 2013

LANDAU ASSOCIATES

Boeing Auburn
Auburn, Washington

VOC Concentration Data

Figure
4



Notes

1. * = PCE was also detected at this well.
2. Total ethene molar fractions are shown as %TCE/%DCE/%VC/%Ethene+Ethane.
3. WT = Water Table
   SZ = Shallow Zone
   IZ = Intermediate Zone
   DZ = Deep Zone
4. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

Legend

● Monitoring Well Location

⊗ Surface Water Sample Location

- - Approximate Delineation Between TCE & cDCE Predominance and VC & Ethene/Ethane Predominance

Wetland Areas

Waterways

Boeing Property

City Limits

Predominance

TCE Predominant

cis-1,2-DCE Predominant

VC Predominant

Ethene/Ethane Predominant

0 600 1,200

Scale in Feet

Data Source: Esri World Imagery, King County GIS

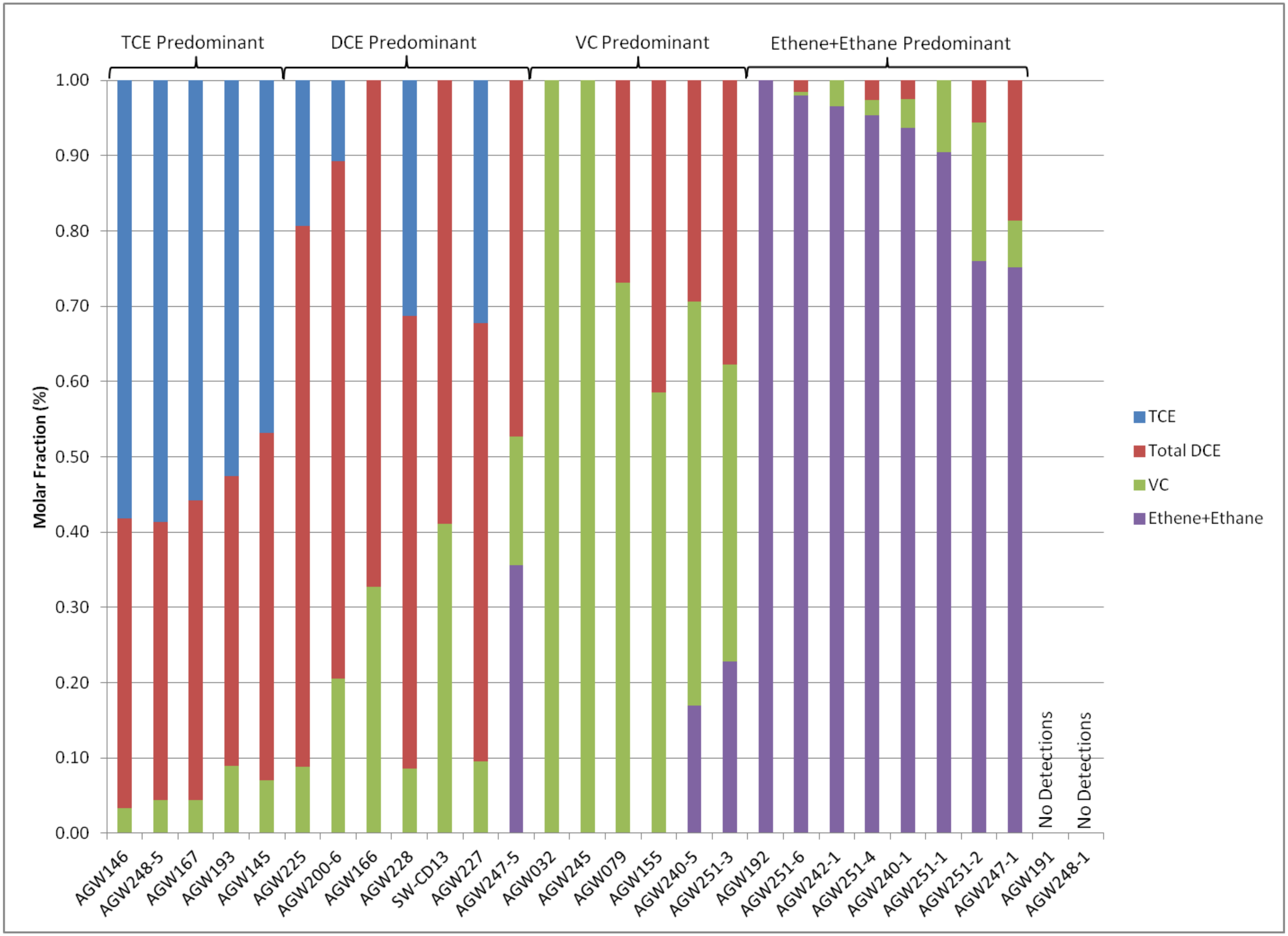
G:\Projects\025\164\120\102\Algona MNA Report\F05MolarFractions.mxd 7/23/2015 NAD 1983 StatePlane Washington North FIPS 4601 Feet

Landau Associates

Boeing Auburn
Auburn, Washington

Molar Fractions and Predominance Distribution

Figure
5



LANDAU ASSOCIATES

Boeing Auburn
Auburn, Washington

Molar Fractions

Figure
6

TABLE 1
NATURAL ATTENUATION MONITORING PARAMETERS
BOEING AUBURN
AUBURN, WASHINGTON

Field Parameters	Data Collection Method	Units	Information Provided
DO	Field Meter (a)	mg/L	Aquifer is considered anaerobic at DO concentrations less than 1.0 mg/L.
ORP	Field Meter (a)	mV	Negative values indicate reducing conditions.
pH	Field Meter (a)	unitless	Optimal for biodegradation in the 6-8 range
Ferrous Iron	Hach® Kit	mg/L	Detected concentrations indicate iron reducing conditions.

Laboratory Analyses	Analytical Method	Bottles	Allowable Holding Time	Information Provided
VOCs (b) (c)	EPA Method 8260C; EPA Method 8260C SIM for VC, PCE	5 40-mL VOA preserved with HCl	14 days	Concentrations of TCE breakdown products are indicative of reductive dechlorination.
TOC	SM 5310 C-2000	2 40-mL VOA preserved with H3PO4	28 days	Indicative of electron donor available to maintain reduced aquifer redox conditions and for reductive dechlorination.
Nitrate/Sulfate	EPA Method 300.0	2 40-mL VOA unpreserved	Nitrate: 48 hours Sulfate: 28 days	Low to non-detect nitrate concentrations indicate nitrate reducing conditions. Low to non-detect sulfate concentrations indicate sulfate-reducing conditions.
Sulfide	SM 4500-S2 D-2000	1 250-mL glass bottle preserved with ZnAc and NaOH	7 days	Detectable sulfide concentrations indicate sulfate-reducing conditions.
AMEE (b)	RSKSOP-175 Modified	2 40-mL VOA preserved with HCl	14 days	Concentrations of ethene and ethane are indicative of complete reductive dechlorination to non-toxic end products. Increasing methane concentrations indicate methanogenic aquifer redox conditions. Acetylene indicates the occurrence of abiotic reductive elimination.

AMEE = Acetylene, Methane, Ethene, Ethane
DO = Dissolved Oxygen
EPA = U.S. Environmental Protection Agency
H3PO4 = Phosphoric acid
HCl = Hydrochloric acid
mg/L = milligrams per liter
mL = milliliter
mV = millivolts
NaOH = Sodium hydroxide
ORP = Oxidation Reduction Potential
PCE = Tetrachloroethene
RSKSOP = EPA Method
SIM = Selected Ion Monitoring
SM = Standard Method
TCE = Trichloroethene
TOC = Total Organic Carbon
VC = Vinyl Chloride
VOA = Volatile Organic Analyte
VOCs = Volatile Organic Compounds
ZnAc = Zinc acetate

(a) Measured using a flow-through cell.

(b) Care to be taken during sample collection to minimize aeration and volatilization. Sample collected with no headspace.

(c) Standard Boeing 38 list of VOCs.

TABLE 2
NATURAL ATTENUATION ASSESSMENT RESULTS
BOEING AUBURN

			Volatile Organic Compounds (all units in micrograms per liter)									Aquifer Redox Conditions								Donor Indicators		VOCs (all units in micromoles per liter)						Molar Fraction				
Well	Aquifer Zone	Date	PCE (µg/L)	TCE (µg/L)	CIS (µg/L)	TRANS (µg/L)	11DCE (µg/L)	VC (µg/L)	Ethene (µg/L)	Ethane (µg/L)	Acetylene (µg/L)	DO (mg/L)	ORP (mV)	Nitrate (mg/L)	Iron II (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (µg/L)	Aquifer Redox State	TOC (mg/L)	pH	PCE µmol/L	TCE µmol/L	Total DCE µmol/L	VC µmol/L	Ethene µmol/L	Ethane µmol/L	PCE	TCE	Sum of cis, trans, 11DCE	VC	Ethene+ Ethane
SW-CD13		12/2/2014	<0.2	<0.2	1.2	<0.2	<0.2	0.54	<1.0	<1.0	<1.0	5.4	-46.2	0.61	5.5	3.4	<0.16	470	Fe/S	9.1	6.62	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.59	0.41	0.00
AGW032	WT/S	12/10/2014	<0.020	<0.2	<0.2	<0.2	<0.2	0.10	<1.0	<1.0	<1.0	0.14	-75	<0.10	1.6	<1.0	<0.16	4500	M	41.7	6.28	0.00	0.00	0.00	0.002	0.00	0.00	0.00	0.00	0.00	1.00	0.00
AGW079	WT/S	12/10/2014	<0.2	<0.2	0.4	<0.2	<0.2	0.7	<1.0	<1.0	<1.0	0.19	-57	<0.10	1.2	<1.0	<0.16	1900	M	16.9	6.04	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.27	0.73	0.00
AGW145	I	12/10/2014	<0.2	14	8.7	1.3	0.2	1.0	<1.0	<1.0	<1.0	0.18	16	<0.10	0.7	7.8	<0.16	61	Fe/S	<1.0	6.32	0.00	0.11	0.11	0.02	0.00	0.00	0.00	0.47	0.46	0.07	0.00
AGW146	D	12/10/2014	<0.2	4.5	1.9	0.3	<0.2	0.12	<1.0	<1.0	<1.0	0.15	12	<0.10	0.0	7.0	<0.16	29	N	<1.0	6.39	0.00	0.03	0.02	0.00	0.00	0.00	0.00	0.58	0.39	0.03	0.00
AGW155	I	12/10/2014	<0.2	<0.2	3.9	0.5	<0.2	4.0	<1.0	<1.0	<1.0	0.08	-28	<0.10	1.3	1.3	<0.16	640	S/M	1.3	6.41	0.00	0.00	0.05	0.06	0.00	0.00	0.00	0.00	0.41	0.59	0.00
AGW166	I	12/1/2014	<0.020	<0.2	0.7	<0.2	<0.2	0.22	<1.0	<1.0	<1.0		-49.2	<0.10	2.0	<1.0	<0.16	2300	M	<1.0	7.04	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.67	0.33	0.00
AGW167	D	12/1/2014	<0.2	5.9	2.8	0.3	<0.2	0.22	<1.0	<1.0	<1.0		14.7	<0.10	0.4	8.7	<0.16	43	Fe/S	<1.0	6.95	0.00	0.04	0.03	0.00	0.00	0.00	0.00	0.56	0.40	0.04	0.00
AGW191	I	12/1/2014	<0.2	<0.2	<0.2	<0.2	<0.2	<0.020	<1.0	<1.0	<1.0	0.62	-123.5	<0.10	3.5	<1.0	<0.16	3200	M	<1.0	7.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AGW192	D	12/1/2014	<0.2	<0.2	<0.2	<0.2	<0.2	<0.020	<1.0	7.9	<1.0	1.55	-140	<0.10	2.5	<1.0	<0.16	11000	M	2.8	7.09	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	1.00
AGW193	S	12/1/2014	0.080	3.7	2.0	<0.2	<0.2	0.3	<1.0	<1.0	<1.0		5.5	<0.10	1.8	9.9	<0.16	190	Fe/S	3.9	6.74	0.00	0.03	0.02	0.00	0.00	0.00	0.01	0.52	0.38	0.09	0.00
AGW200-6	D	12/2/2014	<0.2	1.2	4.9	0.8	<0.2	1.1	<1.0	<1.0	<1.0	1.24	-69	<0.10	2.2	2.0	<0.16	810	S/M	1.1	6.77	0.00	0.01	0.06	0.02	0.00	0.00	0.00	0.11	0.69	0.21	0.00
AGW225	WT	12/1/2014	<0.2	2.3	5.7	0.6	<0.2	0.5	<1.0	<1.0	<1.0	1.2	-76.8	<0.10	2.6	4.8	<0.16	290	Fe/S	3.7	6.55	0.00	0.02	0.06	0.01	0.00	0.00	0.00	0.19	0.72	0.09	0.00
AGW227	I	12/2/2014	<0.2	2.4	2.8	0.4	<0.2	0.34	<1.0	<1.0	<1.0	1.22	-93.7	<0.10	2.1	2.7	<0.16	1300	S/M	1.7	6.70	0.00	0.02	0.03	0.01	0.00	0.00	0.00	0.32	0.58	0.10	0.00
AGW228	S	12/2/2014	<0.2	2.9	3.6	0.5	<0.2	0.38	<1.0	<1.0	<1.0	0.45	-92.4	<0.10	6.0	5.4	<0.16	980	S/M	2.1	6.50	0.00	0.02	0.04	0.01	0.00	0.00	0.00	0.31	0.60	0.09	0.00
AGW240-1	WT	12/1/2014	<0.020	<0.2	<0.2	0.3	<0.2	0.3	<1.0	3.5	<1.0	1.32	-169.5	<0.10	2.7	<1.0	<0.16	3200	M	8.6	6.62	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.02	0.04	0.94
AGW240-5	S	12/1/2014	<0.020	<0.2	4.9	0.7	<0.2	6.6	<1.0	1.0	<1.0	0.51	-116.1	<0.10	2.8	<1.0	<0.16	2200	M	6.6	6.67	0.00	0.00	0.06	0.11	0.00	0.03	0.00	0.00	0.29	0.54	0.17
AGW242-1	S	12/2/2014	<0.020	<0.2	<0.2	<0.2	<0.2	0.11	<1.0	1.5	<1.0	0.65	-88.4	<0.10	4.0	2.5	<0.16	7300	S/M	16.5	6.51	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.03	0.97
AGW245	WT	12/2/2014	<0.020	<0.2	<0.2	<0.2	<0.2	0.11	<1.0	<1.0	<1.0	0.69	74.1	<0.10	2.5	5.7	<1.6	1800	S/M	11.9	5.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
AGW247-1	WT	12/2/2014	<0.020	<0.2	0.8	<0.2	<0.2	0.17	<1.0	1.0	<1.0	0.64	-76.1	<0.10	2.5	6.3	<0.16	3600	S/M	57.4	6.19	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.19	0.06	0.75
AGW247-5	S	12/2/2014	<0.020	<0.2	6.6	0.7	<0.2	1.7	<1.0	1.7	<1.0	0.22	-136	<0.10	5.0	<1.0	<0.16	4000	M	21.3	6.89	0.00	0.00	0.08	0.03	0.00	0.06	0.00	0.00	0.47	0.17	0.36
AGW248-1	WT	12/1/2014	<0.020	<0.2	<0.2	<0.2	<0.2	<0.020	<1.0	<1.0	<1.0		-102	<0.10		13.5	<0.16	14000	S/M	49.8	6.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 2
NATURAL ATTENUATION ASSESSMENT RESULTS
BOEING AUBURN

			Volatile Organic Compounds (all units in micrograms per liter)									Aquifer Redox Conditions								Donor Indicators		VOCs (all units in micromoles per liter)						Molar Fraction				
Well	Aquifer Zone	Date	PCE (µg/L)	TCE (µg/L)	CIS (µg/L)	TRANS (µg/L)	11DCE (µg/L)	VC (µg/L)	Ethene (µg/L)	Ethane (µg/L)	Acetylene (µg/L)	DO (mg/L)	ORP (mV)	Nitrate (mg/L)	Iron II (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (µg/L)	Aquifer Redox State	TOC (mg/L)	pH	PCE µmol/L	TCE µmol/L	Total DCE µmol/L	VC µmol/L	Ethene µmol/L	Ethane µmol/L	PCE	TCE	Sum of cis, trans, 11DCE	VC	Ethene+ Ethane
AGW248-5	S	12/1/2014	0.095	5.6	2.4	0.2	<0.2	0.20	<1.0	<1.0	<1.0	0.99	-62	<0.10	3.0	10.4	<0.16	240	Fe/S	2.2	6.47	0.00	0.04	0.03	0.00	0.00	0.00	0.01	0.58	0.37	0.04	0.00
AGW251-1	WT	12/2/2014	<0.020	<0.2	<0.2	<0.2	<0.2	1.8	2.2	5.8	<1.0	0.83	-73.1	<0.10	3.4	37.2	<0.16	16000	S/M	27.3	6.65	0.00	0.00	0.00	0.03	0.08	0.19	0.00	0.00	0.00	0.10	0.90
AGW251-2	S	12/2/2014	<0.020	<0.2	2.0	0.2	<0.2	4.7	3.2	5.9	<1.0	0.49	-141.9	<0.10	4.0	1.1	<0.16	8500	S/M	11.2	6.92	0.00	0.00	0.02	0.08	0.11	0.20	0.00	0.00	0.06	0.18	0.76
AGW251-3	I	12/2/2014	<0.020	<0.2	5.9	0.5	<0.2	4.3	<1.0	1.2	<1.0	1.09	-112.2	<0.10	3.1	<1.0	<0.16	2500	M	7.6	6.67	0.00	0.00	0.07	0.07	0.00	0.04	0.00	0.00	0.38	0.39	0.23
AGW251-4	I	12/2/2014	<0.020	<0.2	0.4	<0.2	<0.2	0.2	1.4	3.0	<1.0	0.57	-165.3	<0.10	2.0	74.2	<0.16	3500	S/M	23.9	7.06	0.00	0.00	0.00	0.00	0.05	0.10	0.00	0.00	0.03	0.02	0.95
AGW251-6	D	12/2/2014	<0.020	<0.2	0.6	<0.2	<0.2	0.12	3.8	7.7	<1.0	0.6	-173.5	<0.10	1.0	194	<0.16	4400	S/M	37.3	7.08	0.00	0.00	0.01	0.00	0.14	0.26	0.00	0.00	0.02	0.00	0.98

Notes:
Green shading indicates parameter was not analyzed or not measured.
Blue shading indicates the compound with highest molar fraction per event
WT = Water Table Zone
S = Shallow Zone
I = Intermediate Zone
D= Deep Zone

APPENDIX A

Laboratory Analytical Results

TABLE A-1
GROUNDWATER MONITORING RESULTS, SEPTEMBER AND DECEMBER 2014
CITY OF ALGONA WELLS
BOEING AUBURN

Sample ID:	SW-CD13	AGW032	AGW079	AGW145	AGW146	AGW155	AGW166	AGW167	AGW191	AGW192	AGW193	AGW200-6	AGW225	AGW227	AGW228	AGW240-1
Zone:	Surface Water	Shallow	Shallow	Int.	Deep	Int.	Int.	Deep	Int.	Deep	Shallow	Deep	Water Table	Int.	Shallow	Water Table
SDG:	1522529	1524754	1524754	1524754	1524754	1524754	1522243	1522243	1522245	1522245	1522243	1522567	1522244	1522567	1522529	1522244
Lab ID:	7695162	7707124	7707122	7707132	7707130	7707128	7693970	7693974	7693990	7693992	7693972	7695371	7693977	7695362	7695164	7693979
Sample Date:	12/2/2014	12/10/2014	12/10/2014	12/10/2014	12/10/2014	12/10/2014	12/1/2014	12/1/2014	12/1/2014	12/1/2014	12/1/2014	12/2/2014	12/1/2014	12/2/2014	12/2/2014	12/1/2014
VOLATILES (µg/L)																
Method SW8260C																
Acetone	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U
Benzene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Bromodichloromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Bromoform	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Bromomethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
2-Butanone	5.0 U	**14**	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U
Carbon Disulfide	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Carbon Tetrachloride	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Chlorobenzene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Chloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Chloroform	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Chloromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Dibromochloromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1-Dichloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,2-Dichloroethane	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
1,1-Dichloroethene	0.2 U	0.2 U	0.2 U	**0.2**	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
cis-1,2-Dichloroethene	**1.2**	0.2 U	**0.4**	**8.7**	**1.9**	**3.9**	**0.7**	**2.8**	0.2 U	0.2 U	**2.0**	**4.9**	**5.7**	**2.8**	**3.6**	0.2 U
trans-1,2-Dichloroethene	0.2 U	0.2 U	0.2 U	**1.3**	**0.3**	**0.5**	0.2 U	**0.3**	0.2 U	0.2 U	0.2 U	**0.8**	**0.6**	**0.4**	**0.5**	**0.3**
1,2-Dichloropropane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
cis-1,3-Dichloropropene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
trans-1,3-Dichloropropene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Ethylbenzene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
2-Hexanone	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U
4-Methyl-2-Pentanone (MIBK)	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U
Methylene Chloride	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Styrene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1,2,2-Tetrachloroethane	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Tetrachloroethene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Toluene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
1,1,2-Trichloro-1,2,2-trifluoroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1,1-Trichloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1,2-Trichloroethane	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Trichloroethene	0.2 U	0.2 U	0.2 U	**14**	**4.5**	0.2 U	0.2 U	**5.9**	0.2 U	0.2 U	**3.7**	**1.2**	**2.3**	**2.4**	**2.9**	0.2 U
Trichlorofluoromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Vinyl Acetate	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Vinyl Chloride	**0.5**	0.2 U	**0.7**	**1.0**	0.2 U	**4.0**	**0.2**	**0.2**	0.2 U	0.2 U	**0.3**	**1.1**	**0.5**	**0.3**	**0.3**	**0.3**
m,p-Xylene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
o-Xylene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
VOLATILES (µg/L)																
Method 8260C SIM																
Tetrachloroethene		0.020 U					0.020 U				**0.080**	0.020 U				0.020 U
Vinyl Chloride	**0.54**	**0.10**			**0.12**		**0.22**	**0.22**	0.020 U	0.020 U	**0.27**		**0.49**	**0.34**	**0.38**	**0.28**
CONVENTIONALS (mg/L)																
Sulfate (EPA300.0)	**3.4**	1.0 U	1.0 U	**7.8**	**7.0**	**1.3**	1.0 U	**8.7**	1.0 U	1.0 U	**9.9**	**2.0**	**4.8**	**2.7**	**5.4**	1.0 U
Total Organic Carbon (SM5310C)	**9.1**	**41.7**	**16.9**	1.0 U	1.0 U	**1.3**	1.0 U	1.0 U	1.0 U	**2.8**	**3.9**	**1.1**	**3.7**	**1.7**	**2.1**	**8.6**
Nitrate (as N) (EPA300.0)	**0.61**	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U
Sulfide (SM4500-S2D)	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U
NATURAL ATTENUATION PARAMETERS (µg/L)																
Method RSK-175																
Methane	**470**	**4500**	**1900**	**61**	**29**	**640**	**2300**	**43**	**3200**	**11000**	**190**	**810**	**290**	**1300**	**980**	**3200**
Ethane	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	**7.9**	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	**3.5** J
Ethene	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U
Acetylene	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U

TABLE A-1
GROUNDWATER MONITORING RESULTS, SEPTEMBER AND DECEMBER 2014
CITY OF ALGONA WELLS
BOEING AUBURN

Sample ID:	AGW240-5	AGW242-1	AGW245	AGW247-1	AGW247-5	AGW248-1	AGW248-5	AGW251-1	AGW251-2	Dup of AGW251-2 AGW901	AGW251-3	AGW251-4	AGW251-6
Zone:	Shallow	Water Table	Water Table	Water Table	Shallow	Water Table	Shallow	Water Table	Shallow	Shallow	Int.	Int.	Deep
SDG:	1522244	1522529	1522529	1522529	1522529	1522245	1522245	1522567	1522565	1522565	1522567	1522565	1522565
Lab ID:	7693986	7695167	7695169	7695155	7695158	7693994	7693998	7695369	7695354	7695356	7695367	7695350	7695347
Sample Date:	12/1/2014	12/2/2014	12/2/2014	12/2/2014	12/2/2014	12/1/2014	12/1/2014	12/2/2014	12/2/2014	12/2/2014	12/2/2014	12/2/2014	12/2/2014
VOLATILES (µg/L)													
Method SW8260C													
Acetone	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	**31**	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U
Benzene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	**0.3**	**0.3**	0.2 U	0.2 U	0.2 U
Bromodichloromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Bromoform	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Bromomethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
2-Butanone	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U
Carbon Disulfide	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Carbon Tetrachloride	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Chlorobenzene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Chloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Chloroform	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Chloromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Dibromochloromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1-Dichloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,2-Dichloroethane	0.2 U	0.2 U	0.2 U	0.2 U	**0.3**	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
1,1-Dichloroethene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
cis-1,2-Dichloroethene	**4.9**	0.2 U	0.2 U	**0.8**	**6.6**	0.2 U	**2.4**	0.2 U	**2.0**	**2.1**	**5.9**	**0.4**	**0.6**
trans-1,2-Dichloroethene	**0.7**	0.2 U	0.2 U	0.2 U	**0.7**	0.2 U	**0.2**	0.2 U	**0.2**	**0.2**	**0.5**	0.2 U	0.2 U
1,2-Dichloropropane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
cis-1,3-Dichloropropene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
trans-1,3-Dichloropropene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Ethylbenzene	0.5 U	0.5 U	0.5 U	**0.7**	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
2-Hexanone	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U
4-Methyl-2-Pentanone (MIBK)	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U	5.0 U
Methylene Chloride	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Styrene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1,2,2-Tetrachloroethane	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Tetrachloroethene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Toluene	0.2 U	0.2 U	0.2 U	**0.3**	0.2 U	**0.3**	0.2 U	**1.6**	**0.3**	**0.3**	0.2 U	**0.3**	**0.3**
1,1,2-Trichloro-1,2,2-trifluoroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1,1-Trichloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1,2-Trichloroethane	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Trichloroethene	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	**5.6**	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Trichlorofluoromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Vinyl Acetate	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Vinyl Chloride	**5.8**	0.2 U	0.2 U	0.2 U	**1.6**	0.2 U	**0.2**	**1.6**	**4.4**	**4.4**	**3.9**	0.2 U	0.2 U
m,p-Xylene	0.5 U	0.5 U	0.5 U	**4.7**	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
o-Xylene	0.5 U	0.5 U	0.5 U	**3.0**	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
VOLATILES (µg/L)													
Method 8260C SIM													
Tetrachloroethene	0.020 U	0.020 U	0.020 U	0.020 U	0.020 U	0.020 U	**0.095**	0.020 U	0.020 U	0.020 U	0.020 U	0.020 U	0.020 U
Vinyl Chloride	**6.6**	**0.11**	**0.11**	**0.17**	**1.7**	0.020 U	**0.20**	**1.8**	**4.7**	**4.6**	**4.3**	**0.2**	**0.12**
CONVENTIONALS (mg/L)													
Sulfate (EPA300.0)	1.0 U	**2.5**	**5.7**	**6.3** J	1.0 U	**13.5**	**10.4** J	**37.2**	**1.1**	**1.1** J	1.0 U	**74.2**	**194**
Total Organic Carbon (SM5310C)	**6.6**	**16.5**	**11.9**	**57.4**	**21.3**	**49.8**	**2.2**	**27.3**	**11.2**	**11.2**	**7.6**	**23.9**	**37.3**
Nitrate (as N) (EPA300.0)	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 UJ	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U
Sulfide (SM4500-S2D)	0.16 U	0.16 U	1.6 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U	0.16 U
NATURAL ATTENUATION PARAMETERS (µg/L)													
Method RSK-175													
Methane	**2200**	**7300**	**1800**	**3600**	**4000**	**14000**	**240**	**16000**	**8500**	**9800**	**2500**	**3500**	**4400**
Ethane	**1.0** J	**1.5** J	1.0 U	**1.0** J	**1.7** J	1.0 U	1.0 U	**5.8**	**5.9**	**5.7**	**1.2** J	**3.0** J	**7.7**
Ethene	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	**2.2** J	**3.2** J	**3.1** J	1.0 U	**1.4** J	**3.8** J
Acetylene	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U

U = Indicates the compound was undetected at the reported concentration.
J = Indicates the analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
UJ = The analyte was not detected in the sample; the reported sample reporting limit is an estimate.
Bold = Detected compound.