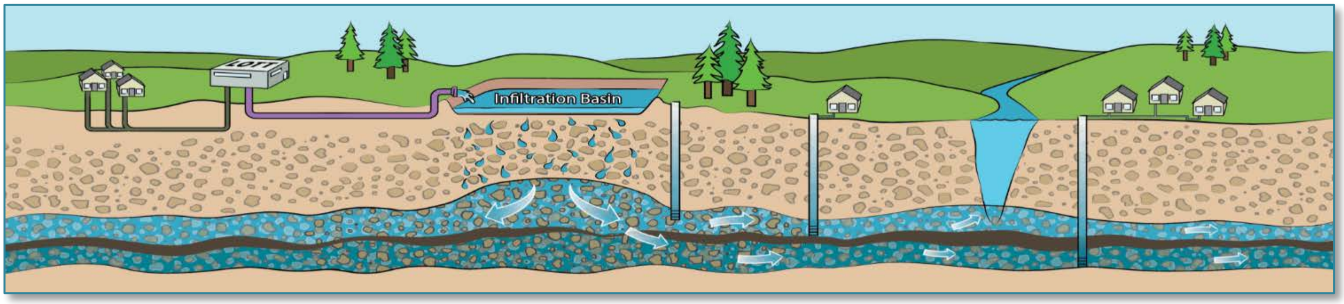
LOTT CLEAN WATER ALLIANCE
RECLAIMED WATER INFILTRATION STUDY

WORK PLAN

TRACER TESTING AND WATER QUALITY MONITORING OF TREATMENT EFFECTIVENESS (TASK 2.1.3)
HAWKS PRAIRIE AREA



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Acronyms and Abbreviations

bgs	Below Ground Surface
btoc	Below Top of Casing
DO	Dissolved Oxygen
EEA	Eurofins Eaton Analytical
EPA	US Environmental Protection Agency
ft	Foot or Feet
gpm	Gallons per Minute
HAA5	Haloacetic Acids
H_2SO_4	Sulfuric Acid
HCl	Hydrochloric Acid
HDR	HDR Engineering, Inc.
IEUA	Inland Empire Utilities Agency
KBr	Potassium Bromide
kg	Kilogram
kg/day	Kilograms per Day
L	Liter
LOTT	LOTT Clean Water Alliance
mgd	Million Gallons per Day
mg/day	Milligrams per Day
mg/L	Milligrams per Liter
mL	Milliliter
mmol/L	Millimole per Liter
MWRWP	Martin Way reclaimed Water Plant
NA	Not Applicable
NaBr	Sodium Bromide
NAVD88	North American Vertical Datum of 1988
NDMA	N-Nitrosodimethylamine
NGVD	National Geodedic Vertical Datum of 1929
ORP	Oxidation-Reduction Potential
PFCs	Perfluorochemicals, Perfluorocarbons, Perfluorinated Compounds
PFOS/PFOA	Perfluorooctanesulfonic Acid/Perfluorooctanoic Acid
Pfu/L	Plaque Forming Units per Liter
ppt	Parts per Trillion
PVC	Polyvinyl Chloride
psi	Pounds per Square Inch
PTFE	Polytetrafluoroethylene (Teflon®)
QA/QC	Quality Assurance/Quality Control
Qc	Pre-Vashon Coarse Deposits
Qf	Kitsap Formation

Acronyms and Abbreviations

Qgof/Qgos	Late Vashon Sediments in Woodland Creek Valley
Qvr/Qgo	Alluvium Vashon Recessional Gravel Outwash
Qvt/Qgt	Vashon Till
Qva/Qga	Vashon Advance Outwash
RWIS	Reclaimed Water Infiltration Study
SF_6	Sulfur Hexafluoride
SOP	Standard Operating Procedure
THMs	Trihalomethanes
TKN	Total Kjeldahl Nitrogen
TQu	Tertiary Unconsolidated and Undifferentiated Sediments
UCSB	University of California, Santa Barbara
µg/L	Micrograms per Liter
VOCs	Volatile Organic Compounds

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1.0 Introduction

1.1 Background

The LOTT Clean Water Alliance (LOTT) provides services to treat and manage wastewater for the urban areas of Lacey, Olympia, and Tumwater in Thurston County, Washington (at the southern end of Puget Sound). Since 2006, LOTT has also produced reclaimed water at the Martin Way Reclaimed Water Plant (MWRWP) that is used for irrigation and other non-drinking purposes. Some of the reclaimed water is used to recharge (replenish) groundwater using infiltration basins at the LOTT Hawks Prairie Ponds and Recharge Basins property (Hawks Prairie property). The long-range plan for meeting future wastewater needs includes expanding reclaimed water production and developing additional groundwater recharge facilities.

LOTT is conducting a Reclaimed Water Infiltration Study (RWIS) to provide local scientific data and community perspectives to help policymakers make informed decisions about future reclaimed water treatment and use. Post-treatment residual chemicals (hereafter referred to as "residual chemicals") remaining in treated wastewater may include household chemicals, pesticides/herbicides, pharmaceuticals, personal care products, cooking products, flame retardants and other chemicals not removed during treatment. LOTT is evaluating which of these residual chemicals exist in the local environment, how infiltrated reclaimed water interacts with soils and local groundwater, and what happens to the residual chemicals over time in the environment. The findings of the study will be used by LOTT and the wider community to make the most appropriate choices for reclaimed water management and protection of public health and the environment.

1.2 Purpose and Scope of Tracer Test and Water Quality Monitoring, Treatment Effectiveness Evaluation

As part of the RWIS project, a tracer testing and water quality monitoring task (Task 2.1.3) is being completed. The purpose of this evaluation is to add to the current understanding of the effectiveness of soil aquifer treatment of reclaimed water, particularly with respect to nutrients and residual chemicals that are infiltrated at the Hawks Prairie property. In 2017, lysimeters and monitoring wells were installed to allow water quality monitoring of the vadose zone and groundwater flow system (HDR 2017a). Part of Task 2.0 includes tracer testing and groundwater quality monitoring, which is scheduled to be conducted from approximately January to December of 2018. The groundwater quality monitoring will be used to assess the biochemical attenuation and degradation as well as the mixing and dilution that occurs over time as reclaimed water travels downgradient from the recharge basins. Tracer testing will be used to identify the downgradient flow path and travel time as reclaimed water is recharged into and travels through the vadose zone and aquifer.

The scope of the 2018 field monitoring involves infiltrating about 0.5 to 1 million gallons per day (mgd) of reclaimed water to recharge the groundwater in two half-acre cells within Basin 4. Reclaimed water will be alternated between the cells to create 7-day wetting and drying cycles. This will create recharge rates similar to the full-build out of 5 to 8 million gallons a day if recharge rates increase in the future. Basin 4 was selected as the recharge test basin because it is the best location to facilitate monitoring of groundwater quality using the existing monitoring well network.

Two tracers (bromide and sulfur hexafluoride) will be introduced for about a one week period and monitoring will be conducted to detect the presence of the tracer at specified time intervals. Recharge flow rates during this period will be approximately 1 mgd. The detection of a tracer at a downgradient monitoring point at a specific time period will be used to measure downgradient travel times. Bromide, a conservative anion tracer (i.e., it travels with the reclaimed water through the vadose zone and the aquifer without being adsorbed or degraded) will be mixed into solution and released with the reclaimed water into the recharge basins and infiltrated into groundwater. Sulfur hexafluoride (a biologically and chemically inert gas that also acts as a conservative tracer) will be bubbled into solution and injected directly into groundwater at monitoring wells MW-1, MW-2, MW-15 and MW-16

Groundwater quality samples will be collected at the lysimeters and groundwater monitoring wells to measure downgradient flow paths, travel time and water quality attenuation. Groundwater quality parameters will include tracers, nutrients, residual chemicals and other organic and inorganic compounds.

1.3 Work Plan Contents

This document is a work plan that describes the approach and methods for water quality monitoring and tracer testing during 2018. Section 2 includes a description of the background physical setting and hydrogeology of the area. Section 3 provides a summary of the proposed recharge flow rates and water level monitoring procedures during the 2018 field monitoring. Section 4 describes the proposed tracer testing procedures. Section 5 details out the water quality monitoring procedures to evaluate attenuation of residual chemicals and nutrients as reclaimed water travels through the subsurface.

2.0 Physical Setting of Hawks Prairie Study Area

This section presents background information on the climate, topography, surface water drainage and hydrogeology of the LOTT Hawks Prairie property and the surrounding area. Figure 2-1 is a site location map showing the regional topography.

2.1 Climate

The area is characterized by mild cool/wet winters and warm/dry summers. HDR (2017a) provides detailed information on precipitation and temperature from nearby climate recording stations.

2.2 Topography and Surface Water Drainage

Figure 2-1 shows the land surface topography and the surface water drainage to the regional creeks, rivers and Puget Sound. The Hawks Prairie Study Area is located on the east side of a broad plateau about 8 miles wide (east to west) formed by deposition of sediments during multiple glaciations.

The Nisqually River and McAllister Creek is located on the east side of the Hawks Prairie Study Area in a valley deeply incised through the glacial deposits. There is a steep east-facing scarp on the western side of the Nisqually River valley. The western edge of the plateau is bound by Puget Sound (Budd Inlet) and the Deschutes River (not shown on Figure 2-1). Woodland Creek flows north through the plateau and drains the west side of the Hawks Prairie Area. Woodland Creek flows from Long Lake to the north into Puget Sound (Henderson Inlet). Large springs (Beatty Springs) are located mid-way in the Woodland Creek drainage. Several tributaries to Woodland Creek (Eagle Creek and Fox Creek) drain the west side of the Hawks Prairie Study Area, the east side is drained by the Nisqually River. Steep scarps and the Puget Sound bound the northern edge of the Hawks Prairie Study Area.

2.3 Description of LOTT Hawks Prairie Recharge Facility

The Hawks Prairie site covers 41 acres and includes five wetland ponds totaling about five acres and eight one-acre groundwater recharge basins totaling eight acres. The facility is shown in Figures 2-2 and 2-3. The wetland ponds are used for aesthetic/recreational purposes. They are between 1 and 6 feet deep and normally contain 10 to 20 million gallons when full. The residence time of the wetland ponds is about 10 to 20 days, assuming 10 to 20 million gallons of capacity with a 1 mgd inflow rate. Water from the wetland ponds can flow into the basins when the MWRWP is producing more water than is needed at Woodland Creek and the ponds. Two basins are online at a time.

The groundwater recharge basins infiltrate reclaimed water to the aquifer. Water discharged into the basins quickly infiltrates. The basins are designed for a maximum recharge rate of 1 mgd per basin. The basins are excavated into the subsurface and contain about 1 foot of imported sand for filtration of fine particulates and for ease of maintenance when tilling the soil.

The basins are operated using wetting drying cycles to control algae growth and to aerate the top soil.

- 3 days of wetting
- 1 day of drying
- 8 days of non-operation

The basins are tilled at least two times a year to aerate the surface soils and to remove any vegetation that may be growing. No sediment removal has been necessary, primarily because of the very low amount of suspended solids in the reclaimed water influent. The basins are operated year-round except during periods of maintenance at the MWRWP.

Reclaimed water recharge rates currently range from 0 to about 1.2 mgd. During the summer months, less reclaimed water is recharged on the Hawks Prairie property (as low as 0.1 to 0.3 mgd) because some of the reclaimed water is used for irrigation and some of it is delivered to the Woodland Creek Groundwater Recharge Facility operated by the City of Lacey. When the basins are operated in rotation, groundwater levels typically increase up to about 10 feet with up to 1 mgd of recharge.

Reclaimed water delivery to the basins is controlled by an adjustable computerized control system that records flow rates to each basin. Power is available on the site (120V) and there are roads between and around the basin with good access. There is no potable water on the site; however, a nearby City of Lacey fire hydrant and portable fire hose can be used to provide potable grade water. The recharge basins are gated and locked.

2.4 Hydrogeology

The information below is from hydrogeologic reports prepared under Tasks 1 and 2 for the RWIS, “Hydrogeologic Characterization Report, On-site Wells and Lysimeter Installation (Off-Site Monitoring Wells Hawks Prairie Area,” and “Groundwater Quality Characterization Technical Memorandum” (HDR 2017a, 2017b). Prior reports on the hydrogeology of the area include Brown and Caldwell (2009, 2004), Drost et al. (1999, 1998), Golder (2011), HDR (2014, 2017a, 2017b); Landau (2016), Northwest Land and Water (2008), Pacific Groundwater Group (2004) and Robinson and Noble (2002, 2000). Figures 2-2 and 2-3 identify the locations of lysimeters and monitoring wells installed on the property.

2.4.1 Hydrogeologic Units

The Hawks Prairie Study Area was heavily glaciated, resulting in a sequence of stratified sediments that are regionally correlated based on their water bearing properties. The geology of the area is presented in surface geologic maps by Drost et al. (1999), Logan et al. (2009, 2003) and Walsh et al. (2003).

The hydrostratigraphic units are discussed below from top to bottom. Hydrogeologic cross sections from prior groundwater supply development projects are presented on Figures 2-4, 2-5, and 2-6. Unit nomenclature differs between the two sources of data. In the unit descriptions below the abbreviations in parenthesis are first from Drost et al. (1999) and second from Logan et al. (2003).

Late Vashon Sediments in Woodland Creek Valley (Qgof/Qgos). Late Vashon sediments were deposited in the Woodland Creek valley during deglaciation. Sediments consist of sand/silt up to 100 feet thick in the upper part of the drainage and less thick silty/clay in the lower part of the drainage. This unit forms an unconfined aquifer within the Woodland Creek valley.

Alluvium Vashon Recessional Gravel Outwash (Qvr, also known as Qgo). Alluvium and recessional glacial outwash sand and gravel form an unconfined aquifer where saturated. Throughout most areas the unit is unsaturated and forms the vadose zone. Approximate thickness of the unit ranges from being absent (eroded) to over 100 feet thick in places. This is the upper-most water bearing unit in the Hawks Prairie Study Area.

Vashon Till (Qvt, also known as Qgt). Deposits of dense (compacted) unsorted silt, clay, sand and gravel form a regional confining unit which impedes the vertical flow of groundwater. The till unit is not present underlying most of the LOTT Hawks Prairie property, but is present nearby to the south and north of the site. Approximate thickness of the unit ranges from being absent to over 50 feet thick, with appearances at the surface and at varying depths

Vashon Advance Outwash (Qva, also known as Qga). The Vashon Advance Outwash is a regional aquifer composed of sand and gravel. This is the upper-most water bearing unit in areas where the Qvr is not saturated. The Qvr and Qva units are sometimes grouped together and called the “Upper Aquifer” or “Shallow Aquifer” in previous studies. The depth to the bottom of the Shallow (Qva) Aquifer is generally less than 150 feet below ground surface (bgs), although may be deeper in places. In the vicinity of the Hawks Prairie property the aquifer is generally unconfined, although in places the groundwater level may rise into the glacial till and become confined. Well yields within the Hawks Prairie Study Area for the Shallow (Qva) Aquifer are reported up to 250 gallons per minute (gpm).

Kitsap Formation (Qf). The Kitsap Formation is a low-permeability silt, sand and clay formation that is a regional confining unit up to 150 feet thick between the upper aquifer and the deeper aquifer. Significant thicknesses of fine sand have been observed in some locations, which may cause the confining unit to behave as a leaky confining unit. The Kitsap Formation appears to be absent near the east side of the Thurston County Landfill.

Pre-Vashon Coarse Deposits (Qc). This thick (up to 150 feet) sequence of coarse stratified sand and gravel is highly permeable and forms a regional aquifer used extensively for public supply. Well yields of up to 1,650 gpm have been reported for this aquifer. This is also sometimes called the “Sea Level (Qc) Aquifer” in previous studies. The aquifer is confined because groundwater levels are well above the top of the formation. The coarse-grained deposits are usually found in beds overlain and underlain by finer-grained sediments that act as confining units or low-permeability units within the aquifer. The coarse-grained sediments are often correlated to be at or below current sea level, but are not necessarily uniform in depth or extent.

Tertiary Unconsolidated and Undifferentiated Sediments (TQu). Layers of clay, silt, sand and gravel of glacial and non-glacial origin above bedrock are characterized as Tertiary unconsolidated and undifferentiated sediments. In some places, deep public supply wells have been completed in the coarse TQu sand and gravel units which form a deep confined aquifer. This is sometimes called the "Deep (TQu) Aquifer" in previous studies. Well yields of up to 860 gpm have been reported on logs for wells completed in the Deep Aquifer within the Hawks Prairie Study Area.

2.4.2 Vadose Zone

The unsaturated vadose zone at the Hawks Prairie property recharge basins is composed of silty sand and gravel with layers of finer-grained deposits that cause water to accumulate (perch) above the Shallow (Qva) Aquifer groundwater level, which is approximately 80 to 90 feet deep. One set of suction lysimeters were installed at depths of 10, 25, and 50 feet to measure vadose zone pore water, and one set of vadose zone monitoring instruments (soil moisture, temperature, conductivity and oxygen) were installed in the east half and west half of Basin 4 (two sets total). The purpose of the suction lysimeters is to collect pore-water samples at discrete intervals above the groundwater table and the purpose of the *in-situ* soil instrumentation is to collect data on vadose zone conditions within the basins.

2.4.3 Groundwater Levels and Flow Directions in Shallow (Qva) and Sea Level (Qc) Aquifer

A network of 25 monitoring wells has been installed to measure groundwater levels and groundwater quality in the Shallow (Qva) and Sea Level (Qc) aquifers. Construction details for monitoring wells are shown in Appendix A and a full description of the monitoring well network, groundwater levels and flow paths are provided in a report by HDR (2017a).

Groundwater levels were measured during August 2017 in monitoring wells located in the vicinity of the LOTT Hawks Prairie property. Figure 2-7 shows the groundwater potentiometric elevations and estimated groundwater flow paths for the Shallow (Qva) Aquifer. Groundwater flows from the northeast to the southwest through the LOTT Hawks Prairie property. The Shallow (Qva) Aquifer groundwater gradient is steeper at the Hawks Prairie property and then flattens to the southwest of the property. The reason for the change in hydraulic gradient to the southwest appears to be due to the structural control of the Kitsap Formation (Qf) confining unit which dips down to the southwest. Groundwater levels and elevations recorded during 2017 are provided in Appendix A.

The groundwater levels in the deeper Sea Level (Qc) Aquifer during August 2017 are shown on Figure 2-8. Groundwater in the Sea Level (Qc) Aquifer flows from the west to the east across the LOTT Hawks Prairie property. The groundwater levels in the Sea Level (Qc) Aquifer at the LOTT Hawks Prairie property are approximately 15 to 68 feet lower than the groundwater levels in the Shallow (Qva) Aquifer, indicating a downward vertical gradient between the two aquifers. At MW-21/MW-22, southwest of the Hawks Prairie property, the vertical gradient is much less, and deep and shallow groundwater levels are similar.

2.4.4 Groundwater Travel Times Shallow (Qva) Aquifer

Groundwater travel times were estimated using the groundwater velocity from the Darcy equation (Fetter, 2001).

$V = (k * i)/n_e$

where:

V = velocity (feet/day)

k = hydraulic conductivity (feet/day)

i = hydraulic gradient (feet/feet)

n_e = effective porosity (percent)

Hydraulic conductivity in the Shallow (Qva) Aquifer was assumed to be between 100 to 200 feet/day based on the results of aquifer testing. Effective porosity was assumed at 20 to 25 percent, typical values for a mixed sand and gravel (Fetter 2001). A hydraulic gradient of 0.023 and 0.0024 was utilized based on the measured groundwater elevations for two zones:

- Zone 1: Center of Recharge Basin 4 southwest to MW-20 with a measured gradient of 0.023 feet/feet.
- Zone 2: MW-20 to the southwest with a measured gradient of 0.00241 feet/feet.

The resulting groundwater velocity ranges from a low of 0.96 feet/day to a high of 23.0 feet/day. Tables describing the calculations are presented in HDR (2017b). As a point of comparison, the startup monitoring investigation completed by HDR in 2014 indicated a groundwater velocity on the LOTT Hawks Prairie property between 13 and 43 feet/day (HDR 2014). These estimated groundwater velocities were based on observations of groundwater temperature and salinity changes at observation wells during restart of infiltration at Basin 4.

Figure 2-7 shows the estimated groundwater travel distance for the Shallow (Qva) Aquifer. The ranges of the 30, 60, 90, 120, and 150-day travel distances were estimated to be 276 – 690, 552 – 1380, 828 – 1851, 1104 – 1923, and 1380 – 1995 feet, respectively.

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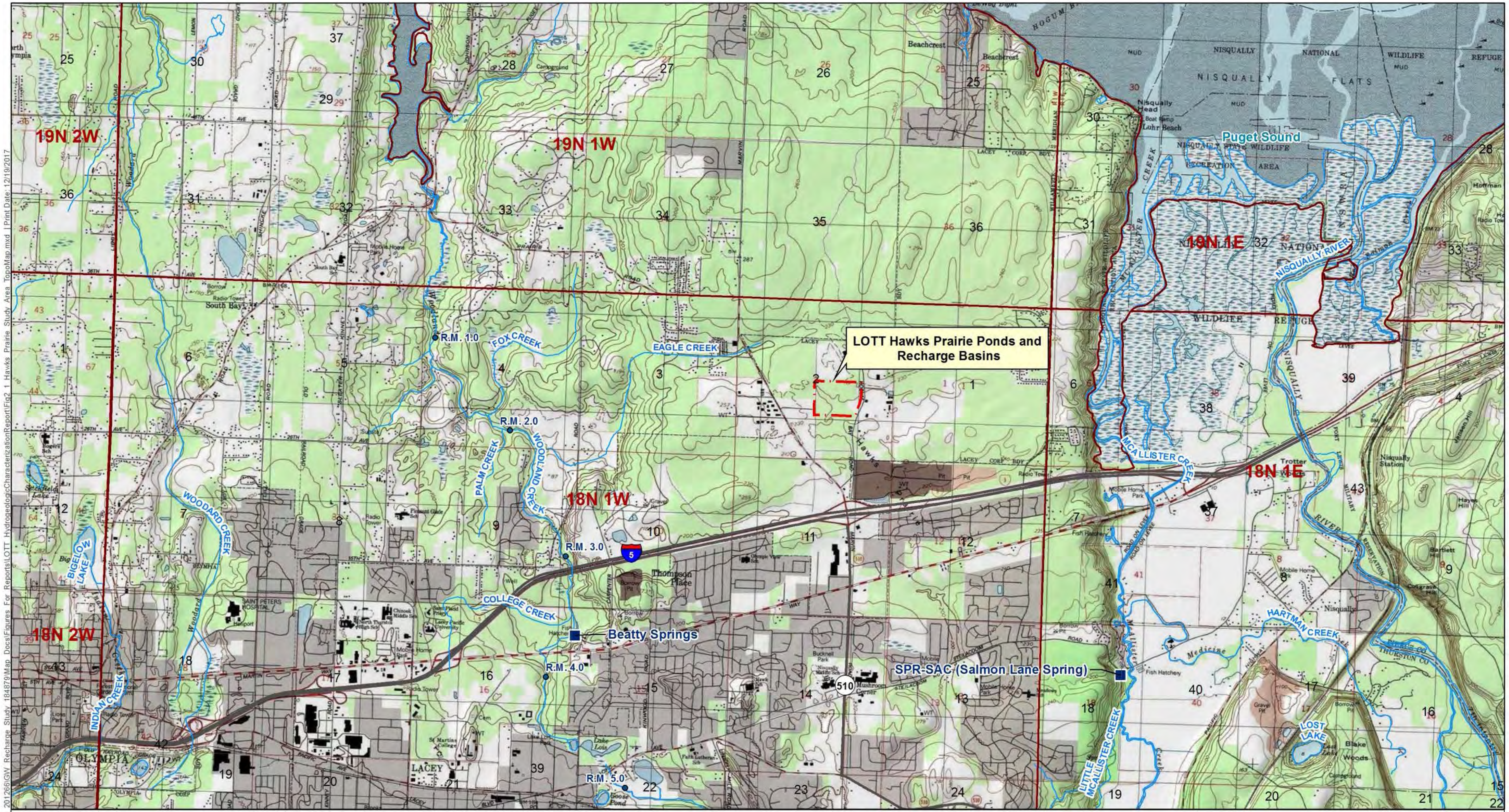

Legend

- Streams
- Major Roads
- LOTT Hawks Prairie Recharge Facility
- Township/ Range
- Section
- ● River Mile

Figure 2-1
Topographic Map Hawks Prairie Area

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Source: Bing Maps (2011), City of Bellevue (2013), WSDOT (2013).

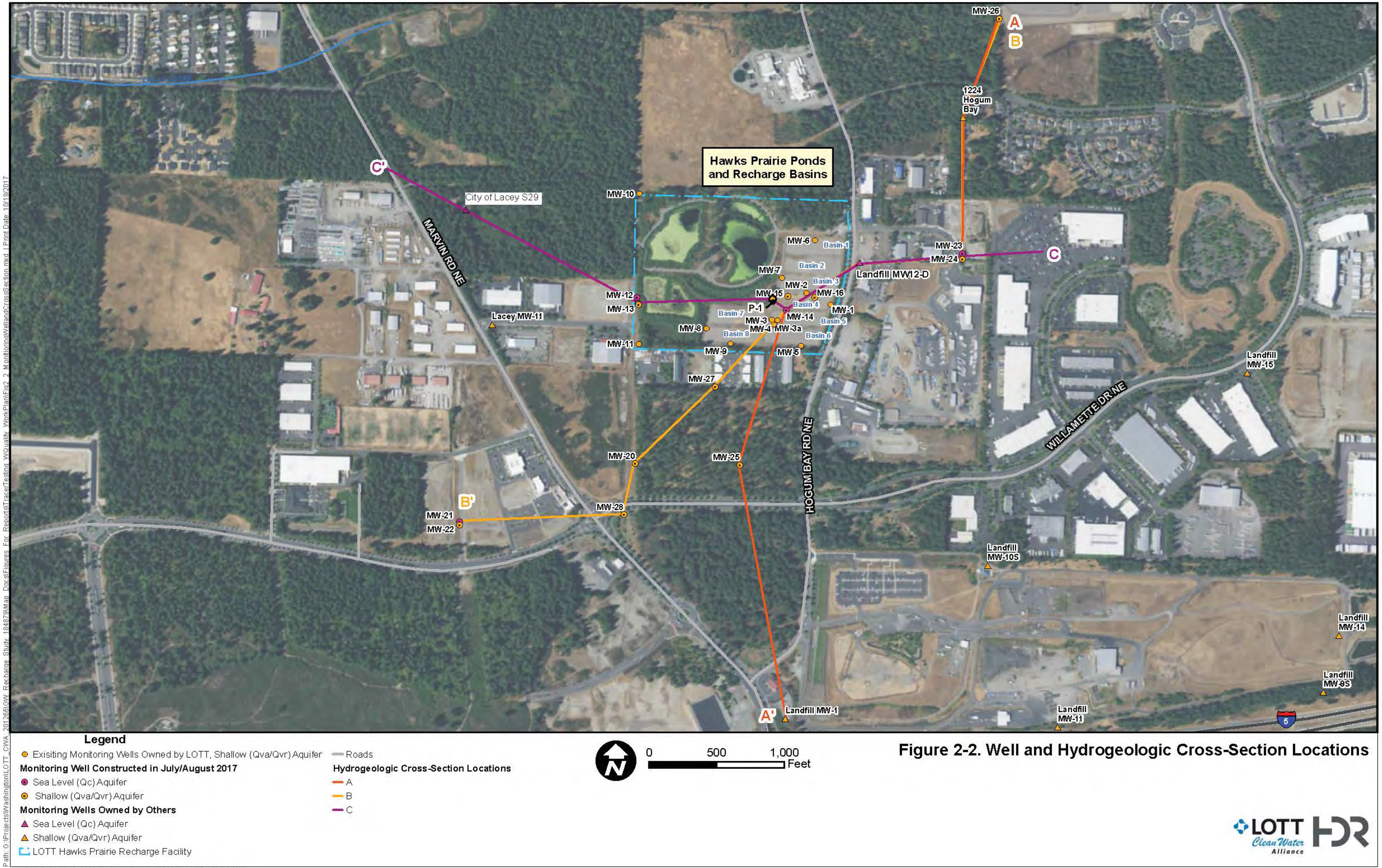

Figure 2-2. Well and Hydrogeologic Cross-Section Locations

Source: Bing Maps (2011), City of Lacey (2014), WSDOT (2013)

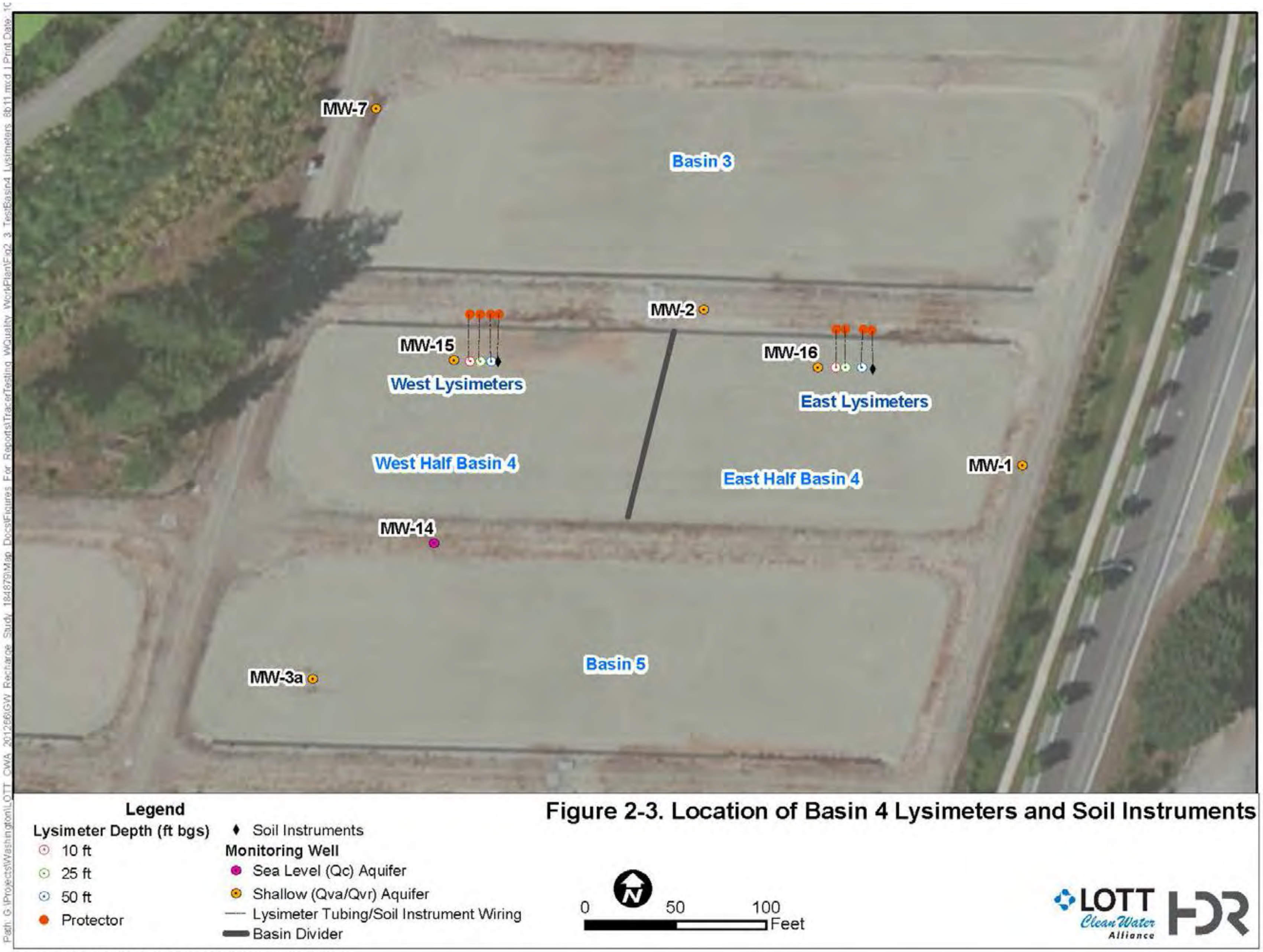

Figure 2-3. Location of Basin 4 Lysimeters and Soil Instruments

Source: Bing Maps (2011), City of Lacey (2014), WSDOT (2013).

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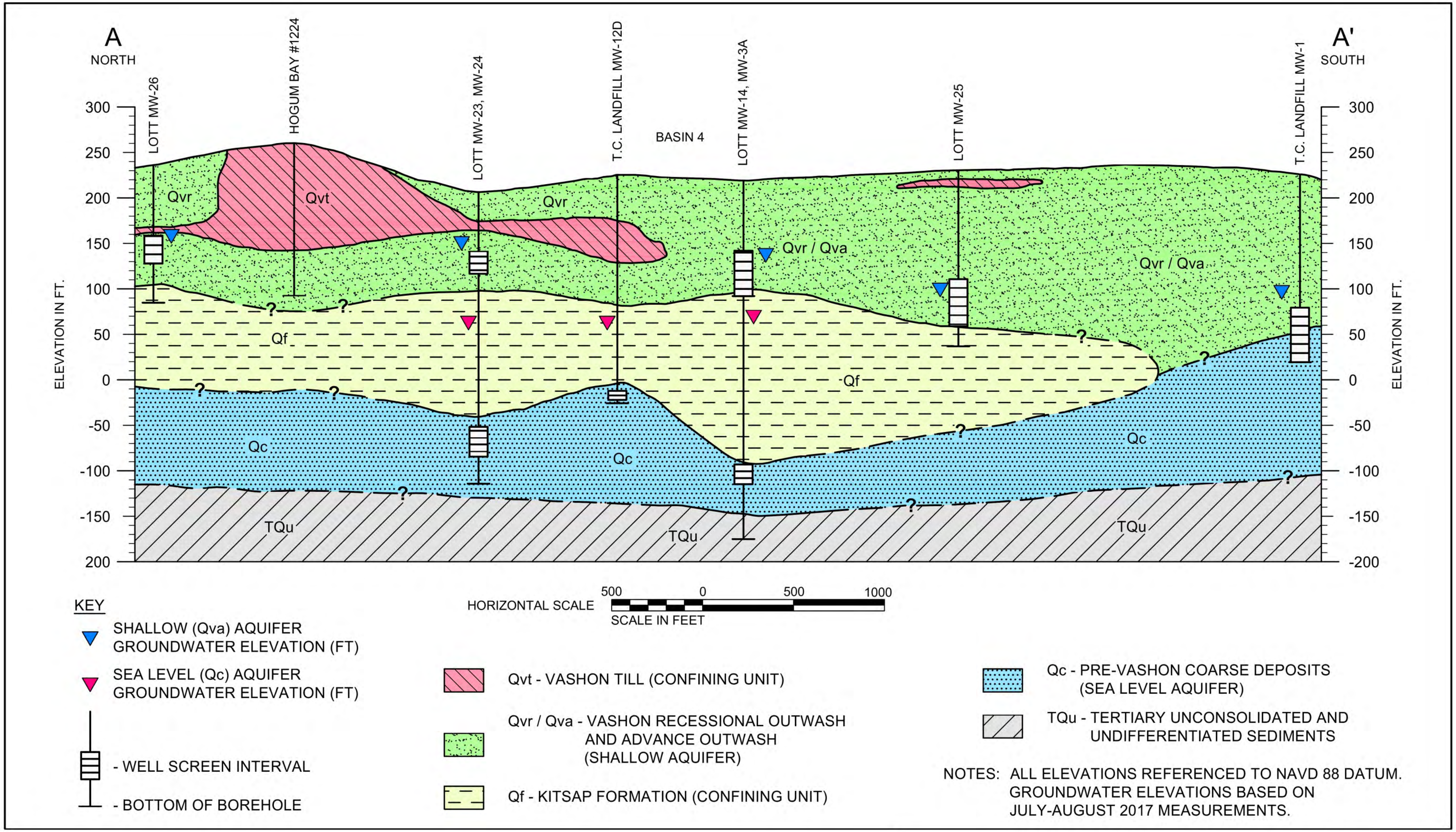

FIGURE 2-4, CROSS-SECTION A-A'

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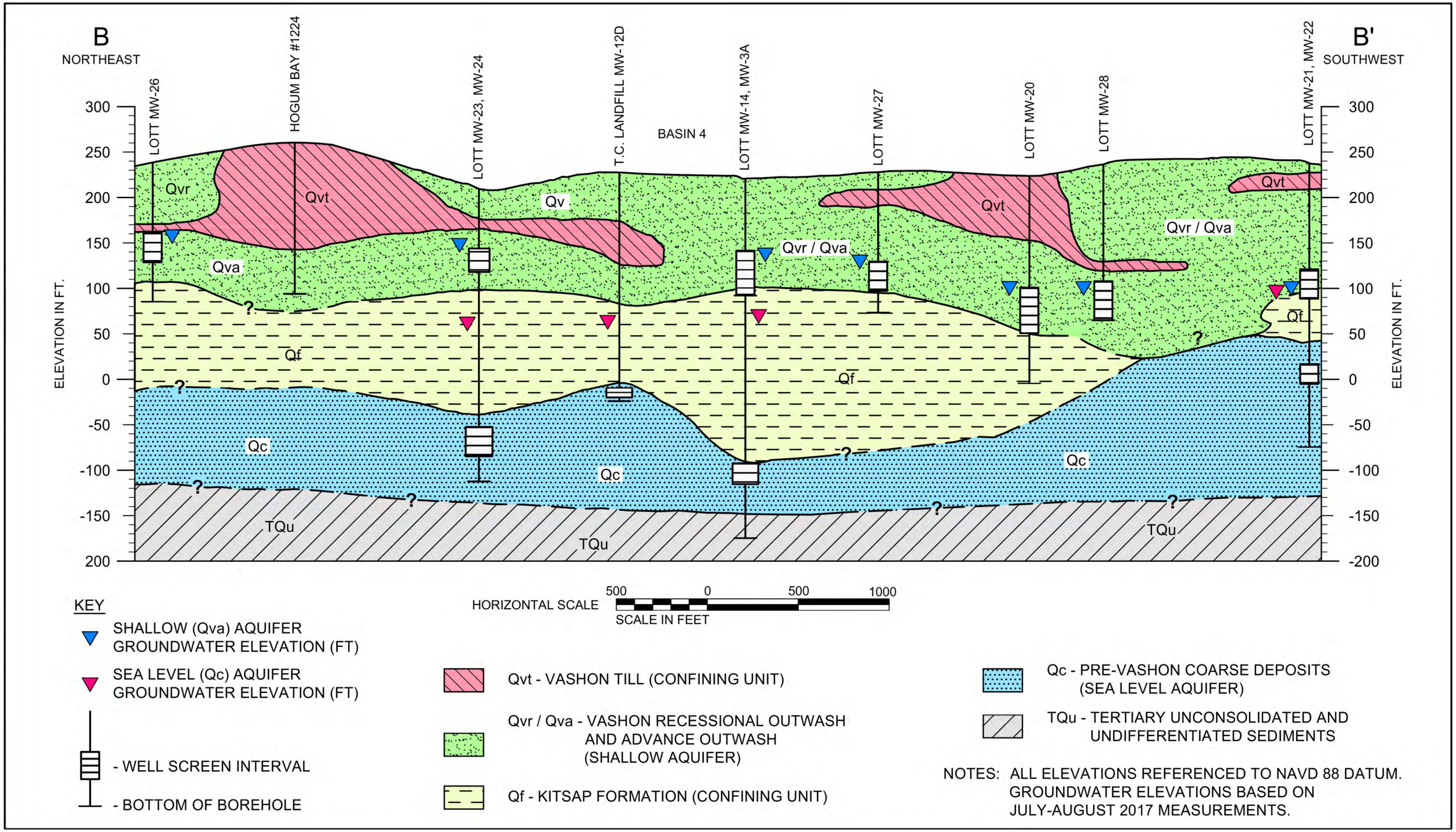
01/26/2018



NOTES: ALL ELEVATIONS REFERENCED TO NAVD 88 DATUM. GROUNDWATER ELEVATIONS BASED ON JULY-AUGUST 2017 MEASUREMENTS.

FIGURE 2-5, CROSS-SECTION B-B'

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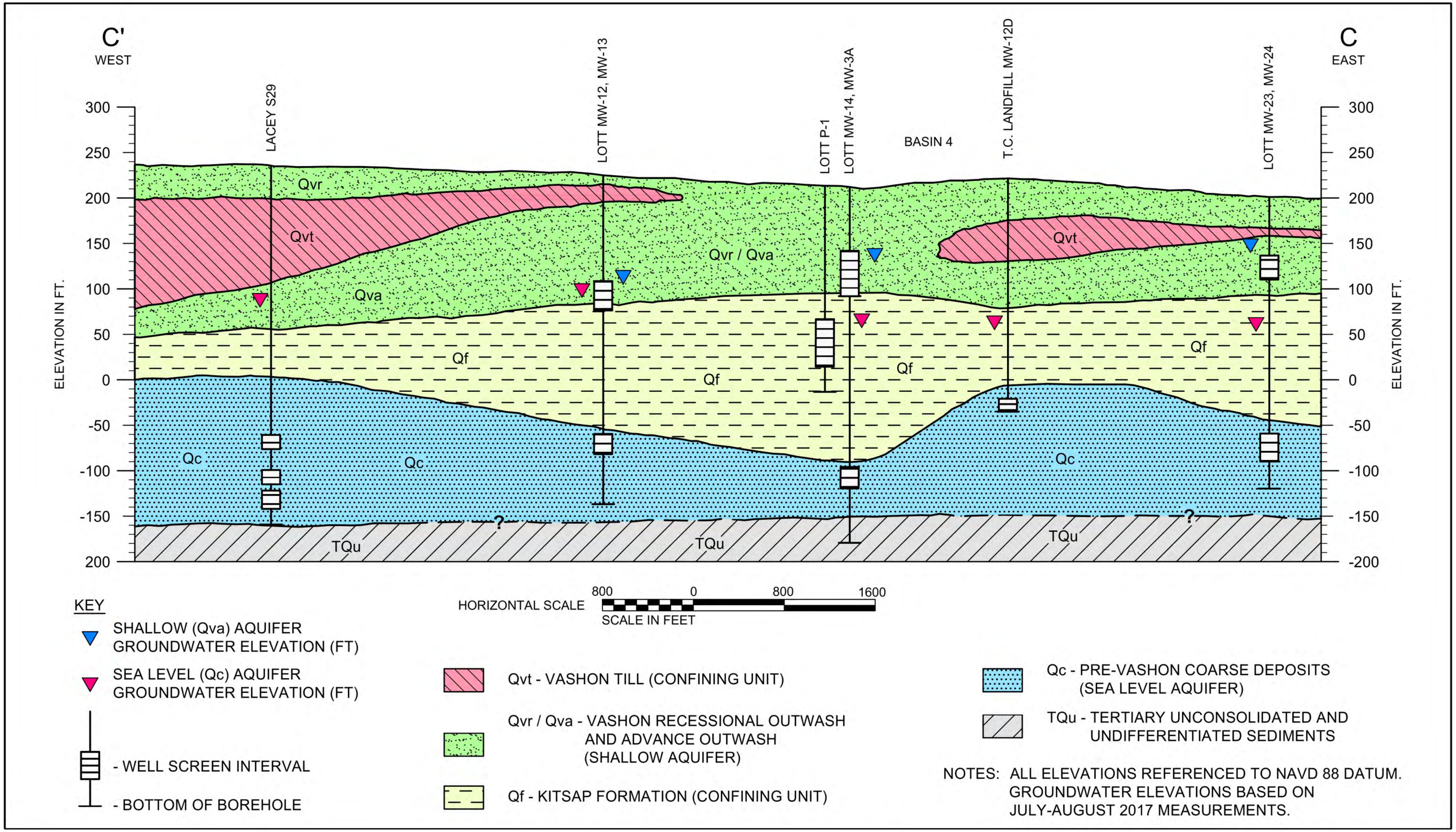

NOTES: ALL ELEVATIONS REFERENCED TO NAVD 88 DATUM. GROUNDWATER ELEVATIONS BASED ON JULY-AUGUST 2017 MEASUREMENTS.

HDR

FIGURE 2-6, CROSS-SECTION C'-C

DATE
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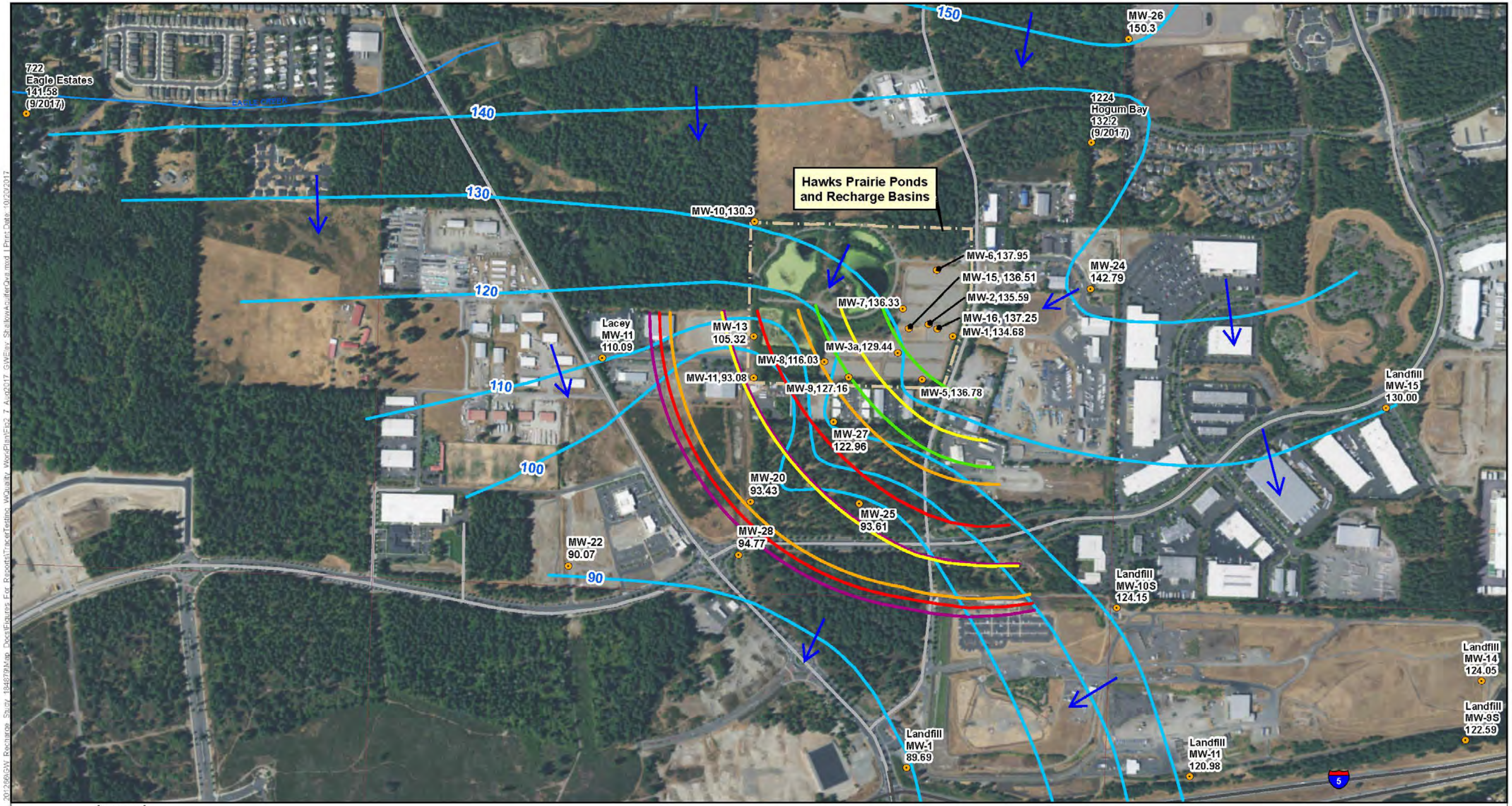

Legend

- ⊙ Well ID, Groundwater Elevation (ft)
- — Groundwater Potentiometeric Surface Contour, Shallow Aquifer (ft)

Estimated Time of Travel

- 🟩 30 Day Travel Time Zone
- 🟨 60 Day Travel Time Zone
- 🟧 90 Day Travel Time Zone
- 🟥 120 Day Travel Time Zone
- 🟪 150 Day Travel Time Zone

N

0 500 1,000 Feet

Notes:

Groundwater elevations from July and August 2017.
Wells Hogum Bay and Eagle Estates were measured 9/13/2017.
Vertical datum for groundwater elevations is NAVD 88.

Figure 2-7
Groundwater Elevation and Estimated Time of Travel
Shallow Aquifer, Qva/Qvr
July/August 2017

LOTT Clean Water Alliance HDR

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Source: Bing Maps (2011), City of Lacey (2014), WSDOT (2013).

Legend

- ● Well ID, Ground Water Elevation (ft)
- Groundwater Potentiometeric Surface Contour, Sea Level Aquifer (ft)
- → Groundwater Flow Direction
- Roads
- ☐ Section

Notes:

Groundwater elevations at wells Classic H, White Fir and Thompson are from summer 2015
Vertical datum for groundwater elevations is NAVD 88.

Figure 2-8
Observed Groundwater Elevations, July/August 2017
Sea Level Aquifer, Qc

Source: Bing Maps (2011), City of Lacey (2014), WSDOT (2013).

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3.0 Setup, Monitoring and Delivery of Reclaimed Water at Basin 4

During the 2018 field monitoring, reclaimed water will only be infiltrated at Basin 4. Basin 4 has been divided in half using a berm, and reclaimed water will be alternated between each half of the basin. The purpose of using only Basin 4 as a test basin for the 2018 field monitoring is so that reclaimed water can be focused in one location at a rate typical of larger-scale recharge operations. Reclaimed water will be alternated between each half of the basin by mechanically separating the flow. Staff gages will be installed with continuous electronic water level recorders to obtain a record of surface water inundation.

Throughout the period of the tracer test and water quality monitoring reclaimed water used for all recharge operations will flow directly to the recharge basins, bypassing the LOTT wetland ponds. The reasons for this decision include: 1) the information gathered from this study will inform current and future recharge facilities which may not have wetland ponds, 2) the reclaimed water (without wetlands) exhibits water quality with a higher concentration of nutrients.

The effects of the wetlands on water quality can be determined from the reclaimed water sampling conducted in 2014 to 2015 (HDR 2017c). This included two sampling events with samples collected pre- and post-wetlands. The results are generalized in Table 3-1. The analytical data indicates that the wetlands had a variable effect on residual chemical concentrations, except for four compounds (1,4 dioxane, atenolol, fluuxetine and lopressor) which exhibited consistent degradation from the wetlands. Nitrate concentrations were significantly reduced pre- and post-wetlands with an average reduction of 3.2 mg/L. Total chlorine was 0.3 to 0.7 mg/L pre-wetlands and was non-detect post wetlands. Pre-wetland samples were non-detect for all samples (likely because of the presence of chlorination). Post wetlands samples showed the presence of coliform bacteria. Total organic carbon ranged from 5 to 6 mg/L pre- and post-wetlands and biodegradable organic carbon ranged from non-detectable up to 0.62 mg/L pre-wetlands and non-detectable to 2.7 mg/L post-wetlands (the effect of the wetlands on biodegradable organic carbon is not consistent). This data shows that the wetlands has the following influence on reclaimed water quality: 1) limited effect on residual chemicals except for four compounds noted above, 2) removal of total chlorine, 3) addition of coliform bacteria, 4) significant decrease in nitrogen concentrations, 5) little effect on total organic carbon, 6) variable influence on biodegradable organic carbon. A map is shown on Figure 3-1 to assist in understanding the flow path of water at the property.

Basin 4 will operate on a 50 percent wetting/drying cycle with 7 days between each cycle. This will allow the basin soils to dry and will help to avoid vegetative growth and encrustation/clogging of the basin soils.

Recharge will begin solely in Basin 4 starting in early December 2017 to mid-January 2018 to acclimate the basins to large-scale recharge. The basins will be monitored during this period to determine the surface water level inundation and the amount of groundwater level rise that will occur at recharge rate of 0.5 to 1.2 mgd. Recharge rates may require adjustment based on the observations during the acclimation period (early December to mid-January). During the 2014 startup monitoring of Basin 4, a recharge rate of about 0.7 mgd resulted in several inches of inundation which did not extend completely over the basin, as shown in Figure 3-2.

Tracer testing will begin during January 2018, and will utilize reclaimed water recharge rates of approximately 1 mgd. Tracer chemical delivery is proposed to occur over 7 days and during this time the basins will not be rotated (i.e., 0.5 mgd will be delivered into each basin during all 7 days.) Reclaimed water flow will be controlled so that the amount of tracer flowing into the basin is within the concentrations identified for the test. Excess reclaimed water will be delivered to other recharge basins on the property.

Recharge rates during the remainder of the field monitoring in 2018 will be dependent on the amount of reclaimed water produced that is available for recharge. Target recharge rates will be between 0.5 to 1.2 mgd, which is an infiltration rate of approximately 3 to 6 feet/day applied over a half-acre basin. The goal is to achieve approximately one foot of surface water inundation in the basin, 10 to 15 feet of groundwater mounding, and an infiltration rate typical of full recharge operations (5 to 8 mgd).

3.1 Basin 4 Water Level and Temperature Monitoring

Staff gages and water level stage recorders will be set up in each half of Basin 4 and continuous recording electronic pressure transducers will record water levels and temperature every six hours. The atmospheric pressure will also be recorded so that the water level recording instruments can be corrected for atmospheric changes.

3.2 Groundwater Level and Temperature Monitoring

Groundwater levels are anticipated to fluctuate up to about 10 to 15 feet when recharge is only infiltrated at half of Basin 4 at a rate of 0.5 to 1 mgd, based on groundwater monitoring completed during the 2014 startup monitoring at Basin 4 (HDR 2014). Groundwater level and temperature data is useful to determine the extent of the groundwater level rise (mounding) and to assist in determining changes in aquifer conditions as a response to recharge activities including possible changes in lateral and vertical gradient and groundwater flow direction.

Groundwater levels will be monitored in monitoring wells in the vicinity of Basin 4 and the Hawks Prairie property using a combination of continuous recording electronic pressure transducers and hand-collection using an electronic water level meter. Groundwater levels in all monitoring wells will be recorded by hand on a monthly basis. The following monitoring wells will have electronic recording instruments recording both groundwater levels and temperature every six hours:

- Shallow (Qva) Aquifer: MW-1, 2, 3a, 5, 6, 7, 8, 9, 13, 15, 16, 22, 24, Lacey MW-11,
- Sea Level (Qc) Aquifer: MW-12, 14, 21, 23

Table 3-1. Water Quality Pre- and Post- Wetlands, 2014 and 2015

	End of Reclaimed Water Inflow Pipe (Pre Wetlands)	Post-Wetlands
Residual Chemicals	Variable	Variable, but consistent degradation four compounds, 1,4 Dioxane, Atenolol, Fluuxetine, Lopressor
Nitrate	Ave. 6.6 mg/L	Ave. 2.8 mg/L (Ave. 3.2 mg/L reduction)
Total Chlorine	0.3 to 0.7 mg/L	All ND
Bacteria	No significant amount of bacteria	Bacteria present
Total Organic Carbon **Biodegradable Organic Carbon**	5 to 6 mg/L ND to 0.62	5 to 6 mg/L ND to 2.7

Notes:

1. Data based on four sampling events pre- and post- wetlands in 2014 and 2015 (HDR 2017c).

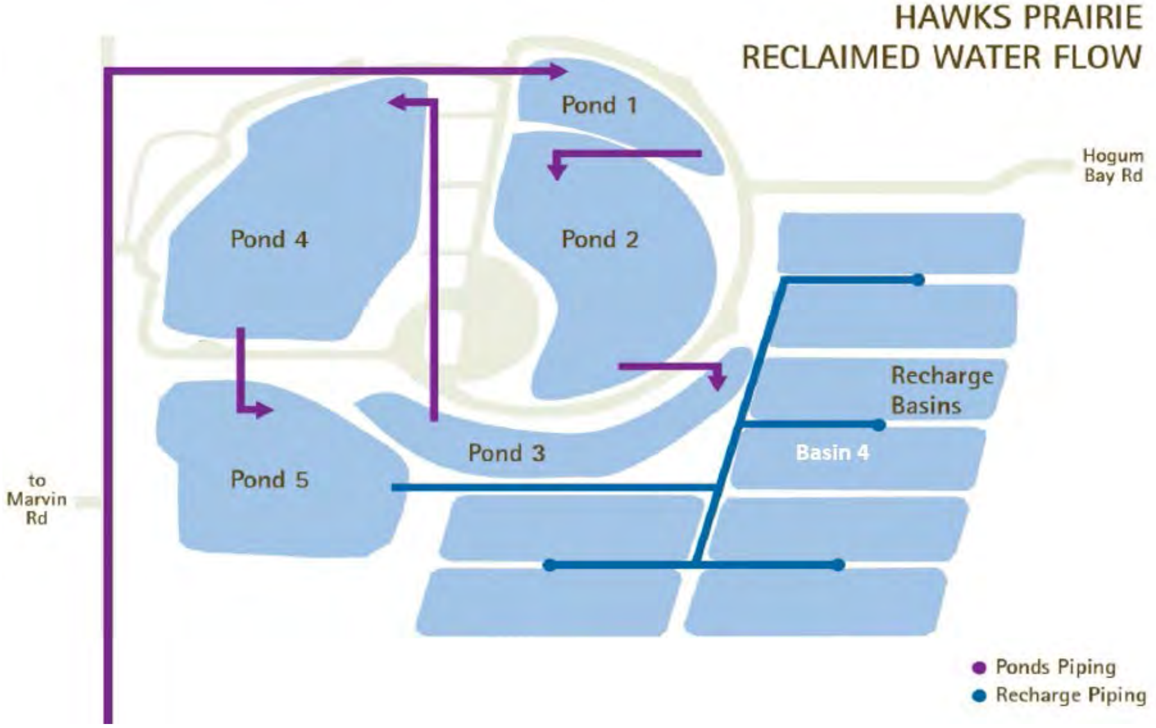

Figure 3-1. Layout of Wetland Ponds and Recharge Basins and Reclaimed Water Flowpath

Figure 3-2. Photograph of west side of Basin 4 during March 3, 2014, start-up monitoring with recharge flow rates ~0.7 mgd.

(Top photo west side of west basin looking east. Bottom photo close up of east side of west basin looking east.)

4.0 Tracer Testing

Two conservative tracers, bromide and sulfur hexafluoride (SF_6), are proposed to be used to measure travel time of groundwater flowing from Basin 4 through the vadose zone and groundwater. A conservative tracer is a constituent that moves through the subsurface along the downgradient flow path at approximately the same rate of travel as groundwater. Two tracers are proposed to provide redundancy in the event that one of the tracers is not detected. This section describes the types and concentration of tracers to be used. A subsequent section describes tracer groundwater monitoring procedures.

4.1 Bromide Tracer

4.1.1 Bromide Type and Source

Bromide is an ideal groundwater tracer because it is nontoxic, inexpensive, easy to detect in trace amounts, chemically stable, not retarded or sorbed in groundwater, and is not present in large amounts in the groundwater being studied (Kass 1998; Davis et al. 1985). Laboratory studies have indicated that above 50 mg/L there may be density affects that cause bromide to sink as it moves laterally downgradient (Istok and Humphrey 1999). The background concentration of bromide ranges between about 10 to 40 micrograms per liter (µg/L) in prior sampling of the Hawks Prairie property wells and regional residential wells (HDR 2014; 2017b).

The process to utilize bromide as a tracer is to introduce it into groundwater by infiltrating it at the surface along with the recharge water. Bromide concentrations in groundwater are then monitored to determine arrival time.

There are two options for chemical types to utilize bromide as a tracer: 1) sodium bromide (NaBr) and potassium bromide (KBr). Both sodium bromide and potassium bromide dissolve readily in water to form two ions: either sodium or potassium and bromide. Both sodium bromide and potassium bromide are available commercially from ICL Group. A specification sheet is provided in Appendix B for sodium bromide and potassium bromide.

<u>Sodium Bromide</u>

Sodium bromide has these characteristics:

- Dry powder NaBr contains 76.1 percent bromide based on percentage bromide in NaBr by molecular weight (77.7 percent) multiplied by 98 percent pure.
- 25 kilogram(kg)/sack, $4.29/kg and 42 sacks on a pallet, total cost per pallet including shipping is $5,150.
- The USEPA drinking water guidance level for sodium is 20 mg/L.[1] There are no federal or state water quality standards for sodium or bromide.

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[1] This value was developed by USEPA for those individuals restricted to a total sodium intake of 500 milligrams per day (mg/day).

Potassium Bromide

Potassium bromide has these characteristics:

- Dry power KBr contains 66.5 percent bromide based on percentage KBr by molecular weight (67.1) multiplied by 99 percent pure.
- 25 kg/sack, $6.16/kg and 40 sacks on a pallet, total cost per pallet including shipping is $6,791.
- There are no federal or state drinking water or groundwater quality standards for potassium or bromide.

Potassium bromide is recommended as a tracer because it does not have the potential drinking water limits associated with sodium bromide, so it can be delivered into the recharge basin at a higher concentration over a shorter time period.

4.1.2 Bromide Tracer Concentration in Recharge Water

Potassium bromide will be introduced directly into the surface infiltration basin recharge water. After reaching groundwater, the concentrations of the bromide in groundwater will lessen with distance from the source due to dilution and hydrodynamic dispersion with native groundwater. The tracer must be detectable above background yet not be at concentrations that are unreasonably high. Concentrations that are too high may cause a density gradient that affects flow and transport.

The process used to determine the concentration of the bromide concentration in the recharge water is as follows:

1. Identify the desired concentration that can be reasonably detected at downgradient monitoring wells assuming a conservative factor of safety for detection above background.
2. Use groundwater modeling to iteratively determine the approximate initial tracer concentration that would be required to achieve detection at the downgradient monitoring wells.

Minimum Downgradient Detection Concentration

These factors were considered in determining downgradient detection concentrations:

- The amount of bromide required to obtain a minimum detected concentration of 100 times background in the downgradient monitoring wells. Background concentrations of bromide range from 10 to 40 µg/L and average about 25 µg/L.
- The bromide tracer groundwater detection limits for field screening/monitoring instruments (0.1 milligrams per liter (mg/L) detection limit) and by the laboratory analysis (5 µg/L).

Based on these factors, the minimum downgradient tracer detection concentration is 2 to 3 mg/L.

Tracer Concentration in Recharge Water

A groundwater modeling exercise was completed to evaluate the approximate arrival times and concentration for recharge of bromide, assuming a range of aquifer parameters and conditions based on the recent hydrogeologic investigations. The time when tracer would be input into the recharge water (as a pulse) was evaluated at between 7 to 14 days of continuous recharge at a rate of 1 mgd over a 1 acre area of Basin 4 to determine the resulting downgradient concentrations. The results of the modeling analysis are summarized in Table 4-1 and 4-2 for 7 days of tracer delivery into Basin 4. The full methods and results of the groundwater modeling evaluations are presented in Appendix C. The modeling results are reported for bromide concentrations, and are valid for either a sodium bromide or potassium bromide being used as the initial tracer compound.

The modeling results show 14 days of tracer delivery into Basin 4 with an initial concentration of 20 mg/L bromide takes 9 days to reach 15 percent of maximum concentration (1 mg/L) and 41 days to reach maximum concentration (8 mg/L) at a distance 250 feet downgradient from the basin. At a distance of 2,500 feet downgradient from Basin 4, it takes about 121 days to reach 15 percent of maximum concentration (0.4 mg/L) and about 212 days to reach maximum concentration (1 mg/L). The 7 day delivery of tracer into Basin 4 results in the same predicted travel times, but with one-half of the predicted concentration arriving at the downgradient monitoring well.

The modeling results can be extrapolated to determine the downgradient predicted concentrations with higher recharge delivery concentrations. Extrapolating the results of the modeling for a 7 day, 25 mg/L delivery at the recharge basins indicates concentrations of about 6 mg/L at 250 feet downgradient from the basin and a concentration of 1.5 mg/L at a distance of 2,500 feet downgradient. Two charts are included in Appendix C to reflect results anticipated assuming an initial concentration of 25 mg/L.

The recommended concentration of potassium bromide delivered to the recharge basins is 25 mg/L over a 7-day period, which will result in downgradient maximum concentrations of 6 to 1.5 mg/L at distances of 250 to 2,500 feet, respectively.

4.1.3 Quantity of Bromide Required

The amount of potassium bromide required to achieve a concentration of 25 mg/L during 7 days of recharge with 1 mgd of reclaimed water was estimated to be about 1,000 kilograms. Since potassium bromide is sold in pallets of 40 sacks each weighing 25 kg, one pallet would be required and there would be no leftover chemicals to dispose. The potassium bromide quantity calculations are presented on Table 4-3.

4.1.4 Bromide Handling, Mixing and Delivery to Recharge Basins

Powdered potassium bromide in sacks will be stored in a nearby storage unit and brought to the site as needed and covered with plastic. Potassium bromide will be mixed into two 1,500-gallon above-ground polyethylene storage tanks filled with potable water until the desired bromide concentration is achieved as necessary to result in an approximately 25 mg/L bromide concentration when the tracer is mixed into the reclaimed water (see Table 4-3 for details on mixing volumes assuming a 1 mgd reclaimed water inflow rate). All potable water will be provided from the City of Lacey potable water supply pipeline using an on-site fire hydrant, water meter, and reduced pressure backflow assembly; the potable water will be delivered by fire hose. Mixing will be conducted using a circulation pump.

Potassium bromide solution will be introduced directly into the reclaimed water pipeline at Vault 5 which is about 1,000 feet upgradient from Basin 4. The potassium bromide solution will be allowed to mix through the pipeline before entering the recharge ponds. The detailed design of the delivery system will be adjusted in the field as needed. During the 7-day tracer injection period, concentrations of bromide in the storage tanks and in the basin recharge water will be measured semi-daily using a calibrated field meter (TruLab 1320 benchtop meter with a TruLine Bromide Laboratory Electrode Kit). It is important to note that the 25 mg/L bromide concentration in recharge water is an approximate target, and will vary daily as reclaimed water inflow to the basin varies over time. This is acceptable for the tracer test, as a precise continuous record of inflow concentrations is not required to analyze the breakthrough curves to determine arrival time at the monitoring wells (explained in more detail in subsequent sections).

4.2 Sulfur Hexafluoride Tracer

4.2.1 Sulfur Hexafluoride Type and Source

Sulfur hexafluoride (SF_6) is proposed to be used as a second groundwater tracer because it is a non-reactive, inexpensive, low toxicity gas that dissolves readily in water and is easily detected at low concentrations. Furthermore, it is present in native groundwater at extremely low concentrations (< 1 fmol/L; 1 fmol = 10^{-15} mol). These properties make it an ideal tracer gas for groundwater. It has been successfully used as a tracer at multiple aquifer recharge projects (Avisar and Clark, 2005; Clark et al., 2009, 2005, 2004; Gamlin et al., 2001; Wilson and Mackay, 1996). It has been used previously in Orange County, LA County, and Ventura County in a variety of settings including recharge basins (Avisar and Clark 2005; Clark et al. 2004, 2005; Fram et al. 2003; Gamlin et al. 2001; McDermott et al. 2006). Dr. Jordan Clark of University of Southern California, Santa Barbara (UCSB) has been retained for this project to provide guidance regarding the use of sulfur hexafluoride as a tracer.

Sulfur hexafluoride will be purchased in a 36 liter (L) aluminum bottle at 320 pounds per square inch (psi) from Praxair (a specialty gas vendor) with a purity of over 99 percent. The tracer is in a gaseous form and will be dissolved in water by diffusion. Sulfur hexafluoride is inert (it does not react with other substances) and is denser than air. The specification sheet for sulfur hexafluoride is presented in Appendix B.

4.2.2 Sulfur Hexafluoride Mixing and Delivery

Sulfur hexafluoride will be delivered using two methods: 1) delivery into the reclaimed water at Vault 5 so that it can flow into Basin 4 and 2) directly into four of the monitoring wells around Basin 4. The reason for introducing SF6 into both the basins and the monitoring wells is to provide redundancy and increase the probability of detection.

4.2.2.1 Delivery of SF6 into Basin 4

Sulfur hexafluoride will be delivered for approximately five days into Basin 4. The procedure for delivering the SF6 into the Basin 4 is as follows. About 20 gallons of sulfur hexafluoride gas will be injected into collapsible nylon 150 gallon bags. The nylon bags will be collapsed prior to filling to evacuate atmospheric air out of the bag. The nylon bags will then be filled with potable water (without allowing air to enter) and the sulfur hexafluoride gas will be allowed to diffuse into solution. Prior experience by Dr. Clark indicates that the concentration of sulfur hexafluoride will be approximately 50 to 100 percent of solubility, which is 7 millimoles per liter (mmol/L), prior to mixing, so the adjusted concentration of the tracer injected water will be approximately 4 to 7 mmol/L. The 150 gallons will then be delivered by gravity flow over an 8-hour period into the reclaimed water Vault 5 pipeline using tubing to avoid aerating the sample during delivery. This will be done two times per day (once in the morning and once in the evening). Vault 5 is approximately 1,000 feet upgradient along the pipeline to Basin 4 so the tracer will have time to mix into the reclaimed water. Assuming an inflow of 1 mgd of reclaimed water, the estimated concentration of sulfur hexafluoride in reclaimed water will be about 0.001 to 0.002 mmol/L. The concentration going into the vault should be about 4 to 7mmol/L for 300 gallons of water delivered (1,100 liters) or a total of about 4,600 to 7,700 mmol. Accounting for the recharge water delivered (assumed at 1 mgd or 3,780,000 liters/day) the amount of sulfur hexafluoride in the reclaimed water will be about 0.001 to 0.002 mmol/L (or 1,000,000 to 2,000,000 pmol/L). The amount of sulfur hexafluoride actually delivered into the recharge basin will be significantly less, because of losses to the atmosphere during delivery. However, this is not anticipated to be an issue because of the very low detection limit for sulfur hexafluoride (pmol/L). Six to eight samples will be collected daily to determine the actual concentration of sulfur hexafluoride entering into the recharge basins.

4.2.2.2 Delivery of SF6 into Monitoring Wells MW-1, 2, 15 and 16

Sulfur hexafluoride will also be injected directly into the groundwater at monitoring wells at Basin 4 including MW-1, MW-2, MW-15 and MW-16. This provides redundancy in the event that the procedure for delivering sulfur hexafluoride into the basins is not successful. The injection into the monitoring wells will occur after the field screening of bromide concentrations, temperature, and conductivity determines that recharge water has reached MW-15 and MW-16 (details on the monitoring approach are provided in the section below), which is anticipated to be about 7 days. Sulfur hexafluoride solution is proposed to be directly injected into MW-1, MW-2, MW-15 and MW-16. Sulfur hexafluoride will be delivered into groundwater monitoring wells twice per day for five days. The procedure for tracer injection into the groundwater monitoring wells is explained below.

A clean 50 gallon polyethylene tank filled with potable-grade water will be set up next to the monitoring wells on a portable stand. Five-gallon plastic bags will be collapsed and then filled with about 1 gallon of sulfur hexafluoride gas, and then filled with potable water leaving about 1 gallon of sulfur hexafluoride gas head space and allowed to stand so the gas diffuses into solution. Without exposing the sulfur hexafluoride tagged water to the atmosphere, the water will be released from the bag by gravity to the bottom of the monitoring well using polyethylene tubing over a period of about 10 minutes. At the same time, about 50 gallons of water will be slowly released from the tank into the top of the saturated portion of the well screen through polyethylene tubing (so as to not aerate the water in the well) to push the sulfur hexafluoride tagged water in the well out into the formation.

A groundwater sample will be collected from MW-15 or MW-16 daily to measure the concentration of the sulfur hexafluoride in groundwater under the basin. Prior experience by Dr. Clark indicates that the concentration of sulfur hexafluoride will be approximately 50 to 100 percent of solubility which is 7 millimoles per liter (mmol/L) prior to mixing, so the adjusted concentration of the tracer injected water will be approximately 0.04 to 0.07 mmol/L.

Field adjustments to these procedures, volumes and concentrations will be made as necessary in consultation with Dr. Clark.

4.3 Monitoring of Tracers in Downgradient Lysimeters and Monitoring Wells

This section describes the schedule, locations and procedures for monitoring of downgradient tracers in groundwater at monitoring wells.

4.3.1 Monitoring Locations and Schedule

Groundwater samples will be collected at monitoring wells in the Shallow (Qva) Aquifer to monitor for the arrival of the tracers bromide and sulfur hexafluoride. Four of the Sea Level (Qc) Aquifer monitoring wells will also be monitored (two upgradient, one on-site and one downgradient) to determine if groundwater flows down through the Kitsap Formation confining unit and into the lower aquifer during the tracer period. The monitoring wells to be monitored include downgradient wells and three cross-gradient wells to evaluate if the estimated flow paths from groundwater gradients are accurate.

Pore-water samples will also be collected from the 10, 25 and 50 foot depth lysimeters in both the west and east halves of the basin on a daily basis for analysis of bromide samples. Lysimeters will be sampled for a two week period, based on the time estimated for full vertical migration throughout the vadose zone).

The monitoring locations and schedule, presented in Table 4-4, were based on the estimated arrival time determined from groundwater modeling. The monitoring schedule includes daily to every-other-day monitoring during the first month, semi-weekly monitoring during months 2, 3, and 4, and monthly monitoring thereafter for 1 year. However, if tracer detection is achieved in downgradient wells during the first six months and the arrival data is sufficiently complete so that the desired information about travel times can be concluded, the test will be determined to be successful and will be terminated.

4.3.2 Groundwater Tracer Sample Collection Methods

Groundwater tracer samples will be collected using low-flow sample collection procedures. The Standard Operating Procedure (SOP) for groundwater sample collection is provided in Appendix D.

Bromide samples will be collected into 125 milliliter (mL) plastic bottles with no preservative and placed on ice. Hold time is 28 days, so samples will be delivered weekly to the laboratory (Eurofins Eaton Analytical (EEA) in Monrovia, California). Field measurements of bromide at each monitoring well will also be measured using a YSI TruLab 1320 benchtop meter with a TruLine Bromide Laboratory Electrode Kit to obtain a screening-level determination of bromide concentrations and to field-estimate tracer arrival time at the same time a water sample is collected.

Sulfur hexafluoride samples will be collected into pre-weighed 10 mL vacutainers without preservative. The vaccutainers are capped with a rubber septum and have a vacuum inside the container. The sample collection tubing is a T sampling line fitted with an 18 gage needle. The needle is plunged into the rubber septum without allowing air to enter the vessel, and sample enters the vessel until filled. After the vaccutainer is filled half way (5 mL) the vaccutainer is pulled off the needle; this methods prevents the sample from being exposed to air. Samples will be placed on ice and delivered to USCB. There is no hold time for sulfur hexafluoride because it is biologically inert and does not degrade in water, however, samples will be analyzed within 14 days of receipt of sample.

Collected samples will follow a standard naming procedure:

- Wells owned by LOTT: MW-xx (where xx is the ID number of the well)
- Wells owned by the City of Lacey: Lacey MW-xx
- Wells owned by Thurston County Landfill: TC Landfill MW-xx
- Lysimeters owned by LOTT: Lys-x-yy (where x is East or West for location and yy is depth)
- Reclaimed Water at Basin 4: Reclaimed Water Basin 4

4.3.3 Laboratory Analytical Procedures for Tracer Water Samples

Bromide samples will be analyzed by EEA using ion chromatography EPA Method 300.0. The method detection limit is 5 µg/L and there is a 28 day hold time. Samples will be kept on ice without preservative. Sample collection is in a 125 mL plastic bottle. The cost of the analysis is $25/sample.

The sulfur hexafluoride samples will be analyzed by staff at UCSB under the direction of Dr. Clark using the Wanninkhof et al. (1987) head space method modified by Clark et al. (2004). Vacutainer samples will be weighed (to determine the sample size) and carefully filled with ultra-high purity nitrogen gas (so that the final pressure is equal to ~1 atmosphere). After a brief shaking to equilibrate the nitrogen gas with the water sample, the head space gas will be injected through a column of $Mg(ClO_4)_2$ (to remove water vapor) into a small sample loop of known volume (about 1.4 mL). Subsequently, the gas in the sample loop will be flushed into a gas chromatograph equipped with an electron capture detector with ultra-high purity nitrogen carrier gas. SF_6 will be separated from other gases with a Molecular Sieve 5a column held at room temperature. The detector response will be calibrated about every 30 minutes with gas standards (~148.1 parts per trillion (ppt), ~524 ppt, ~1947 ppt) certified by Scott-Marrin, Inc. One duplicate and one control sample (a sample of known concentration) will be run for each batch to provide quality control. Error on duplicate measurements is typically less than ±10 percent. Laboratory experiments have shown that sulfur hexafluoride samples can be stored for at least 6 months without an appreciable loss compound in a Vacutainer. The cost of the analysis is $25/sample.

4.4 Analysis of Laboratory and Field Data

The analytical and field tracer delivery volume, time, and concentration data will be recorded daily on field forms during the tracer delivery period. These data will be compiled into graphs showing the recorded data.

During the groundwater monitoring period, field determinations of bromide concentrations will be input into field forms. Tracer detections of bromide and sulfur hexafluoride at monitoring wells will be compiled into tables showing detected concentrations and into graphs of concentration over time. These graphs are commonly known as “breakthrough curves.” The breakthrough curves will be examined on a weekly basis for the first two months and on a bimonthly basis for the remainder of the project to determine how effective the monitoring program is at detecting tracer arrival and whether the monitoring frequency and schedule requires adjustment.

The breakthrough curves will be analyzed to determine center of mass, peak arrival, and 15, 50, and 85 percent breakthrough. Travel time and velocity will be calculated from the breakthrough curves using the center of mass. Effective porosity and dispersivity will be calculated from the percentage arrival time at the breakthrough curves using center of mass and 15, 50, and 85 percent arrival concentrations. Hydraulic conductivity cannot be directly determined from the breakthrough curves but it can be qualitatively evaluated for reasonableness. The methods utilized to perform this analysis will be based on the procedures described in Kass (1998) and Payne et al. (2008). Groundwater elevation contours will be developed on a quarterly frequency. Figures will be prepared that overlay collected groundwater elevation contours with tracer testing flow paths and travel times.

4.5 Tracer Test Report

A technical memorandum report will be developed that presents an introduction of the task, an explanation of the field and laboratory procedures, and a presentation and discussion of the results. Tables, figures and graphs will be used to aid in the presentation of the results. Raw data will be presented in tabular form in appendices.

Table 4-1. Model Simulated Time of Travel from Basin 4 to Downgradient Locations Assuming 7 Days of Tracer Delivery into Basin 4 at a Delivery Concentration of 20 mg/L.

			Downgradient Arrival Time (days)						
			Travel Distance						
	Percent of Maximum Arrival Concentration		*250 feet*	*500 feet*	*1000 feet*	*1500 feet*	*2000 feet*	*2500 feet*	*3000 feet*
Summary All Model Runs	15	Minimum	6	13	29	43	58	72	86
		Average	8	23	50	74	99	123	147
		Maximum	12	35	76	112	149	184	219
	50	Minimum	10	20	39	56	73	90	107
		Average	17	35	67	97	126	154	182
		Maximum	26	53	103	146	189	231	272
	100	Minimum	24	37	61	84	104	128	146
		Average	40	64	106	143	180	215	248
		Maximum	62	96	162	217	268	321	365

Table 4-2. Model Simulated Bromide Downgradient Concentrations Assuming 7 Days of Tracer Delivery into Basin 4 at a Concentration of 20 mg/L.

		Downgradient Travel Distance (feet)						
		250 ft	500 ft	1000 ft	1500 ft	2000 ft	2500 ft	3000 ft
Percentage of Maximum Arrival Concentration		Concentration (mg/L)						
15	Minimum	0.62	0.45	0.30	0.23	0.19	0.16	0.14
	Average	0.71	0.51	0.35	0.27	0.23	0.19	0.17
	Maximum	0.80	0.58	0.40	0.31	0.26	0.23	0.20
50	Minimum	2.07	1.50	1.01	0.77	0.64	0.54	0.47
	Average	2.36	1.72	1.18	0.91	0.76	0.65	0.57
	Maximum	2.68	1.93	1.34	1.05	0.88	0.76	0.67
100	Minimum	4.15	2.99	2.03	1.55	1.28	1.09	0.94
	Average	4.72	3.43	2.36	1.82	1.51	1.30	1.13
	Maximum	5.36	3.87	2.69	2.09	1.76	1.52	1.34

Table 4-3. Estimated Potassium Bromide Mass, Concentrations and Flow Rates Required for Tracer Test at 1 mgd Reclaimed Water Recharge Flow Rates

Recharge Rate		Desired Concentration of Bromide Tracer Going Into Recharge Basin	Mass of KBr Solute Needed (67% of Solid is Bromide, 33% Potassium)				Volume of Water Per Day in Portable Solute Tank (gallons)	Volume of Water Per Day in Portable Solute Tank (liters)	Concentration of KBr in Portable Tank (mg/L)	Daily Flow of Water Out of Tank (gpm)
gallons per day	liters per day	mg/L	mg/day	kg/day	kg/7 days	# of 25 kg sacks/7 days				
1,000,000	3,790,000	25	141,417,910	141	990	40	1500	5685	16,667	1.0

Table 4-4. Tracer Testing Groundwater Monitoring Frequency

Flow Direction and Travel Distance (feet)	Estimated Travel Time from GW Modeling, Average All Scenarios (days)			Monitoring Wells and Lysimeters Within Travel Distance (feet)	Tracer Monitoring Frequency											
	15% Max. Arrival Conc.	50% Max. Arrival Conc.	100% Max. Arrival Conc.		Background	Week 1	Week 2	Week 3	Week 4	Month 2	Month 3	Month 4	Month 5	Month 6	3rd Quarter *(Optional if Needed)*	4th Quarter *(Optional if Needed)*
Shallow (Qva) Aquifer																
Upgradient	NA	NA	NA	MW-26	Once	None	None	None	None	None	None	None	None	None	None	None
Cross-Gradient	NA	NA	NA	MW-24	Once	1 Per Week	1 Per Week	1 Per Week	1 Per Week	Monthly	Monthly	Monthly	Monthly	Monthly	Monthly	Monthly
At Basin 4	NA	NA	~1-7	East and West Lysimeters 10, 25 and 50 ft depth	Once	Daily[1]	Daily[1]	None	None	None	None	None	None	None	None	None
At Basin 4	NA	NA	~<7	MW-1, 2, 15, 16	Once	Every Other Day[1]	Every Other Day[1]	Every Other Day[1]	1 Per Week[1]	2 Per Month[1]	2 Per Month[1]	2 Per Month[1]	Monthly[1]	Monthly[1]	Monthly[1]	None
Downgradient: 250 ft	9	17	41	MW-3a, 5	Once	Every Other Day	Every Other Day	Every Other Day	1 Per Week	2 Per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	None
Downgradient: 500 ft	22	35	64	MW-6, 7, 8, 9	Once	Every Other Day	Every Other Day	Every Other Day	1 Per Week	2 Per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	None
Downgradient 1,000 ft	48	68	104	MW-11, 12, 13, 27	Once	1 Per Week	1 Per Week	1 Per Week	1 Per Week	2 Per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	Monthly
Downgradient: 1,500 ft	73	97	143	MW-20, 25	Once	1 Per Week	1 Per Week	1 Per Week	1 Per Week	2 Per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	Monthly
Downgradient: 2,000 ft	95	126	177	MW-28	Once	1 Per Week	None	1 Per Week	1 Per Week	2 Per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	Monthly
Downgradient: 2,500 ft	121	154	212	Lacey MW-11, Landfill MW-10S	Once	1 Per Week	None	1 Per Week	1 Per Week	2 Per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	Monthly
Downgradient: 3,500 ft	148	183	246	MW-22, Landfill MW-1	Once	1 Per Week	None	1 Per Week	1 Per Week	2 Per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	Monthly
Sea Level (Qc) Aquifer																
At Basins	Unknown	Unknown	Unknown	MW-14	Once	1 Per Week	1 Per Week	Every Other Day	1 Per Week	2 Per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	Monthly
Upgradient	Unknown	Unknown	Unknown	MW-12	Once	1 Per Week	1 Per Week	1 Per Week	1 Per Week	2 Per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	Monthly
Downgradient	Unknown	Unknown	Unknown	MW-23	Once	1 Per Week	1 Per Week	1 Per Week	1 Per Week	2 Per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	Monthly
Downgradient	Unknown	Unknown	Unknown	MW-21	Once	1 Per Week	None	1 Per Week	1 Per Week	2 per Month	2 Per Month	2 Per Month	Monthly	Monthly	Monthly	Monthly

Note:

1. Lysimeters and monitoring wells MW-1, 2, 15 and 16 will only be sampled for bromide, all other monitoring wells will be sampled for both bromide and sulfur hexafluoride.

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5.0 Groundwater and Vadose Zone Water Quality Monitoring

Groundwater and vadose zone water quality samples will be collected periodically and analyzed for water quality parameters during 2018. The purpose of this water quality monitoring is to determine the effectiveness of soil aquifer treatment in attenuating residual chemicals, and to assess the concentrations of nutrients, total organic carbon and other constituents as the residual chemicals travel through the vadose zone and groundwater. Prior studies have shown that with proper operational criteria (wetting/drying cycles, maintenance of basin soils) surface infiltration of highly treated reclaimed water through the vadose zone and aquifer provides significant attenuation and degradation of organic compounds and a reduction of organic matter and nutrients (Naranaswamy et al. 2001; Abushon and Fox 2005; IEUA 2008; Quanrud 2008; Racuh-Williams et al. 2010; Hoppe-Jones et al. 2010; Laws et al. 2011; Regnery et al. 2016). Monitoring will extend over a full year to evaluate the seasonal changes in water observed in the vadose zone and in groundwater and to evaluate the effects of changing organic compound inflow concentrations and types of compounds in reclaimed water over multiple periods in the year.

The proposed groundwater and vadose zone water quality monitoring will provide valuable information on the water quality associated with a functioning reclaimed water aquifer recharge facility in the type of climate present in the Pacific Northwest (cool wet winters, dry hot summers) and with the types of glacial soils present at the Hawks Prairie property. This will provide a point of comparison to other studies of reclaimed water aquifer recharge facilities which mostly are in hot and arid climates with alluvial soils. The effects of the concentration of organic carbon, biodegradable organic carbon, nutrient and oxygenation of the reclaimed water on vadose zone and groundwater will also be evaluated and will provide valuable information on the function of reclaimed water recharge facilities and their effects on water quality.

5.1 Sample Locations, Schedule, Sampling Procedure, Analytical Parameters

This section describes the locations, schedule, procedures and analytical parameters that will be performed for the collected reclaimed water, vadose-zone pore-water, and groundwater samples. Table 5-1 provides a summary of the overall sampling strategy, and Tables 5-2 and 5-3 describe the analytical parameters that will be tested for during monthly and quarterly monitoring events, respectively. Table 5-4 provides a summary of the analytical methods, sample containers and preservatives to be used, and hold times.

Samples will be collected for water quality parameters from the reclaimed water entering the recharge basin, vadose zone, and groundwater. Water quality monitoring is proposed to be conducted quarterly for residual chemicals and other reclaimed water parameters of interest, and monthly (during non-quarter events) for indicator parameters (nitrogen species, ortho-phosphorous, chloride, total organic carbon, biodegradable organic carbon). The reason for collecting the more rigorous suite of organic compounds on quarterly events is that the cost to run samples on a monthly basis is high, and because spacing out the analysis over four quarterly events provides information on seasonal variability. The reason for collecting nutrient, chloride and organic carbon samples during monthly events is to evaluate the performance of soil aquifer treatment at attenuating nutrients and determining the influence of biodegradable carbon on performance. Field parameters will be collected including water level, temperature, conductivity, pH, dissolved oxygen and bromide concentration during sampling. Samples will be submitted to EEA for laboratory analysis.

Collected samples will follow a standard naming procedure:

- Wells owned by LOTT: MW-xx (where xx is the ID number of the well)
- Wells owned by the City of Lacey: Lacey MW-xx
- Wells owned by Thurston County Landfill: TC Landfill MW-xx
- Lysimeters owned by LOTT: Lys-x-yy (where x is East or West for location and yy is depth)
- Reclaimed Water at Basin 4: Reclaimed Water Basin 4

5.1.1 Reclaimed Water

Samples of reclaimed water will be collected to determine the types and concentrations of constituents entering the recharge basins. Two samples will be collected during each monitoring event with at least 24 hours between each sample. The reclaimed water sample analytical parameters for monthly and quarterly sampling are identified in Table 5-2 and Table 5-3. The samples will be grab samples from the water entering the recharge basin using the procedures described in Appendix D.

5.1.2 Vadose Zone

Vadose zone samples will be collected from the three lysimeter sets installed in each of the east and west sides of Basin 4 at depths of 10, 25 and 50 feet. The vadose zone pore-water sample analytical parameters for monthly and quarterly sampling are identified in Table 5-2 and Table 5-3. Vadose zone monitoring procedures are described in Appendix D.

5.1.3 Groundwater

Groundwater samples will be collected from the following twelve monitoring wells. All of these wells are completed in the Shallow (Qva) Aquifer, except for MW-14, which is completed in the Sea Level (Qc) Aquifer.

- Upgradient samples: MW-26
- Basin 4 samples: MW-15, MW-16
- Downgradient samples on Hawks Prairie property: MW-3a, MW-5, MW-8, MW-9, MW-11, and MW-14
- Downgradient samples off Hawks Prairie property: MW-27, MW-20, MW-25

The groundwater sample analytical parameters for monthly and quarterly sampling are identified in Table 5-2 and Table 5-3. Groundwater monitoring procedures are described in Appendix D.

5.2 Field and Laboratory Quality Control Samples

The overall quality assurance/quality control (QA/QC) objective for this investigation is to ensure that all laboratory and field data upon which decisions are based are technically sound, statistically valid, and properly documented. There are two parts to the QA/QC program for this effort: field and laboratory.

Field QA/QC samples will consist of the following items:

- One field duplicate sample will be collected for each analyte per sampling event (quarterly and monthly).
- A trip blank will not be submitted. Instead, the laboratory will run a method blank for the batch.

The laboratory QA/QC samples will consist of the following items (for water chemical analysis):

- Laboratory control sample, method blank, surrogates, matrix spike, matrix spike duplicate.

5.3 Analysis of Laboratory and Field Data

The water quality monitoring data will be validated and then compiled into summary tables. Graphs and tables will be developed to examine key components of the analytical data. Of particular interest is the change in water quality over the flow path and the relationship between nutrients, organic carbon, bioavailable organic carbon and trace organic compounds. The relationship between travel time and concentrations of compounds will be examined to assist in determining attenuation over time. The information collected during the tracer test will be used to assist in travel time determinations. Graphs, figures and tables will be developed that highlight and explain the data.

5.4 Report

A technical memorandum report will be developed that presents an introduction of the task, an explanation of the field and laboratory procedures, and a presentation and discussion of the results. Tables, figures and graphs will be used to aid in the presentation of the results. Raw data will be presented in tabular form in appendices.

Table 5-1. Water Quality Monitoring Program.

Water Quality Monitoring Frequency	Water Quality Monitoring Location		
	Reclaimed Water Entering Recharge Basin	Vadose Zone Soil Pore-Water (Lysimeters)	Groundwater Monitoring Wells
Monthly and quarterly monitoring for one year.	• Monthly monitoring for Table 5-2 water quality parameters during non-quarter periods (8 events). Two samples collected per event (16 samples). • Quarterly monitoring for Table 5-3 water quality parameters (4 events). Two samples will be collected during each event to more fully characterize reclaimed water inflow (8 samples total).	• Monthly monitoring for Table 5-2 water quality parameters during non-quarter periods (8 events). One sample collected from each of six lysimeters (48 samples total). • Quarterly monitoring for Table 5-3 water quality parameters (4 events), 1 sample from each of six lysimeters (24 samples total).	• Monthly monitoring for Table 5-2 water quality parameters during non-quarter periods (8 events), 1 sample from 12 monitoring wells (96 samples total). • Quarterly monitoring for Table 5-3 water quality parameters (4 events), 1 sample from 12 monitoring wells (48 samples total).

Notes:

1. Field monitoring will be completed during all sampling events. Groundwater and reclaimed water sampling will include field measurements of depth to water, conductivity, temperature, pH, oxidation-reduction potential, and dissolved oxygen. Vadose zone sampling will include field measurements of conductivity and pH.
2. Monitoring instruments will be used in the recharge test basin to record depth of water, conductivity and temperature on an hourly basis.

Table 5-2. Monthly (during non-quarter months) reclaimed water, vadose zone pore-water, and groundwater quality monitoring analytical parameters.

Parameter	Method
TKN, nitrate, nitrite, ammonia	EPA 300. 351.1, 351.2
Total organic carbon	SM 5310C
Ortho-phosphorous	SM4500P-E
Biodegradable organic carbon [1]	Allegier, 1996
Chloride	EPA 300.

Notes:

1. Only reclaimed water samples will be analyzed for biodegradable organic carbon.

Table 5-3. Quarterly reclaimed water, vadose-zone pore-water, and groundwater quality monitoring analytical parameters.

Parameter	Method
Residual Chemicals, including metformin and thiabendazole	EEA's PPCP LC/MS/MS Method (See PPCP list and method description in Appendix A)
1,4-Dioxane and NDMA	EPA 521/522
PFOS/PFOA + Other PFCs	LC- MS-M S
HAA5	SM 6251B
THMs/VOCs	EPA 525.2
TKN, nitrate, nitrite, ammonia	EPA 300. 351.1, 351.2
Total phosphorous, ortho-phosphorous	EPA 365.1&365.2, SM4500P-E
Total organic carbon	SM 5310C
Biodegradable organic carbon	Allegier, 1996
Chloride	EPA 300.0
Sulfate	EPA 300
Total dissolved solids	SM 2540C
Alkalinity/carbonate	SM2320B
Total coliform	SM 9223
Metals (Ag, As, Ca, Cd, Cr, Cu, Fe, Hg, Pb, Mg, Mn, Na, Pb, Ni, Se, Si, Zn)	EPA 200 series

Table 5-4. Parameters and Methods for Groundwater, Vadose-Zone Pore-water and Reclaimed Water Quality Monitoring.

Parameter	Method	Sample Bottles & Preservative	Field Filtration	Hold Time Extraction	Hold Time Analysis	Units
Residual Chemicals, including metformin and thiabendazole.	EEA's PPCP LC/MS/MS Method	2 40 mL amber glass vial –sodium omadine & ascorbic acid	No	----	28	Days
Trihalomethanes/VOCs	EPA 524.2	3 40 mL amber glass vials – ascorbic acid - add HCL in field or 3 x 40 ml amber glass plus HCl	No	----	14	Days
HAA5	SM 6251B	3 40 mL amber glass vials – ammonium chloride	No	14	14	Days
PFOS/PFOA + Other PFCs	LC- MS-MS	1 x 250 mL poly - Trizma buffer	No	14	14	Days
NDMA	EPA 521	3 500 mL amber glass bottles – sodium thiosulfate	No	14	28	Days
1,4-Dioxane	EPA 522	3 125 mL amber glass bottles – sulfite and bisulfite	No	28	28	Days
TKN, ammonia	EPA 300. 351.1, 351.2	1 250 mL poly bottle – H_2SO_4	No	----	28	Days
Nitrate, nitrite,	EPA 300.0, 353.2	1 125 mL poly bottle – no preservative	No	----	48	Hours
Total phosphorous,	SM4500P-E	1 250 mL poly- H_2SO_4	Yes	----	28	Days
Ortho-phosphorous	SM4500P-E	1 125 mL poly- no preservative	Yes		48	Hours
Total organic carbon	SM 5310C	1 125 mL amber glass –H_2SO_4	No	----	28	Days
Biodegradable organic carbon	Allegier, 1996	2 250 mL amber glass - thiosulfate	No	48	NA	Hours
Total coliform	SM 9223	1 100 mL poly bottle – thio	No	----	24	Hours

Parameter	Method	Sample Bottles & Preservative	Field Filtration	Hold Time Extraction	Hold Time Analysis	Units
Metals (Ag, As, Ca, Cd, Cr, Cu, Fe, Hg, Pb, Mg, Mn, Na, Pb, Ni, Se, Si, Zn)	EPA 200 series	1 250 mL acid poly bottle – with HNO_3	Yes	----	6	Months
Sulfate, chloride	EPA 300	1 125 mL poly – no preservative	No	----	28	Days
Total dissolved solids	EPA SM2540C	1 500 mL poly bottle – no preservative	No	----	7	Days

6.0 Data Management, Laboratory Data Validation

6.1 Data Management

HDR will maintain program data in its Olympia, Washington, office. These data include:

- Work plans
- Field sampling forms and notebooks
- Daily reports
- Chain-of-custody records
- Laboratory reports (data and QA/QC information)
- Data validation records
- Reports.

All paper records will be scanned weekly and placed in electronic form in the HDR electronic Projectwise File System which is backed up by tape drive daily. Electronic data will be downloaded onto a laptop computer and placed into the electronic filing system. Paper records will be maintained until the conclusion of the project. The project directory is hosted on a secure server with regular onsite and offsite backup and archive procedures. Laboratory data and reports are also maintained by EEA.

6.2 Laboratory Data Validation Process

The laboratory data package will be downloaded and reviewed for completeness at the end of each quarterly event. At the conclusion of the quarterly monitoring, a laboratory data validation review will be completed to confirm accuracy and completeness for these items: sample identification, chain-of-custody and sample receiving, preservation methods, hold and extraction times, laboratory detection limits, surrogate recovery, blanks, spikes, duplicates, control samples, matrix spike, and duplicate.

7.0 Project Team Roles and Responsibilities

The project team and their roles/responsibilities are shown below.

Name and Contact	Organization	Role	Responsibility
Wendy Steffensen WendySteffensen@lottcleanwater.org (360) 528-5773	LOTT	Environmental Project Manager	Overall LOTT project manager and facilitator.
John Damitio JohnDamitio@lottcleanwater.org (360) 791-3174	LOTT		Contact for LOTT water lab, receive samples
Meghan Feuk meghanfeuk@lottcleanwater.org (253) 882-9737	LOTT		Contact for LOTT water lab, receive samples
Jeff Hansen, PE jhansen@hdrinc.com (360) 970-9752	HDR	Project Manager	Ensuring that project maintains schedule, budget and quality control.
John Koreny, PG, PHG jkoreny@hdrinc.com (206) 391-8559	HDR	Technical Lead	Responsible for directing staff and resources to complete work and providing technical review.
Adam Kessler, PG akessler@hdric.com (763) 202-6356	HDR	Project Hydrogeologist	Senior hydrogeologist responsible for sampling, data collection, management and analysis.
Kim Hawkins khawkins@hdrinc.com (303) 803-7884	HDR	Project Scientist	Senior field scientist assisting with project coordination and analysis.
Chad Hearn Chad.Hearn@hdrinc.com (828) 279-8313	HDR	Project Scientist	Senior field scientist responsible for sampling, data collection, management and analysis.
Ida Fischer Ifischer@hdrinc.com (206)249-6354	HDR	Staff Hydrologist	Staff hydrogeologist responsible for sampling, data collection and analysis.
Dan Graves dgraves@hdrinc.com (512) 828-9158	HDR	Staff Scientist	Staff scientist assisting with sampling, data collection and analysis.

Name and Contact	Organization	Role	Responsibility
Michael Murray, PhD mmurray@hdrinc.com (208) 387-7033	HDR	Quality Control Officer	Provides quality control/quality assurance reviews, comments and oversight.
Jordan Clark jfclark@geol.ucsb.edu (805) 893-7838	University of California, Santa Barbara	Technical Expert	Provides expert review and guidance on tracer testing.
Peter Fox, PhD Peter.Fox@asu.edu (480) 965-1734	Arizona State University	Technical Expert	Provides expert review and guidance on water quality, reclaimed water and soil aquifer treatment.

8.0 Schedule

The schedule for the tasks described in this work plan is described below.

Description	Dec. 2017	Jan 2018	Feb 2018	Mar 2018	Apr 2018	June 2018	Jul. 2018	Aug. 2018	Sept. 2018	Oct. 2018	Nov. 2018	Dec. 2018	1st Qtr. 2019
Setup and start Reclaimed Water into Basin 4	🟦	🟦											
Tracer Test Setup and Delivery to Basin 4 (January15, 22 and 29 Weeks)		🟦											
Tracer Test Monitoring (Examine Results Weekly to Bi-Monthly, Determine if Tracer Test Can be Stopped After 6 Months)		🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩 **Optional Period to Extend Tracer Test If Needed**	🟩	🟩	
Water Quality Monitoring (Quarterly and Monthly Events) and Viral Transport Study		🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Data Compilation and Analysis							🟦					🟦	🟦
Reports													🟦

9.0 References

Anders, R., W. Yanko, R. Schroeder, J. Jackson (2004). Virus Fate and Transport During Recharge Using Recycled Water at a Research Field Site in the Montebello Forebay, Lost Angeles County, 1997-2000. *USGS Scientific Investigations Report 2004-5161*. U.S. Geological Survey, Sacramento, California.

Avisar, D. and J. F. Clark (2005). Evaluating travel times beneath an artificial recharge pond using sulfur hexafluoride. *Environmental and Engineering Geoscience*, 11, 309-317.

Betancourt, W., M. Kitajima, A. Wing, J. Regnery, J. Drewes, I. Oeoer, C. Gerba. (2014). Assessment of virus removal by managed aquifer recharge at three full-scale operations. *Journal of Environmental Science and Health*, 49, 1685-1692.

Brown and Caldwell (2004). *Hawks Prairie Reclaimed Water Satellite, Final Groundwater Flow Modeling Results*. Prepared for LOTT Wastewater Alliance, Olympia, Washington.

Clark, J.F. (2009). *Brooks Street Basin Tracer Experiment Chino Groundwater Basin, California, Final Report*. Prepared for Inland Empire Utilities District. By J.F. Clark, Department of Earth Science, University of California, Santa Barbara.

Clark, J. F., G. B. Hudson, M. L. Davisson, G. Woodside, and R. Herndon (2004). Geochemical imaging of flow near an artificial recharge facility, Orange County, CA. *Groundwater*, 42, 167-174.

Clark, J. F., G. B. Hudson, and D. Avisar (2005). Gas transport below artificial recharge ponds: Insights from dissolved noble gases and a dual gas (SF6 and 3He) tracer experiment. *Environmental Science and Technology*, 39, 3939-3945.

Davis, S.N., G.M. Thompson, H.W. Bentley and G. Stiles (1980). Groundwater Tracers: a short review. *Groundwater*, 18: 14-23.

Davis, S.N., D.J. Campbell, H.W. Bentley and T.J. Flynn (1985). *Ground Water Tracers*. National Water Well Association (Now National Ground Water Association), Worthington, Ohio.

Deborde, D., W. Woessner, Q. Kley, P. Ball (1999). Rapid transport of virus in a floodplain aquifer. *Water Research*, 33 (10): 2229-2238.

Domenico, P.A. and F.W. Schwartz (1990). *Physical and Chemical Hydrogeology*. John Wiley and Sons, New York.

Drost, B., D. Ely and W. Lum (1999). Conceptual Model and Numerical Simulation of the Ground-water Flow System in the Unconsolidated Sediments of Thurston County, Washington. *U.S. Geological Survey Water Resources Investigations Report*, 99-4165.

Drost, B., G. Turney, N, Dion and M. Jones (1998). Hydrology and Quality of Groundwater in Northern Thurston County, Washington, *Water Resources Investigation Report 92-4109*. U.S. Geological Survey, Tacoma, Washington.

Fetter, C. W. (2001). *Applied Hydrogeology. Fourth Edition*. Prentice Hall. Page 75.

Fram, M. S., B. A. Bergamaschi, K. D. Goodwin, R. Fujii, and J. F. Clark (2003). Processes affecting the trihalomethane concentrations associated with the third injection, storage, and recovery test at Lancaster, Antelope Valley, California, March 1998 through April 1999. *Water-Resources Investigations Report 03-4062*, 72 p.

Gamlin, J. D., J. F. Clark, G. Woodside, and R. Herndon (2001). Tracing groundwater flow patterns in an area of artificial recharge using sulfur hexafluoride. *Journal of Environmental Engineering*, ASCE. 127, 171-174.

Geber, C., D. Powelson, M. Yahya, L. Wilson, G. Amy (1991). Fate of viruses during soil aquifer treatment designed for wastewater reclamation and reuse. *Water Science and Technology* 24. 95-102.

Golder Associates, Inc. (2011). *City of Lacey Wellhead Protection Report for the Water System Plan Update 2011*. Submitted to Carollo Engineers, Inc.

Lester, D. and L. A. Greenberg (1950). The toxicity of sulfur hexafluoride. *Arch. Ind. Hyd. Occup. Med.*, 2, 348-349.

HDR (2017a). *Hydrogeologic Characterization Report, On-site Wells and Lysimeter Installation (Task 2.1.1.a) Off-Site Monitoring Wells (Task 2.1.2.c), Hawks Prairie Area*. Prepared for LOTT Clean Water Alliance, Olympia, Washington.

HDR (2017b). *Reclaimed Water Infiltration Study Task 1.1 Groundwater Quality Characterization*. February 7, 2017. Prepared for LOTT Clean Water Alliance, Olympia, Washington.

HDR (2017c). *Wastewater and Reclaimed Water Quality Characterization (Task 1.3), LOTT Clean Water Alliance Reclaimed Water Infiltration Study*, Technical Memorandum, February 7, 2017. Prepared for LOTT Clean Water Alliance, Olympia, Washington.

HDR (2014). *Reclaimed Water Infiltration Study Startup Water Quality Monitoring Report Hawks Prairie Reclaimed Water Ponds and Recharge Basins*, November 20, 2014. Prepared for LOTT Clean Water Alliance, Olympia, Washington.

Hoppe-Jones, C., Oldham, G., Drewes, J.E. (2010). Attenuation of Total Organic Carbon and Unregulated Trace Organic Chemicals in U.S. Riverbank Filtration Systems. *Water Research*, 44, 4643-4659.

Inland Empire Utilities Agency (2008). *Chino Basin Recycled Water Groundwater Recharge Program*, Start-up Period Report for Turner Basin.

Inland Empire Utilities Agency (2003). Ely Basin No. 3 Lysimeter Installation and Sampling, Draft Work Plan.

Istok, J. and M. Humphrey (1995). Laboratory Investigation of Buoyance-Induced Flow (Plume Sinking) During Two Well Tracer Tests. *Groundwater* 33(4): 597-604.

Kass, W. (1998). *Tracing Technique in Geohydrology*. CRC Press, New York.

Landau Associates, Inc. (2016). Monitoring Well Installation and Testing, City of Lacey, Lacey, Washington, Project No. 1524001.010.015. Prepared for City of Lacey.

Laws, B.V., Dickenson, E.R.V., Johnson, T.A., Snyder, S.A., Drewes, J.E. (2011). Attenuation of contaminants of emerging concern during surface-spreading aquifer recharge. *Science of the Total Environment*, 409, 1087–1094.

Lee, W., J. Clark, M. Abbaszadegan, P. Fox, H. Ryu, J. Koreny, and G. Carpenter(2008). Selection and Testing of Tracers for Measuring Travel Times in Groundwater Aquifers Augmented with Reclaimed Water. WateReuse Foundation.

Logan, R.L., T. Walsh, B. Stanton; I. Sarikhan (2009), Geologic map of the Maytown 7.5-minute quadrangle, Thurston County, Washington, Geologic Map GM-72. Washington Division of Geology and Earth Resources, Olympia, Washington.

Logan, R., T. Walsh, H. Schasse, and M. Polenz (2003). Geologic Map of the Lacey 7.5-minute Quadrangle, Thurston County, Open File Report 2003-9. Washington Division of Geology and Earth Resources, Olympia, Washington

McDermott, J. A., D. Avisar, T. Johnson, and J. F. Clark (submitted) Groundwater travel times near spreading ponds: Inferences from geochemical and physical approaches. Submitted to: Journal of Hydrologic Engineering, ASCE.Brown and Caldwell. 2009. LOTT Hawks Prairie Groundwater Modeling Update. Prepared for LOTT Alliance. Prepared for LOTT Wastewater Alliance, Olympia, Washington.

Naranaswamy, K., Fox, P., and J. E. Drewes. (2001) Water Quality Transformations during Soil Aquifer Treatment at the Mesa Northwest Water Reclamation Plant, USA, *Water Science and Technology*, 43(10): 343-350.

Noble, J.B., and E.F. Wallace. (1966). Geology and Groundwater Resources of Thurston County, Washington, vol. 2: Washington Division of Water Resources. Water-Supply Bulletin No. 10.

Northwest Land and Water, Inc.(2008). *Hawks Prairie Area Hydrogeology Characterization Report*. Prepared for City of Lacey, Washington.

Pacific Groundwater Group (2002). *City of Lacey Hydrogeologic Summary and Wellhead Protection Assessment Report*. Prepared for City of Lacey, Washington.

Pang, L. (2009). Microbial removal rates in subsurface media estimated from published studies of field experiments and large soil cores. *Journal of Environmental Quality*. 38: 1531-1559.

Payne, F., J. Quinnan, S. Potter. (1998). *Remediation Hydraulics*. CRC Press, Boca Rotan, Florida.

Quanrud, D., Zhang, J., Tomanek, M., Dong, H., Arnold, R., Ela, W., Sáez, E. (2008). Fate of Polybrominated Diphenyl Ethers, Nonylphenol and Estrogenic Activity during the Managed Infiltration of Wastewater Effluent. *Journal of Environmental Engineering*. 134(6):433-442.

Rauch-Williams, T., Hoppe-Jones, C. Drewes J.E. (2010) The role of organic matter in the removal of emerging trace organic chemicals during managed aquifer recharge. *Water Research 44*(2)449-460

Regnery, J., Wing, A., Barringer, J., Drewes, J. (2016). Introducing sequential managed aquifer recharge technology (SMART)- From laboratory to full-scale application. Chemosphere 154(2016): 8-16.

Robinson & Noble, Inc. (2002). Technical Memorandum 18763.400, *LOTT Wastewater Alliance, Monitor Well Drilling and Construction at Groundwater Recharge Basin A*. Prepared for LOTT Wastewater Alliance, Olympia, Washington.

Robinson & Noble, Inc. (2000). Technical Memorandum 200F H.P. Area, *LOTT Wastewater Resource Management Plan, Hydrogeologic Investigation of the Finley and Corners Properties*. Prepared for LOTT Wastewater Alliance, Olympia, Washington.

Walsh T., R. Logan, M. Polenz and H. Schasse. (2003). Geologic Map of the Nisqually 7.5-minute Quadrangle, Thurston County, Open File Report 2003-10. Washington Division of Geology and Earth Resources, Olympia, Washington.

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Appendix A – Monitoring Well Construction Information and Groundwater Level Data

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Table A-1. Monitoring Well Construction Details

Well ID	Location	Date Constructed	Depth Drilled (feet bgs)	Type	Screen Interval (feet bgs)	Screen Construction	Northing[1] (feet)	Easting[1] (feet)	Top of Casing Elevation (NAVD 88) (feet)	Screened Geologic Unit[2]
MW-1	On-site, near basins	12/7/2001	155	Flush	87-97	4-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,684	1,076,316	219.46	Qva
MW-2	On-site, near basins	12/8/2001	125	Flush	97-107	4-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,770	1,076,140	218.27	Qva
MW-3	On-site, near basins	12/10/2001	135	Stick-up	117-127	4-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,566	1,075,924	218.15	Qf
MW-3a	On-site, near basins	12/17/2013	127	Stick-up	77-127	2-in. dia. Sch. 40 PVC w/ 0.010-in. factory slot	642,566	1,075,924	219.17	Qva, Qf
MW-5	On-site, near basins	12/12/2001	124	Flush	76-96	4-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,379	1,076,096	219.09	Qva
MW-6	On-site, near basins	6/29/2005	115	Flush	83-103	4-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	643,157	1,076,201	218.97	Qva
MW-7	On-site, near basins	5/19/2005	145	Flush	100-120	4-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,881	1,075,959	218.91	Qva, Qf
MW-8	On-site, near basins	6/23/2005	138	Flush	105-125	4-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,506	1,075,400	218.70	Qva, Qf

Well ID	Location	Date Constructed	Depth Drilled (feet bgs)	Type	Screen Interval (feet bgs)	Screen Construction	Northing[1] (feet)	Easting[1] (feet)	Top of Casing Elevation (NAVD 88) (feet)	Screened Geologic Unit[2]
MW-9	On-site, near basins	5/23/2005	135	Flush	89-109	4-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,394	1,075,575	218.69	Qva
MW-10	On-site, near basins	6/16/2005	140	Stickup	112-132	4-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	643,502	1,074,903	224.89	Qva, Qf
MW-11	On-site, near basins	11/18/2011	160	Stick-up	150-160	4-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,391	1,074,897	228.00	Qva, Qf
MW-12	On-site, west side	6/13/2017	340	Flush	284.7-304.7	2.5-in. dia. Sch. 80 PVC w/ 0.020-in. factory slot	642,690	1,074,893	227.00	Qc
MW-13	On-site, west side	6/15/2017	150	Flush	118.7-148.7	2-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,684	1,074,897	226.80	Qva
MW-14	On-site, near basins	7/5/2017	390	Flush	310-330	2.5-in. dia. Sch. 80 PVC w/ 0.020-in. factory slot	642,641	1,075,991	218.04	Qc
MW-15	On-site, near basins	8/2/2017	100	Stick-up	75-95	4-in. dia. Sch. 80 PVC w/ 0.040-in. factory slot	642,742	1,076,002	219.20	Qva
MW-16	On-site, near basins	8/4/2017	100	Stick-up	74.5-94.5	4-in. dia. Sch. 80 PVC w/ 0.040-in. factory slot	642,738	1,076,203	219.34	Qva

Well ID	Location	Date Constructed	Depth Drilled (feet bgs)	Type	Screen Interval (feet bgs)	Screen Construction	Northing[1] (feet)	Easting[1] (feet)	Top of Casing Elevation (NAVD 88) (feet)	Screened Geologic Unit[2]
MW-20	Off-site, southwest	1/13/2017	225	Flush	120-150	2-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	641,507	1,074,874	219.22	Qva
MW-21	Off-site, southwest	7/19/2017	310	Flush	220-240	2.5-in. dia. Sch. 80 PVC w/ 0.020-in. factory slot	641,077	1,073,574	227.16	Qc
MW-22	Off-site, southwest	7/21/2017	142	Flush	110-140	2-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	641,051	1,073,575	227.23	Qva
MW-23	Off-site, east	7/17/2017	320	Flush	259.8-289.8	2.5-in. dia. Sch. 80 PVC w/ 0.020-in. factory slot	643,061	1,077,296	204.54	Qc
MW-24	Off-site, east	7/28/2017	90	Flush	65-90	2-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	643,021	1,077,296	204.90	Qva
MW-25	Off-site, south	7/20/2017	190	Flush	118-168	2-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	641,496	1,075,647	228.95	Qva
MW-26	Off-site, northeast	7/26/2017	150	Flush	75-105	2-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	644,799	1,077,568	233.18	Qva
MW-27	Off-site, south	7/28/2017	150	Flush	95-120	2-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,077	1,075,465	220.16	Qva

Well ID	Location	Date Constructed	Depth Drilled (feet bgs)	Type	Screen Interval (feet bgs)	Screen Construction	Northing[1] (feet)	Easting[1] (feet)	Top of Casing Elevation (NAVD 88) (feet)	Screened Geologic Unit[2]
MW-28	Off-site, southwest	8/5/2017	170	Flush	130-170	2.5-in. dia. Sch. 80 PVC w/ 0.020-in. factory slot	641,129	1,074,790	224.85	Qva
Lacey MW-11	Off-site, west	12/2/2015	140	Flush	119.3-129.3	2-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	642,533	1,073,816	232.12	Qva
Landfill MW-1	Off-site, south	NA	200	Stick-up	140-200	Unknown	639,545	1,076,077	220.58	Qva, Qc
Landfill MW-10S	Off-site, southeast	2/1/1989	137	Stick-up	125-135	2-in. dia. Sch. 40 PVC w/ 0.020-in. factory slot	640,758	1,077,542	228.09	Qf

Notes:

[1] Northing and Easting are given in the projected coordinate system NAD 1983 Washington State Plane South

[2] Qva = Shallow (Qva) Aquifer, Qf = Upper Confining Unit (Kitsap Formation), Qc = Sea Level (Qc) Aquifer.

Table A-2. Groundwater Level Measurements

Groundwater Level Measurements, Upper (Qva/Qvr) Aquifer											
Well Name	Top of Casing Elevation (NAVD88) (feet)	Screen Interval (feet bgs)	July 2017			August 2017			September 2017		
			Measurement Date	Depth to Groundwater (feet btoc)	Groundwater Elevation (NAVD88) (feet)	Measurement Date	Depth to Groundwater (feet btoc)	Groundwater Elevation (NAVD88) (feet)	Measurement Date	Depth to Groundwater (feet btoc)	Groundwater Elevation (NAVD88) (feet)
LOTT Hawks Prairie MW-1	219.46	87-97	7/24/2017	83.30	136.16	8/15/2017	84.78	134.68	9/12/2017	86.83	132.63
LOTT Hawks Prairie MW-2	218.27	97-107	7/24/2017	81.20	137.07	8/15/2017	82.68	135.59	9/12/2017	84.72	133.55
LOTT Hawks Prairie MW-3	218.15	117-127	7/24/2017	89.00	129.15	8/15/2017	89.74	128.41			
LOTT Hawks Prairie MW-3a	219.17	77-127	7/24/2017	88.95	130.22	8/16/2017	89.73	129.44	9/12/2017	91.4	127.77
LOTT Hawks Prairie Mw-5	219.09	76-96	7/24/2017	79.20	139.89	8/15/2017	82.31	136.78	9/12/2017	84.98	134.11
LOTT Hawks Prairie MW-6	218.97	83-103	7/24/2017	79.30	139.67	8/15/2017	81.02	137.95	9/12/2017	82.88	136.09
LOTT Hawks Prairie MW-7	218.91	100-120	7/24/2017	81.00	137.91	8/15/2017	82.58	136.33	9/12/2017	84.6	134.31
LOTT Hawks Prairie MW-8	218.70	105-125	7/24/2017	101.50	117.20	8/15/2017	102.67	116.03	9/12/2017	103.85	114.85
LOTT Hawks Prairie MW-9	218.69	89-109	7/24/2017	90.70	127.99	8/15/2017	91.53	127.16	9/12/2017	92.66	126.03
LOTT Hawks Prairie MW-10	224.89	112-132	7/25/2017	93.10	131.79	8/16/2017	94.59	130.3	9/12/2017	96.23	128.66
LOTT Hawks Prairie MW-11	228.00	150-160	7/25/2017	133.30	94.70	8/16/2017	134.92	93.08	9/12/2017	136.61	91.39
LOTT Hawks Prairie MW-13	226.80	118.7-148.7	7/25/2017	120.10	106.70	8/11/2017	121.48	105.32	9/12/2017	124.4	102.4
LOTT Hawks Prairie MW-15	219.20	75-95				8/18/2017	82.69	136.51	9/12/2017	83.76	135.44
LOTT Hawks Prairie MW-16	219.34	74.5-94.5				8/18/2017	82.09	137.25	9/12/2017	85.27	134.07
LOTT Hawks Prairie MW-20	219.22	120-150	7/31/217	124.81	94.41	8/11/2017	125.79	93.43	9/12/2017	125.52	93.7
LOTT Hawks Prairie MW-22	227.23	110-140	7/25/2017	135.20	92.03	8/15/2017	137.16	90.07	9/13/2017	dry	
LOTT Hawks Prairie MW-24	204.90	65-90				8/16/2017	62.11	142.79	9/13/2017	63.99	140.91
LOTT Hawks Prairie MW-25	228.95	118-168	7/24/2017	133.70	95.25	8/18/2017	135.34	93.61	9/14/2017	137.07	91.88
LOTT Hawks Prairie MW-26	233.18	75-105				8/11/2017	82.88	150.3	9/13/2017	80.38	152.8
LOTT Hawks Prairie MW-27	220.16	95-120				8/15/2017	97.2	122.96	9/13/2017	98.08	122.08
LOTT Hawks Prairie MW-28	224.85	130-170				8/18/2017	130.08	94.77	9/14/2017	132.7	92.15
Thurston Cty Landfill MW-1	220.58		7/25/2017	130.89	89.69						
Thurston Cty Landfill MW-9S	253.24	130-145	7/25/2017	130.65	122.59						
Thurston Cty Landfill MW-10S	228.09	125-135	7/25/2017	103.94	124.15						
Thurston Cty Landfill MW-11	225.07	90-105	7/25/2017	104.09	120.98						
Thurston Cty Landfill MW-12S	220.18	158-168	7/25/2017	120.50	99.68						
Thurston Cty Landfill MW-13S	213.97	110-120	7/25/2017	112.00	101.97						
Thurston Cty Landfill MW-14	226.35	222.9 (4)	7/25/2017	102.30	124.05						
Thurston Cty Landfill MW-15	226.41	222.74 (4)	7/25/2017	96.41	130.00						
Eagle Estates 722 (3)	198.30	141.75-153.75							9/13/2017	109.76	88.54
Hogum Bay 1224 (3)	251.34	-							9/13/2017	99.92	151.42
Lacey MW-11 (2)	232.12	119.3-129.3	7/26/2017	121.80		8/16/2017	122.03	110.09	9/13/2017	122.3	109.822
Lacey MW-12 (2)	181.52	71.5-81.5	6/22/2017	37.37							

Groundwater Level Measurements, Sea Level (Qc) Aquifer											
Well Name	**Top of Casing Elevation (NAVD88) (feet)**	**Screen Interval (feet bgs)**	**July 2017**			**August 2017**			**September 2017**		
			Measurement Date	**Depth to Groundwater (feet btoc)**	**Groundwater Elevation (NAVD88) (feet)**	**Measurement Date**	**Depth to Groundwater (feet btoc)**	**Groundwater Elevation (NAVD88) (feet)**	**Measurement Date**	**Depth to Groundwater (feet btoc)**	**Groundwater Elevation (NAVD88) (feet)**
Lacey S29 (Betti) (2)	230.62	294-394	7/31/2017	148.40	82.22						
Hill-Betti Well	234.20	-									
Thurston Cty Landfill MW-6R	227.87	224.34 (4)	7/25/2017	192.55	35.32						
Thurston Cty Landfill MW-9D	252.53	248-258	7/25/2017	222.92	29.61						
Thurston Cty Landfill MW-10D	227.51	253-258	7/25/2017	188.67	38.84						
Thurston Cty Landfill MW-12D	220.18	238-248	7/25/2017	164.97	55.21						
Thurston Cty Landfill MW-13D	214.04	218-228	7/25/2017	181.78	32.26						
LOTT Hawks Prairie MW-12	227.00	284.7-304.7	7/25/2017	135.10	91.90	8/11/2017	136.27	90.73	9/12/2017	138.22	88.78
LOTT Hawks Prairie MW-14	218.04	310-330	7/25/2017	155.50	62.54	8/9/2017	156.45	61.59	9/13/2017	156.99	61.05
LOTT Hawks Prairie MW-21	227.16	220-240	7/25/2017	135.50	91.66	8/15/2017	137.37	89.79	9/13/2017	139.81	87.35
LOTT Hawks Prairie MW-23	204.54	259.8-289.8	7/24/2017	151.20	53.34	8/10/2017	151.16	53.38	9/13/2017	152.02	52.52

Notes:
[1] Elevation datum is NAVD88 (feet).
[2] City of Lacey well top of casing elevation is reported as NGVD 29 datum and has been converted to NAVD 88 datum.
[3] Eagle Estates 722 and Hogum Bay 1224 top of casing vertical datum is unconfirmed.
[4] Screened interval is not available; total depth of the well is given.

Appendix B – Tracer Chemical Information

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Sulfur Hexafluoride SF_6

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Transportation Information **UN Number:** 1080	🇺🇸	🇨🇦	🇲🇽
Shipping Name	Sulfur Hexafluoride	Sulfur Hexafluoride	Sulfur Hexafluoride
Hazard Class	2.2	2.2	2.2
Label	Nonflammable Gas	Nonflammable Gas	Nonflammable Gas

(M)SDS Reference
P-4657

CAS Number
2551 - 62 - 4

General Description
Colorless, odorless, nonflammable liquefied gas.

Product/Grade	**Purity**	**Part Number**	**Cylinder**	**$O_2 + N_2$**	**H_2O**	**Acidity (HF)**	**CF_4**	**CO**	**CO_2**	**CH_4**
Semiconductor, 5.0	99.999%	SH 5.0SP	K, AS	6	2	0.3	5	0.5	0.5	0.1
Semiconductor, 4.5	99.995%	SH 4.5SP	K, AS	50	8	0.7	17	–	–	–
Dielectric[1], 3.0	99.9 wt%	SH 3.0	K	500 ppm/w	8	0.3 ppm/w	500 ppm/w	–	–	–
Semiconductor, 2.8	99.8%	SH 2.8SP	K	1500	8	–	350	–	–	–

Concentrations given are ppm by volume unless otherwise specified.
Maximum ppm unless otherwise noted.

[1] Meets ASTM D2472 standard specification for Sulfur Hexafluoride.

Cylinders

Cylinder Type	**Style**	**Size in (cm)**	**Connection CGA/DISS**	**Pressure psig (bar)**	**Volume lb (kg)**	**Gross Weight lb (kg)**
K	High Pressure Steel	51 x 9 (129.5 x 22.9)	590/716	320 (22)	115 (52.2)	250 (114)
AS	High Pressure Aluminum	48 x 8 (121.9 x 20.3)	590/716	320 (22)	70 (38.1)	120 (55)

Equipment Recommendations

Semiconductor, 5.0	Valve panels and 4000 series regulators
Semiconductor, 4.5	Valve panels and 4000 series regulators
Dielectric, 3.0	2000 series regulators
Semiconductor, 4.5	3000 series regulators

2012 Series – High Purity Economical Regulator for Non-Corrosive Service (see page E•256)

✻

Not for use in pneumatic retinopexy.

See Sections F and G for safety and technical information.

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Sulfur hexafluoride

Safety Data Sheet P-4657

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Date of issue: 01/01/1979 Revision date: 11/23/2016 Supersedes: 01/28/2015

SECTION: 1. Product and company identification

1.1. Product identifier

Product form : Substance
Name : Sulfur hexafluoride
CAS No : 2551-62-4
Formula : SF6

1.2. Relevant identified uses of the substance or mixture and uses advised against

Use of the substance/mixture : Industrial use. Use as directed.

1.3. Details of the supplier of the safety data sheet

Praxair, Inc.
10 Riverview Drive
Danbury, CT 06810-6268 - USA
T 1-800-772-9247 (1-800-PRAXAIR) - F 1-716-879-2146
www.praxair.com

1.4. Emergency telephone number

Emergency number : Onsite Emergency: 1-800-645-4633

CHEMTREC, 24hr/day 7days/week
— Within USA: 1-800-424-9300, Outside USA: 001-703-527-3887
(collect calls accepted, Contract 17729)

SECTION 2: Hazard identification

2.1. Classification of the substance or mixture

GHS-US classification

Liquefied gas H280

2.2. Label elements

GHS-US labeling

Hazard pictograms (GHS-US) :

GHS04

Signal word (GHS-US) : WARNING

Hazard statements (GHS-US) : H280 - CONTAINS GAS UNDER PRESSURE; MAY EXPLODE IF HEATED
OSHA-H01 - MAY DISPLACE OXYGEN AND CAUSE RAPID SUFFOCATION
CGA-HG01 - MAY CAUSE FROSTBITE

Precautionary statements (GHS-US) : P202 - Do not handle until all safety precautions have been read and understood
P262 - Do not get in eyes, on skin, or on clothing
P271+P403 - Use and store only outdoors or in a well-ventilated place
CGA-PG05 - Use a back flow preventive device in the piping
CGA-PG06 - Close valve after each use and when empty
CGA-PG02 - Protect from sunlight when ambient temperature exceeds 52°C (125°F)

2.3. Other hazards

Other hazards not contributing to the classification : Asphyxiant in high concentrations

Contact with liquid may cause cold burns/frostbite.

2.4. Unknown acute toxicity (GHS US)

No data available

SECTION 3: Composition/Information on ingredients

3.1. Substance

Name : Sulfur hexafluoride
CAS No : 2551-62-4

Name	Product identifier	%
Sulfur hexafluoride	(CAS No) 2551-62-4	99.5 - 100

3.2. Mixture

Not applicable

SECTION 4: First aid measures

4.1. Description of first aid measures

First-aid measures after inhalation : Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

First-aid measures after skin contact : In case of frostbite spray with water for at least 15 minutes. Apply a sterile dressing. Obtain medical assistance. The liquid may cause frostbite. For exposure to liquid, immediately warm frostbite area with warm water not to exceed 105°F (41°C). Water temperature should be tolerable to normal skin. Maintain skin warming for at least 15 minutes or until normal coloring and sensation have returned to the affected area. In case of massive exposure, remove clothing while showering with warm water. Seek medical evaluation and treatment as soon as possible.

First-aid measures after eye contact : Immediately flush eyes thoroughly with water for at least 15 minutes. Hold the eyelids open and away from the eyeballs to ensure that all surfaces are flushed thoroughly. Contact an ophthalmologist immediately.

First-aid measures after ingestion : Ingestion is not considered a potential route of exposure.

4.2. Most important symptoms and effects, both acute and delayed

No additional information available

4.3. Indication of any immediate medical attention and special treatment needed

None.

SECTION 5: Firefighting measures

5.1. Extinguishing media

Suitable extinguishing media : Use extinguishing media appropriate for surrounding fire.

5.2. Special hazards arising from the substance or mixture

Reactivity : No reactivity hazard other than the effects described in sub-sections below.

5.3. Advice for firefighters

Firefighting instructions : Evacuate all personnel from the danger area. Use self-contained breathing apparatus (SCBA) and protective clothing. Immediately cool containers with water from maximum distance. Stop flow of gas if safe to do so, while continuing cooling water spray. Remove ignition sources if safe to do so. Remove containers from area of fire if safe to do so. On-site fire brigades must comply with OSHA 29 CFR 1910.156 and applicable standards under 29 CFR 1910 Subpart L—Fire Protection.

Protection during firefighting : Compressed gas: asphyxiant. Suffocation hazard by lack of oxygen.

Special protective equipment for fire fighters : Use self-contained breathing apparatus. Standard protective clothing and equipment (Self Contained Breathing Apparatus) for fire fighters.

Specific methods : Use fire control measures appropriate for the surrounding fire. Exposure to fire and heat radiation may cause gas containers to rupture. Cool endangered containers with water spray jet from a protected position. Prevent water used in emergency cases from entering sewers and drainage systems

Stop flow of product if safe to do so

Use water spray or fog to knock down fire fumes if possible.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

General measures : Evacuate area. Ensure adequate air ventilation. Prevent from entering sewers, basements and workpits, or any place where its accumulation can be dangerous. Monitor concentration of released product. Try to stop release.

6.1.1. For non-emergency personnel

No additional information available

6.1.2. For emergency responders

No additional information available

6.2. Environmental precautions

Try to stop release. Prevent waste from contaminating the surrounding environment. Prevent soil and water pollution. Dispose of contents/container in accordance with local/regional/national/international regulations. Contact supplier for any special requirements.

6.3. Methods and material for containment and cleaning up

No additional information available

6.4. Reference to other sections

See also sections 8 and 13.

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Precautions for safe handling : Wear leather safety gloves and safety shoes when handling cylinders. Protect cylinders from physical damage; do not drag, roll, slide or drop. While moving cylinder, always keep in place removable valve cover. Never attempt to lift a cylinder by its cap; the cap is intended solely to protect the valve. When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders. Never insert an object (e.g, wrench, screwdriver, pry bar) into cap openings; doing so may damage the valve and cause a leak. Use an adjustable strap wrench to remove over-tight or rusted caps. Slowly open the valve. If the valve is hard to open, discontinue use and contact your supplier. Close the container valve after each use; keep closed even when empty. Never apply flame or localized heat directly to any part of the container. High temperatures may damage the container and could cause the pressure relief device to fail prematurely, venting the container contents. For other precautions in using this product, see section 16.

7.2. Conditions for safe storage, including any incompatibilities

Storage conditions : Store in a cool, well-ventilated place. Store and use with adequate ventilation. Store only where temperature will not exceed 125°F (52°C). Firmly secure containers upright to keep them from falling or being knocked over. Install valve protection cap, if provided, firmly in place by hand. Store full and empty containers separately. Use a first-in, first-out inventory system to prevent storing full containers for long periods

OTHER PRECAUTIONS FOR HANDLING, STORAGE, AND USE: When handling product under pressure, use piping and equipment adequately designed to withstand the pressures to be encountered. Never work on a pressurized system. Use a back flow preventive device in the piping. Gases can cause rapid suffocation because of oxygen deficiency; store and use with adequate ventilation. If a leak occurs, close the container valve and blow down the system in a safe and environmentally correct manner in compliance with all international, federal/national, state/provincial, and local laws; then repair the leak. Never place a container where it may become part of an electrical circuit.

7.3. Specific end use(s)

None.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

Sulfur hexafluoride (2551-62-4)		
ACGIH	ACGIH TLV-TWA (ppm)	1000 ppm
USA OSHA	OSHA PEL (TWA) (mg/m³)	6000 mg/m³

Sulfur hexafluoride (2551-62-4)		
USA OSHA	OSHA PEL (TWA) (ppm)	1000 ppm

Sulfur hexafluoride (2551-62-4)		
ACGIH	ACGIH TLV-TWA (ppm)	1000 ppm
USA OSHA	OSHA PEL (TWA) (mg/m³)	6000 mg/m³
USA OSHA	OSHA PEL (TWA) (ppm)	1000 ppm

8.2. Exposure controls

Appropriate engineering controls	: Oxygen detectors should be used when asphyxiating gases may be released. Consider work permit system e.g. for maintenance activities. Systems under pressure should be regularly checked for leakages. Provide adequate general and local exhaust ventilation. Ensure exposure is below occupational exposure limits (where available).
Hand protection	: Wear working gloves when handling gas containers.
Eye protection	: Wear safety glasses with side shields or goggles when transfilling or breaking transfer connections. Wear safety glasses with side shields.
Respiratory protection	: When workplace conditions warrant respirator use, follow a respiratory protection program that meets OSHA 29 CFR 1910.134, ANSI Z88.2, or MSHA 30 CFR 72.710 (where applicable). Use an air-supplied or air-purifying cartridge if the action level is exceeded. Ensure that the respirator has the appropriate protection factor for the exposure level. If cartridge type respirators are used, the cartridge must be appropriate for the chemical exposure. For emergencies or instances with unknown exposure levels, use a self-contained breathing apparatus (SCBA).
Thermal hazard protection	: Wear cold insulating gloves when transfilling or breaking transfer connections.
Environmental exposure controls	: Refer to local regulations for restriction of emissions to the atmosphere. See section 13 for specific methods for waste gas treatment.
Other information	: Wear safety shoes while handling containers. Wear leather safety gloves and safety shoes when handling cylinders.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Physical state	: Gas
Appearance	: Colorless gas.
Molecular mass	: 146 g/mol
Color	: Colorless.
Odor	: Irritating choking
Odor threshold	: No data available
pH	: Not applicable.
Relative evaporation rate (butyl acetate=1)	: No data available
Relative evaporation rate (ether=1)	: Not applicable.
Melting point	: -50.8 °C
Freezing point	: No data available
Boiling point	: -63.8 °C
Flash point	: Not applicable.
Critical temperature	: 45.5 °C
Auto-ignition temperature	: No data available
Decomposition temperature	: No data available
Flammability (solid, gas)	: No data available
Vapor pressure	: 23.07 bar (334.6 psia) (@20°C)
Critical pressure	: 37.6 bar (545.3 psia)
Relative vapor density at 20 °C	: No data available
Relative density	: 1.4
Relative density of saturated gas/air mixture	: 5.04

Density : 0.0061 g/cm^3 (at 20 °C)
Relative gas density : 5
Solubility : Water: 41 mg/l
Log Pow : 1.68
Log Kow : Not applicable.
Viscosity, kinematic : Not applicable.
Viscosity, dynamic : Not applicable.
Explosive properties : Not applicable.
Oxidizing properties : None.
Explosion limits : Non flammable.

9.2. Other information

Sublimation point : -63.9 °C
Gas group : Liquefied gas
Additional information : Gas/vapor heavier than air. May accumulate in confined spaces, particularly at or below ground level

SECTION 10: Stability and reactivity

10.1. Reactivity

No reactivity hazard other than the effects described in sub-sections below.

10.2. Chemical stability

Stable under normal conditions.

10.3. Possibility of hazardous reactions

May occur.

10.4. Conditions to avoid

Avoid temperature above 800°C (1472°F).

10.5. Incompatible materials

Explodes violently in contact with disilane.

10.6. Hazardous decomposition products

Under normal conditions of storage and use, hazardous decomposition products should not be produced. Thermal decomposition may produce : Fluorides. Sulfur dioxide.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity : Not classified

Skin corrosion/irritation : Not classified
pH: Not applicable.
Serious eye damage/irritation : Not classified
pH: Not applicable.
Respiratory or skin sensitization : Not classified
Germ cell mutagenicity : Not classified
Carcinogenicity : Not classified

Reproductive toxicity : Not classified
Specific target organ toxicity (single exposure) : Not classified
Specific target organ toxicity (repeated exposure) : Not classified
Aspiration hazard : Not classified

SECTION 12: Ecological information

12.1. Toxicity

Ecology - general : No ecological damage caused by this product.

12.2. Persistence and degradability

Sulfur hexafluoride (2551-62-4)	
Persistence and degradability	Not applicable for inorganic gases.

Sulfur hexafluoride (2551-62-4)	
Persistence and degradability	Not applicable for inorganic gases.

12.3. Bioaccumulative potential

Sulfur hexafluoride (2551-62-4)	
Log Pow	1.68
Log Kow	Not applicable.
Bioaccumulative potential	No data available.

Sulfur hexafluoride (2551-62-4)	
Log Pow	1.68
Bioaccumulative potential	No data available.

12.4. Mobility in soil

Sulfur hexafluoride (2551-62-4)	
Mobility in soil	No data available.
Ecology - soil	Because of its high volatility, the product is unlikely to cause ground or water pollution.

Sulfur hexafluoride (2551-62-4)	
Ecology - soil	Because of its high volatility, the product is unlikely to cause ground or water pollution.

12.5. Other adverse effects

Effect on ozone layer : None

Global warming potential [CO2=1] : 22200

Effect on the global warming : Contains Fluorinated greenhouse gases covered by the Kyoto protocol

SECTION 13: Disposal considerations

13.1. Waste treatment methods

Waste treatment methods : Do not discharge into any place where its accumulation could be dangerous. Avoid discharge to atmosphere.

Waste disposal recommendations : Dispose of contents/container in accordance with local/regional/national/international regulations. Contact supplier for any special requirements.

SECTION 14: Transport information

In accordance with DOT

Transport document description : UN1080 Sulfur hexafluoride, 2.2

UN-No.(DOT) : UN1080

Proper Shipping Name (DOT) : Sulfur hexafluoride

Class (DOT) : 2.2 - Class 2.2 - Non-flammable compressed gas 49 CFR 173.115

Hazard labels (DOT) : 2.2 - Non-flammable gas

Additional information

Emergency Response Guide (ERG) Number : 126

Other information : No supplementary information available.

Special transport precautions : Avoid transport on vehicles where the load space is not separated from the driver's compartment. Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency. Before transporting product containers: - Ensure there is adequate ventilation. - Ensure that containers are firmly secured. - Ensure cylinder valve is closed and not leaking. - Ensure valve outlet cap nut or plug (where provided) is correctly fitted. - Ensure valve protection device (where provided) is correctly fitted.

Transport by sea

UN-No. (IMDG) : 1080
Proper Shipping Name (IMDG) : SULPHUR HEXAFLUORIDE
Class (IMDG) : 2 - Gases
MFAG-No : 126

Air transport

UN-No. (IATA) : 1080
Proper Shipping Name (IATA) : Sulphur hexafluoride
Class (IATA) : 2
Civil Aeronautics Law : Gases under pressure/Gases nonflammable nontoxic under pressure

SECTION 15: Regulatory information

15.1. US Federal regulations

Sulfur hexafluoride (2551-62-4)	
Listed on the United States TSCA (Toxic Substances Control Act) inventory	
SARA Section 311/312 Hazard Classes	Immediate (acute) health hazard Sudden release of pressure hazard

15.2. International regulations

CANADA

Sulfur hexafluoride (2551-62-4)
Listed on the Canadian DSL (Domestic Substances List)

Sulfur hexafluoride (2551-62-4)
Listed on the Canadian DSL (Domestic Substances List)

EU-Regulations

Sulfur hexafluoride (2551-62-4)
Listed on the EEC inventory EINECS (European Inventory of Existing Commercial Chemical Substances)

15.2.2. National regulations

Sulfur hexafluoride (2551-62-4)
Listed on the AICS (Australian Inventory of Chemical Substances) Listed on IECSC (Inventory of Existing Chemical Substances Produced or Imported in China) Listed on the Japanese ENCS (Existing & New Chemical Substances) inventory Listed on the Korean ECL (Existing Chemicals List) Listed on NZIoC (New Zealand Inventory of Chemicals) Listed on PICCS (Philippines Inventory of Chemicals and Chemical Substances) Listed on the Canadian IDL (Ingredient Disclosure List) Listed on INSQ (Mexican National Inventory of Chemical Substances) Listed on CICR (Turkish Inventory and Control of Chemicals)

15.3. US State regulations

Sulfur hexafluoride(2551-62-4)	
U.S. - California - Proposition 65 - Carcinogens List	No

Sulfur hexafluoride(2551-62-4)	
U.S. - California - Proposition 65 - Developmental Toxicity	No
U.S. - California - Proposition 65 - Reproductive Toxicity - Female	No
U.S. - California - Proposition 65 - Reproductive Toxicity - Male	No
State or local regulations	U.S. - Massachusetts - Right To Know List U.S. - New Jersey - Right to Know Hazardous Substance List U.S. - Pennsylvania - RTK (Right to Know) List

Sulfur hexafluoride (2551-62-4)

U.S. - California - Proposition 65 - Carcinogens List	U.S. - California - Proposition 65 - Developmental Toxicity	U.S. - California - Proposition 65 - Reproductive Toxicity - Female	U.S. - California - Proposition 65 - Reproductive Toxicity - Male	Non-significant risk level (NSRL)
No	No	No	No	

Sulfur hexafluoride (2551-62-4)

U.S. - Massachusetts - Right To Know List
U.S. - New Jersey - Right to Know Hazardous Substance List
U.S. - Pennsylvania - RTK (Right to Know) List

SECTION 16: Other information

Other information : When you mix two or more chemicals, you can create additional, unexpected hazards. Obtain and evaluate the safety information for each component before you produce the mixture. Consult an industrial hygienist or other trained person when you evaluate the end product. Before using any plastics, confirm their compatibility with this product

Praxair asks users of this product to study this SDS and become aware of the product hazards and safety information. To promote safe use of this product, a user should (1) notify employees, agents, and contractors of the information in this SDS and of any other known product hazards and safety information, (2) furnish this information to each purchaser of the product, and (3) ask each purchaser to notify its employees and customers of the product hazards and safety information

The opinions expressed herein are those of qualified experts within Praxair, Inc. We believe that the information contained herein is current as of the date of this Safety Data Sheet. Since the use of this information and the conditions of use are not within the control of Praxair, Inc, it is the user's obligation to determine the conditions of safe use of the product

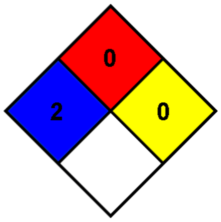
Praxair SDSs are furnished on sale or delivery by Praxair or the independent distributors and suppliers who package and sell our products. To obtain current SDSs for these products, contact your Praxair sales representative, local distributor, or supplier, or download from www.praxair.com. If you have questions regarding Praxair SDSs, would like the document number and date of the latest SDS, or would like the names of the Praxair suppliers in your area, phone or write the Praxair Call Center (Phone: 1-800-PRAXAIR/1-800-772-9247; Address: Praxair Call Center, Praxair, Inc, P.O. Box 44, Tonawanda, NY 14151-0044)

PRAXAIR and the Flowing Airstream design are trademarks or registered trademarks of Praxair Technology, Inc. in the United States and/or other countries.

NFPA health hazard : 2 - Intense or continued exposure could cause temporary incapacitation or possible residual injury unless prompt medical attention is given.

NFPA fire hazard : 0 - Materials that will not burn.

NFPA reactivity : 0 - Normally stable, even under fire exposure conditions, and are not reactive with water.



HMIS III Rating

Health : 1 Slight Hazard - Irritation or minor reversible injury possible
Flammability : 0 Minimal Hazard
Physical : 2 Moderate Hazard

SDS US (GHS HazCom 2012) - Praxair

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Sodium Bromide Powder

ICL Industrial
PRODUCTS

www.icl-ip.com

Chemical Name:	Sodium bromide
Formula:	NaBr
CAS Number:	7647-15-6
MW:	102.9

General & Use:

Sodium bromide is used as a completion, fracturing, workover, and packer fluid with density up to 12.5 lb/US gallon.

For health & safety matters please refer to the MSDS

Typical Analysis:

Appearance	white crystalline solid
Appearance of 25% Solution	clear colorless

	Min	**Max**
Assay (as NaBr) (%)	98	
Loss on Drying (%)		0.5
pH of a 5% aqueous solution	5.5	8.5
Chlorides (as Cl^-) (wt%)		1
Iodides (as I^-) %		0.01
Sulfates (as SO_4^{-2}) (Wt%)		0.03

Flammability and Explosivity:

Sodium bromide is non-flammable and non-explosive.

Toxicity:

LD_{50} (oral, rat): 4,200 mg/Kg
LD_{50} (dermal, rabbit): >2,000 mg/Kg
Sodium bromide is a mild irritant to the eyes and non-irritant to the intact skin.

Packaging:

1050 Kg net pallets each carrying 42 PE/PP bags of 25 Kg in shrink wrapping.

Storage and Handling:

Store in a dry, cool, well ventilated area. Keep containers tightly closed. Avoid bodily contact.

For more information Please Contact Us.

ICL Industrial
PRODUCTS

Sodium Bromide Powder

Studio rave-peleg

Visit our Website: www.icl-ip.com

For more information about our products and to place an order, please contact one of our regional sales offices.

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ICL-IP Israel Ltd.
E-mail: bip.info@icl-ip.com

North America
ICL-IP America INC
E-mail: bip.nam@icl-ip.com

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ICL Industrial
PRODUCTS
BROMINE COMPOUNDS LTD. | Shipping Department
P.O. Box 180 Beer Sheva 8410101 Israel | Tel +972-8-6297613 | Fax +972-8-6297847 | www.icl-ip.com

Dispatch No.: 187209022

16 December 2012

CERTIFICATE OF ANALYSIS

SODIUM BROMIDE COMPACTED
HERMANN
Shipment number: 118765
P.O. Number: 4600039044
Total Weight: 11,550.000 KG

Inspection Characteristics	**Batches>>>**	**710120310**
Appearance: .	white crystalline material	O.K.
Assay (as NaBr)	99.0 % min	99.66
Loss on drying	0.5 % max	0.010
Transmittance, 25% w/v 410 nm	93.0 % min	98.91
pH of solution, 25% w/v	4.5 - 7.5	7.50
Chlorides (as Cl^-)	0.2 % max	0.010
Iodides (as I^-)	60 ppm max	<60
Oxydizing substances (as $NaBrO_3$)	0.001% max	<0.001
Ammonia	15 ppm max	<15
Nitrite	1 ppm max	<1
Sulfide	60 ppb max	<60
Color (Pt-Co Scale)	15 max	<15
Haze NTU	1.5 max	<1.5
Mercury (Hg)	5 ppb max	<5
Iron (Fe)	600 ppb max	80
Bismuth (Bi)	100 ppb max	<100
Cadmium (Cd)	100 ppb max	<100
Cobalt (Co)	100 ppb max	<100
Chromium (Cr)	200 ppb max	<200
Copper (Cu)	100 ppb max	<100
Manganese (Mn)	100 ppb max	<100
Nickel (Ni)	200 ppb max	<200
Lead (Pb)	200 ppb max	<200
Tin (Sn)	150 ppb max	<150
Zinc (Zn)	200 ppb max	<200
Exp. Date (MM/YY)		11/14

Batch No. 710120310
Quantity 11 x 1,050.000 KG

LABORATORIES & INSPECTION DEPARTMENT -
Form:BCL000601/V1
DR. FAZA NAIM

Naim Faza

SAFETY DATA SHEET

According to OSHA Hazard Communication Standard 29 CFR 1910.1200 (GHS)

Product name	**Sodium Bromide**	
Product id	2270	
Revision date	23/04/2012	**Revision:** 7
Supersedes	21/04/2009	

---

1. Identification of the substance & the company

Chemical name	Sodium bromide
CAS number	7647-15-6
Chemical formula	NaBr
Chemical family	Inorganic bromide
Molecular weight	102.9
Type of product and use	For use in photographic emulsions and developing solutions Brominating agent

Supplier

ICL-IP America Inc.
95 MacCorkle Ave. SW, South Charleston, WV 25303-1411, USA
Tel: (304) 720-3950
Fax: (304) 746-3101

Emergency Telephone

Chemtrec: (800) 424-9300
Medical: PROSAR 1-888-875-1685 (24HRS)

2. Hazards identification

GHS classification	Not Classified
Labels and other form of warning	Not classified

3. Composition / information on ingredients

Components	CAS No.	Weight %
Sodium Bromide	7647-15-6	98-99.5

4. First-aid measures

Eye contact

Holding the eyelids apart, flush eyes promptly with copious flowing water for at least 20 minutes. Get medical attention immediately.

Skin contact	Remove contaminated clothing. Wash skin thoroughly with mild soap and plenty of water for at least 15 minutes. Wash clothing before reuse. Get medical attention if irritation occurs.
Inhalation	In case of dust inhalation or breathing fumes released from heated material, remove person to fresh air. Keep him quiet and warm. Apply artificial respiration if necessary and get medical attention immediately.
Ingestion	If swallowed, wash mouth thoroughly with plenty of water. Get medical attention immediately. -- NOTE: Never give an unconscious person anything to drink --

Most important symptoms and effects, acute or delayed

None known

Notes to the physician	No specific antidote. Treat symptomatically and supportively.

5. Fire - fighting measures

Suitable extinguishing media	Material is not combustible. Use extinguishing media appropriate to surrounding fire conditions.
Unusual fire and explosion hazards	Will decompose from ca. 800°C releasing poisonous and corrosive fumes of hydrogen bromide and sodium oxide.
Fire fighting procedure	Cool containers with water spray. In closed stores, provide fire-fighters with self-contained breathing apparatus in positive pressure mode.

6. Accidental release measures

Personal precautions	Use dust respirator, rubber gloves and chemical safety goggles
Methods for cleaning up	Sweep up, place in a bag and hold for waste disposal or possible reuse Ventilate area and wash spill site after material pickup is complete.
Environmental precautions	Avoid access to streams, lakes or ponds.

7. Handling and storage

Handling	Avoid bodily contact. Keep containers tightly closed.
Storage	Keep in a well-ventilated place away from incompatible materials (see "materials to avoid").

Product name	**Sodium Bromide**	
Product id	2270	
Revision date	23/04/2012	**Revision:** 7
Supersedes	21/04/2009	

8. Exposure controls / personal protection

Exposure Limits :

Components	ACGIH-TLV Data	OSHA (PEL) Data
Sodium Bromide 7647-15-6	Not determined	Not determined

Ventilation requirements	Provide adequate ventilation.
Personal protective equipment:	
- Respiratory protection	In case of significant or accidental dust emissions, dust mask should be worn
- Hand protection	Protective gloves
- Eye protection	Chemical safety goggles
- Skin and body protection	Body covering clothes and boots
Hygiene measures	Do not eat, smoke or drink where material is handled, processed or stored. Wash hands thoroughly after handling and before eating or smoking. Safety shower and eye bath should be provided.

9. Physical and chemical properties

Appearance	White granular powder or compacted solid, odourless
Melting point/range	755°C
Boiling point/range	1390°C
Flash point	None
Evaporation rate (ether=1)	Not applicable under standard conditions
Flammable/Explosion limits	Not flammable
Vapor pressure	1 mmHg (806°C)
Vapor density	Not applicable under standard conditions
Solubility:	
- Solubility in water	94.6 gr/100ml at 25°C
- Solubility in other solvents	ethanol: 95%: 7 g/100g at 25°C methanol: 14.8 g/100g at 25°C
Partition coefficient (n-octanol/water)	Not applicable since this material is almost completely soluble in water.
Auto-ignition temperature	Not applicable
Viscosity	Not applicable
Specific gravity	3.203
Explosive properties	Not explosive
Oxidising properties	Not oxidising

10. Stability and reactivity

Reactivity	Reacts explosively with bromine trifluoride .
Stability	Stable under normal conditions The powder product tends to cake under normal storage conditions.

Possibility of hazardous reactions	Not expected to occur
Conditions to avoid	Heating above decomposition temperature.
Materials to avoid	Strong acids. Heavy metal salts. Strong oxidants.
Hazardous decomposition products	Hydrogen bromide and sodium oxide Bromine fumes

11. Toxicological information

Likely Routes of Exposure	Skin Eye contact Inhalation Ingestion
Acute toxicity:	
- Rat oral LD50	4200 mg/kg
- Rabbit dermal LD50	>2000 mg/kg
- Rat dermal LD50	>2000 mg/kg
- Dermal irritation (rabbit)	Not irritant
- Eye irritation (rabbit)	Slightly irritant
Dermal sensitization	Not a sensitizer
Chronic toxicity	Repeated skin contact may cause dermatitis. Repeated oral intake of bromides (>9 mg/kg body weight/day) may affect the central nervous system. Warning symptoms include mental dullness, slurred speech, weakened memory, apathy, anorexia, constipation, drowsiness and loss of sensitivity to touch and pain.
Mutagenicity	Does not induce DNA repair in cultured human epithelioid cells. Not clastogenic in human lymphocytes metaphase analysis. Not mutagenic by the Ames Test.
Carcinogenicity	Not classified by IARC Not included in NTP 13th Report on Carcinogens
Reproductive toxicity	Sodium bromide has been shown to cause embryo-fetal toxicity and malformations in rats at dose levels which also produce maternal toxicity. The No-Observed Effect Level (NOEL) is 100 mg/kg/day, and the Acceptable Daily Intake (ADI) for sodium bromide from food and drinking water in humans is 1 mg/kg/day. Comparable high doses of sodium chloride (table salt) similarly cause malformations, embryo-fetal toxicity, and maternal toxicity in mice.

Teratogenicity	In the oral gavage pre-natal developmental toxicity study in the Rabbit, there were no obvious effects of maternal treatment on the survival, growth or development of the offspring at any of the dosages investigated. The No Observed Effect Level (NOEL) for the developing conceptus was considered to be 250 mg/kg/day.
Aspiration hazard	Not expected to occur

12. Ecological information

Environmental fate	NaBr is an inorganic salt, which fully dissociates in aquatic environment to bromide and sodium ions. It also undergoes degradation in soil to bromide ion (no further degradation or biodegradation will occur).
Aquatic toxicity :	
- 96 Hour-LC50, Fish	>1000 mg/l (rainbow trout) >1000 mg/l (bluegill sunfish)
- 48 Hour-EC50, Daphnia magna	>1000 mg/l
Avian toxicity:	
- Oral LD50, Bobwhite quail	>2250 mg/kg
- Dietary LC50, Mallard duck	>5633 ppm
- Dietary LC50, Bobwhite quail	>5633 ppm
Toxicity to micro-organisms	Activated sewage sludge respiration inhibition test: EC50 > 1000 mg/l (3 hours). NOEC was 1000 mg/l (3 hours)
Persistence and degradability	Not relevant for inorganic salts
Bioaccumulative potential	Not expected to bioaccumulate BCF=0.23-1.41
Mobility in soil	Not relevant for inorganic salts

13. Disposal considerations

Waste disposal	Observe all federal, state and local environmental regulations when disposing of this material.
Disposal of Packaging	Dispose of in a safe manner in accordance with local/national regulations.

14. Transportation information

DOT	Not regulated
IMDG	Not regulated
ICAO/IATA	Not regulated

15. Regulatory information

USA	Reported in the EPA TSCA Inventory.
Canada	Listed in DSL
-WHMIS hazard class	D2A Very toxic material causing other toxic effects
EU	Reported in EINECS
EC No.	231-599-9
Japan	ENCS no. 1-113 ISHL no. 1-113
Australia	Listed in AICS
China	
- China inventory	Listed in IECSC
Korea	Listed in ECL (KE-31368)
Philippines	Listed in PICCS

16. Other information

Note:
All sections reformatted in accordance with OSHA Hazard Communication Standard 29 CFR 1910.1200 (GHS)

Health, Safety & Environment Policy
We will strive to ensure that our operations and products meet the needs of the present global community without compromising the ability of future generations to meet their needs We accept that the success of our business is dependent on the supply of products and services that will benefit society whilst ensuring human safety and protection of the environment and natural resources Within the framework of our commitment to the Responsible Care program, we will provide a healthy and safe work environment for employees and will responsibly manage our products at all stages of their life cycle in order to protect human health and the environment whilst maintaining high production standards of operation

TO MEET THIS COMMITMENT WE WILL: Comply with or exceed applicable national and international regulatory requirements and other requirements to which we subscribe Communicate openly and actively encourage dialogue with employees, customers and community concerning our products and operations Implement documented management systems consistent with and for promotion of the Responsible Care ethics

Develop and supply products that can be manufactured, transported, used and disposed of safely whilst best meeting the needs of our customers Regularly assess, continually improve and responsibly manage health, safety and environmental risks associated with products and processes throughout their life-cycles Share knowledge and expertise with others and seek to learn from and incorporate improved practices into our own operations

Educate and train employees, contractors and customers to improve their HSE performance Communicate up-to-date information to enable our workers, customers and other interested parties to handle our products in a safe and environmentally responsible manner Endeavor to work with customers, suppliers, distributors and contractors to foster the safe use, transport and disposal of our chemicals Support Product Stewardship programs in cooperation with customers, distributors and transporters

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End of safety data sheet

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Potassium Bromide Powder

ICL Industrial
PRODUCTS

www.iclfr.com

Chemical name: Potassium Bromide Powder
Formula: KBr
CAS Number: 7758-02-3

General & Use:

Potassium Bromide is used in combination with Copper complexes as heat stabilizer in Polyamide compounds, where high thermal stability during the product›s life cycle is needed. The main applications of such heat stabilized polyamides are in automotive under-the-hood parts and specialty fibers. It is as well used in preparing photographic emulsions and developing solutions and in pharmaceutical preparations.

For health & safety matters please refer to MSDS

Typical Analysis:

Appearance	WHITE CRYSTALLINE POWDER
Appearance of 25% solution	CLEAR, COLORLESS

	Min	Max
Assay (as KBr) %	99.5	
Loss on Drying %		0.3
PSD		82%>0.4mm
pH of a 5% aqueous solution	6	7.5
pH of a 25% Solution	6	7.5
Chlorides (as Cl^-) wt %		0.1
Iodides (as I^-) %		0.01
Iron (as Fe_2O_3) ppm		2

Flammability and Explosivity:

Non flammable and non-explosive. When strongly heated, it may emit bromine fumes.

Toxicity:

LD_{50} (oral,rat): >5,000 mg/kg.
Potassium Bromide is an irritant to eyes.

Storage and Handling:

Store in a cool, dry, well ventilated area. Avoid inhalation, ingestion and contact with eyes and skin.

For more information Please Contact Us.

Packaging:

Available in bulk tank trucks, isocontainers, 2,800 lb totes, and 590 lb drums.

For more information Please Contact Us.

Studio rave-peleg

Visit our Website: www.icl-ip.com

3/2014

For more information about our products and to place an order, please contact one of our regional sales offices.

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E-mail: fr.row@icl-ip.com

SAFETY DATA SHEET

According to OSHA Hazard Communication Standard 29 CFR 1910.1200 (GHS)

Product name	**Potassium bromide**		
Product id	2160		
Revision date	02/11/2016	**Revision:**	10
Supersedes	09/12/2013		

---

1. Identification of the substance & the company

Chemical name	Potassium bromide
Chemical formula	KBr
Molecular weight	120.98
Type of product and use	For use in photographic emulsions and developing solutions Heat stabilizer in nylon Brominating agent
Supplier	ICL-IP America Inc. 622 Emerson Road - Suite 500 St Louis, Missouri 63141, USA Tel:(314)983-7884 Fax:(314)983-7607 e-mail:msdsinfo@icl-group.com
Emergency Telephone	Chemtrec: (800) 424-9300 Medical: PROSAR 1-888-875-1685 (24HRS)

2. Hazards identification

GHS classification	Eye Irrit. 2, H319 Causes serious eye irritation USA: Eye Irrit. 2A, Causes serious eye irritation

Labels and other form of warning

Symbol(s)

Signal Word	WARNING
Hazard statements	H319 - Causes serious eye irritation
Precautionary statements	P264 - Wash hands thoroughly after handling P280 - Wear protective gloves/protective clothing/eye protection/face protection P305 + P351 + P338 - IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing P337 + P313 - If eye irritation persists: Get medical advice/attention.

3. Composition / information on ingredients

Components	CAS No.	Weight %
Potassium bromide	7758-02-3	99.5

4. First-aid measures

Eye contact	Holding the eyelids apart, flush eyes promptly with copious flowing water for at least 20 minutes. Get medical attention immediately.
Skin contact	Remove contaminated clothing. Wash skin thoroughly with mild soap and plenty of water for at least 15 minutes. Wash clothing before reuse. Get medical attention if irritation occurs.
Inhalation	In case of dust inhalation or breathing fumes released from heated material, remove person to fresh air. Keep him quiet and warm. Apply artificial respiration if necessary and get medical attention immediately.
Ingestion	If swallowed, wash mouth thoroughly with plenty of water. Get medical attention immediately. -- NOTE: Never give an unconscious person anything to drink ---

Most important symptoms and effects, acute or delayed

- Ocular	Irritant
- Dermal	Not irritant to intact skin. Slightly irritant on prolonged contact to abraded skin.
- Inhalation	May cause irritation to mucous membranes and upper respiratory tract.
- Ingestion	Abdominal pain, nausea and vomiting. May cause falling asleep, muscular incoordination and respiratory depression.
Notes to the physician	No specific antidote. Treat symptomatically and supportively.

5. Fire - fighting measures

Suitable extinguishing media	Material is not combustible. Use extinguishing media appropriate to surrounding fire conditions.
Unusual fire and explosion hazards	Will decompose from ca. 800°C releasing poisonous and corrosive fumes of HBr.

Fire fighting procedure	Cool containers with water spray. In closed stores, provide fire-fighters with self-contained breathing apparatus in positive pressure mode.

6. Accidental release measures

Personal precautions	Wear respirator, chemical safety goggles, rubber gloves and boots.
Methods for cleaning up	Sweep up, place in a bag and hold for waste disposal or possible reuse. Avoid raising dust. Ventilate area and wash spill site after material pickup is complete.

7. Handling and storage

Handling	Avoid bodily contact. Keep containers tightly closed.
Storage	Hygroscopic. Avoid exposure to moisture. Store in a dry, cool, well-ventilated area away from incompatible materials (see "materials to avoid").

8. Exposure controls / personal protection

Exposure Limits :

Components	ACGIH-TLV Data	OSHA (PEL) Data
Potassium bromide 7758-02-3	Not determined	Not determined

Ventilation requirements	Mechanical exhaust required.

Personal protective equipment:

- Respiratory protection	Dust respirator
- Hand protection	Neoprene gloves
- Eye protection	Chemical safety goggles
- Skin and body protection	Body covering clothes and boots

Hygiene measures	Do not eat, smoke or drink where material is handled, processed or stored. Wash hands thoroughly after handling and before eating or smoking. Safety shower and eye bath should be provided.

9. Physical and chemical properties

Appearance	White, odourless, crystalline solid
Odor	None.
Odor threshold	Not determined
pH	Not determined
Melting point/range	734°C
Boiling point/range	1435°C
Flash point	Not applicable
Evaporation rate (ether=1)	Not applicable under standard conditions
Flammability (solid, gas)	Not determined

Flammable/Explosion limits	Not flammable
Vapor pressure	1 mmHg (795°C)
Vapor density	Not applicable under standard conditions
Density	Not determined
Solubility:	
- Solubility in water	65.5 g/100ml at 20°C 102 gr/100ml at 100°C
- Solubility in other solvents	Alcohol: 0.142 g/100g at 25°C
Partition coefficient (n-octanol/water)	Not applicable since this material is almost completely soluble in water.
Auto-ignition temperature	Not applicable
Decomposition temperature	> 800°C
Viscosity	Not applicable
Specific gravity	2.75
Particle size	Not determined

10. Stability and reactivity

Reactivity	Hygroscopic. Reacts explosively with bromine trifluoride .
Stability	Stable under normal conditions
Possibility of hazardous reactions	Reacts explosively with bromine trifluoride
Conditions to avoid	Exposure to moisture. Heating above decomposition temperature.
Materials to avoid	Strong oxidants. Strong acids. Heavy metal salts.
Hazardous decomposition products	HBr

11. Toxicological information

Likely Routes of Exposure	Eye contact Skin Ingestion Inhalation
Acute toxicity:	
- Rat oral LD50	> 2000 mg/kg
- Rabbit dermal LD50	>2000 mg/kg
- Dermal irritation (rabbit)	Not irritant
- Eye irritation (rabbit)	Irritant
Dermal sensitization	Not a skin sensitizer

Chronic toxicity	Repeated skin contact may cause dermatitis. Repeated oral intake of bromides (>9 mg/kg body weight/day) may affect the central nervous system. Warning symptoms include mental dullness, slurred speech, weakened memory, apathy, anorexia, constipation, drowsiness and loss of sensitivity to touch and pain.
Mutagenicity	Not mutagenic by the Ames Test.
Carcinogenicity	Not classified by IARC Not included in NTP 13th Report on Carcinogens
Reproductive toxicity	No data available for potassium bromide. Studies in rats fed high doses of sodium bromide showed a reversible reduction in fertility.
Specific Target Organ Toxicity (STOT) - Single exposure	No effects on specific target organs have been identified during acute toxicity studies
Specific Target Organ Toxicity (STOT) - Repeat exposure	The available data are not sufficient to address classification for repeated dose toxicity.
Aspiration hazard	Not expected to occur

12. Ecological information

Toxicity data of BROMIDE ION (tested as sodium bromide)

Aquatic toxicity :

- 96 Hour-LC50, Fish	> 1000 mg/kg
- 48 Hour-EC50, Daphnia magna	>100 mg/l
Avian toxicity:	
- Oral LD50, Bobwhite quail	>2500 mg/kg
- Dietary LC50, Bobwhite quail	6000 ppm
Persistence and degradability	KBr is an inorganic salt, which fully dissociatesin aquatic environment to bromide and potassium ions. It also undergoes degradation in soil to bromide ion (no further degradation or biodegradation will occur).
Bioaccumulative potential	Bioaccumulation is not likely to occur since this material is highly soluble in water.
Mobility in soil	Expected to be mobile because of high solubility.

13. Disposal considerations

Waste disposal	Observe all federal, state and local environmental regulations when disposing of this material
Disposal of Packaging	Empty containers should be disposed of in accordance with all applicable laws and regulations

14. Transportation information

DOT	Not regulated
IMDG	Not regulated
ICAO/IATA	Not regulated

15. Regulatory information

USA	Reported in the EPA TSCA Inventory.
- SARA 313	Not listed
Canada	Listed in DSL
WHMIS hazard class	D2B Toxic materials causing other toxic effects
EU	Reported in EINECS
Japan	ENCS no. 1-108 ISHL no. 1-108
Australia	Listed in AICS
New Zealand Inventory	Listed in NZIoC
China	
- China inventory	Listed in IECSC
Mexico	Listed in the National Inventory of Chemical Substances (INSQ).
Korea	Listed in ECL (KE-29079)
Taiwan	Listed
Philippines	Listed in PICCS

16. Other information

This data sheet contains changes from the previous version in section(s)
11, 12, 15

Health, Safety & Environment Policy
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TO MEET THIS COMMITMENT WE WILL: Comply with or exceed applicable national and international regulatory requirements and other requirements to which we subscribe Communicate openly and actively encourage dialogue with employees, customers and community concerning our products and operations Implement documented management systems consistent with and for promotion of the Responsible Care ethics

Develop and supply products that can be manufactured, transported, used and disposed of safely whilst best meeting the needs of our customers Regularly assess, continually improve and responsibly manage health, safety and environmental risks associated with products and processes throughout their life-cycles Share knowledge and expertise with others and seek to learn from and incorporate improved practices into our own operations

Educate and train employees, contractors and customers to improve their HSE performance Communicate up-to-date information to enable our workers, customers and other interested parties to handle our products in a safe and environmentally responsible manner Endeavor to work with customers, suppliers, distributors and contractors to foster the safe use, transport and disposal of our chemicals Support Product Stewardship programs in cooperation with customers, distributors and transporters

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Appendix C – Groundwater Modeling of Tracer Arrival Time and Concentration

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Techincal Memorandum

Date: Friday, October 27, 2017

(Updated January 5, 2018)

Project: LOTT Tracer Test Model Simulations

To: File

From: Richard Walther and John Koreny

Subject: Tracer Test Model Simulations

A simplified 1 layer groundwater flow and transport model was developed In order to better estimate the groundwater travel time within the shallow unconfined aquifer system and the concentrations arriving at monitoring wells of a conservative tracer (sodium bromide) applied to water recharged at Basin 4 of the LOTT Hawks Prairie Ponds and Recharge Basins property.

Methods

The model was created using MODFLOW2005 for groundwater flow and MT3D-USGS for transport of sodium bromide. The following parameters were based on observed conditions at the site and used in the design and build of the model:

- Model area: 5,000 x 5,000 feet.
- Rotation: 45 degrees (clockwise)
- Grid Cells: 50 ft x 50 ft (100 cells x 100 cells)
- Model Domain: 5,000 ft x 5,000 ft
- Layer 1 top (upgradient to downgradient): 205 ft to 90 ft
- Layer 1 bottom (upgradient to downgradient): 125 ft to 10 ft
- Upgradient Constant Head: 155 ft
- Downgradient Constant Head: 40 ft
- Saturated thickness (constant): 30 ft
- Distance between Constant Heads: 5,000 ft
- Hydraulic Groundwater Gradient = 0.023 ft/ft.

Model Periods

Two sets of scenarios were evaluated: 14 day and 7 day tracer injection. Each version of the model included set-up for a transient simulation using 2 stress periods. The first stress period length was 14 or 7 days and includes the recharge of 1 MGD of water over a 1 acre area (infiltration basin 4). The recharged water contained a concentration of 20 mg/L of sodium bromide. The second stress period was 351 days (for a total time of 365 days) and simulated no recharge. This set-up simulated a 14 or 7 day “pulse” of sodium bromide water, with a 351 day period for observation of the tracer downgradient. Simulated “observation wells” were placed downgradient of infiltration basin 4 at distances of 250 feet, 500 feet, 1,000 feet, 1,500 feet, 2,000 feet, 2,500 feet, and 3,000 feet to provide the velocity and concentration of sodium bromide over time at specific distances from the basin.

A total of eight model scenarios were completed for each scenario to simulate transport of sodium bromide under different aquifer flow and transport parameters.

The following transport parameters were held constant during the model simulations:

- Background concentration of sodium bromide = 0.025 mg/L based on the reported concentrations at the Hawks Prairie property and in the region (HDR, 2014, HDR, 2017)
- Dispersion values of 100/10/10 feet for longitudinal, transverse and transverse vertical, respectively.

The flow and transport parameters hydraulic conductivity, specific yield, and porosity were varied during model simulations to provide a range of estimates based on the heterogeneity of the shallow unconfined aquifer system. Table C-1 lists the model simulations performed and the values of hydraulic conductivity, specific yield, and porosity used.

Results

The modeling results are shown below in Table C-2 to C-4 and in graphs in Attachment A and B.

Update January 5, 2018

Two model runs were adjusted to reflect a recharge concentration of 25 mg/L, as opposed to the original concentration of 20 mg/L. This is in response to LOTT's decision to target 25 mg/L as the recharge concentration. Figures 17 and 18 contain these results.

Table C-1. Summary Table of Travel Time Simulation Scenarios

Scenario	Hydraulic Conductivity (feet/day)	Specific Yield	Porosity (percent)	Recharge Period (days)
Build 1	200	0.1	20	14
Build 2	100	0.1	20	14
Build 3	200	0.15	20	14
Build 4	100	0.15	20	14
Build 5	200	0.1	25	14
Build 6	100	0.1	25	14
Build 7	200	0.15	25	14
Build 8	100	0.15	25	14
Build 9	100	0.1	20	7
Build 10	200	0.1	20	7
Build 11	200	0.15	20	7
Build 12	100	0.15	20	7
Build 13	200	0.1	25	7
Build 14	100	0.1	25	7
Build 15	200	0.15	25	7
Build 16	100	0.15	25	7

Table C-2. Arrival Time for Distance Traveled for 14 Days Recharge

Scenario	Percentage of Maximum Arrival Concentration	Travel Distance						
		250 feet	500 feet	1000 feet	1500 feet	2000 feet	2500 feet	3000 feet
		Arrival Time (days)						
Build 1	15	7.3	14	19	30	59	52	87
	50	12.2	21	40	57	73	91	108
	100	25.7	38	62	84	105	126	147
Build 2	15	9	24	56	87	78	144	175
	50	17	39	78	113	146	179	214
	100	48	77	124	168	207	250	291
Build 3	15	7	15	32	48	62	78	90
	50	13	24	44	62	79	96	112
	100	26	40	64	85	105	126	148
Build 4	15	10	27	62	93	123	152	179
	50	19	44	86	123	158	190	223
	100	52	81	126	182	225	261	303
Build 5	15	8	16	35	52	70	88	107
	50	13	25	47	68	88	110	131
	100	33	45	72	96	121	151	177
Build 6	15	11	29	67	103	140	175	212
	50	21	47	92	135	177	218	262
	100	50	88	141	199	248	302	351
Build 7	15	8	18	38	57	75	93	110
	50	14	27	52	73	95	115	137
	100	32	49	80	109	132	159	186
Build 8	15	11	32	74	112	149	184	220
	50	23	52	101	146	189	231	273
	100	63	97	163	218	275	322	365

Table C-3. Concentration for Distance Traveled for 14 Days Recharge

		Travel Distance						
		250 feet	500 feet	1000 feet	1500 feet	2000 feet	2500 feet	3000 feet
Scenario	Percentage of Maximum Arrival Concentration	Concentration (mg/L)						
Build 1	15	1.39	1.05	0.73	0.57	0.48	0.41	0.36
	50	4.65	3.49	2.44	1.90	1.59	1.37	1.19
	100	9.30	6.99	4.88	3.80	3.17	2.73	2.39
Build 2	15	1.21	0.93	0.67	0.53	0.44	0.38	0.34
	50	4.05	3.11	2.22	1.75	1.47	1.28	1.12
	100	8.10	6.21	4.44	3.51	2.95	2.55	2.24
Build 3	15	1.35	1.03	0.73	0.58	0.49	0.43	0.38
	50	4.50	3.42	2.44	1.94	1.64	1.43	1.27
	100	9.00	6.85	4.89	3.88	3.28	2.86	2.53
Build 4	15	1.21	0.94	0.69	0.55	0.47	0.41	0.36
	50	4.02	3.13	2.28	1.83	1.56	1.37	1.22
	100	8.04	6.25	4.57	3.66	3.12	2.74	2.43
Build 5	15	1.20	0.88	0.60	0.46	0.38	0.33	0.28
	50	4.00	2.94	2.01	1.54	1.28	1.09	0.95
	100	8.00	5.87	4.01	3.09	2.55	2.18	1.89
Build 6	15	1.05	0.79	0.55	0.43	0.36	0.30	0.27
	50	3.49	2.62	1.83	1.42	1.18	1.02	0.88
	100	6.98	5.24	3.66	2.84	2.37	2.03	1.77
Build 7	15	1.16	0.86	0.60	0.47	0.39	0.34	0.30
	50	3.87	2.88	2.01	1.57	1.31	1.13	0.99
	100	7.75	5.77	4.02	3.14	2.63	2.27	1.99
Build 8	15	1.04	0.79	0.56	0.45	0.37	0.32	0.28
	50	3.47	2.64	1.88	1.48	1.25	1.08	0.95
	100	6.94	5.28	3.76	2.97	2.50	2.16	1.90

Table C-4. Summary Table of Arrival Times for Distance Traveled for 14 Days Recharge

			Travel Distance						
			250 feet	500 feet	1000 feet	1500 feet	2000 feet	2500 feet	3000 feet
	Percentage of Maximum Arrival Concentration		Arrival Time (days)						
All Scenarios	15	Minimum	7	14	19	30	59	52	87
		Average	9	22	48	73	95	121	148
		Maximum	11	32	74	112	149	184	220
	50	Minimum	12	21	40	57	73	91	108
		Average	17	35	68	97	126	154	183
		Maximum	23	52	101	146	189	231	273
	100	Minimum	26	38	62	84	105	126	147
		Average	41	64	104	143	177	212	246
		Maximum	63	97	163	218	275	322	365

Table C-5. Summary Table of Concentration for Distance Traveled for 14 Days Recharge

			Travel Distance						
			250 feet	500 feet	1000 feet	1500 feet	2000 feet	2500 feet	3000 feet
	Percentage of Maximum Arrival Concentration		Concentration (mg/L)						
Summary All Model Runs	15	Minimum	1.04	0.79	0.55	0.43	0.36	0.30	0.27
		Average	1.20	0.91	0.64	0.50	0.42	0.37	0.32
		Maximum	1.39	1.05	0.73	0.58	0.49	0.43	0.38
	50	Minimum	3.47	2.62	1.83	1.42	1.18	1.02	0.88
		Average	4.01	3.03	2.14	1.68	1.41	1.22	1.07
		Maximum	4.65	3.49	2.44	1.94	1.64	1.43	1.27
	100	Minimum	6.94	5.24	3.66	2.84	2.37	2.03	1.77
		Average	8.01	6.06	4.28	3.36	2.82	2.44	2.14
		Maximum	9.30	6.99	4.89	3.88	3.28	2.86	2.53

Table C-6. Arrival Time for Distance Traveled for 7 Days Recharge

Scenario	Percentage of Maximum Arrival Concentration	Travel Distance						
		250 feet	500 feet	1000 feet	1500 feet	2000 feet	2500 feet	3000 feet
		Arrival Time (days)						
Build 9	15	8	26	57	87	116	145	173
	50	19	40	78	113	147	180	215
	100	46	73	124	165	213	251	288
Build 10	15	6	13	29	43	58	72	86
	50	10	20	39	56	73	90	107
	100	24	37	61	84	104	128	146
Build 11	15	6	15	32	47	62	76	90
	50	12	23	43	61	78	95	111
	100	26	41	67	90	112	132	156
Build 12	15	9	30	64	95	124	152	180
	50	22	46	86	125	158	191	223
	100	50	85	137	182	226	265	306
Build 13	15	7	16	34	51	70	87	105
	50	12	23	46	67	88	108	131
	100	26	43	71	101	127	154	178
Build 14	15	11	31	68	103	139	174	211
	50	23	47	93	133	177	219	263
	100	53	87	145	199	253	305	358
Build 15	15	7	18	39	56	74	92	109
	50	13	26	51	73	94	115	136
	100	35	48	82	108	135	160	185
Build 16	15	12	35	76	112	149	184	219
	50	26	53	103	146	189	231	272
	100	62	96	162	217	268	321	365

Table C-7. Concentration for Distance Traveled for 7 Days Recharge

Scenario	Percentage of Maximum Arrival Concentration	Travel Distance						
		250 feet	500 feet	1000 feet	1500 feet	2000 feet	2500 feet	3000 feet
		Concentration (mg/L)						
Build 9	15	0.74	0.54	0.38	0.29	0.24	0.21	0.18
	50	2.46	1.81	1.25	0.97	0.80	0.69	0.60
	100	4.93	3.62	2.50	1.93	1.60	1.38	1.20
Build 10	15	0.80	0.58	0.39	0.30	0.25	0.21	0.19
	50	2.68	1.93	1.32	1.01	0.84	0.71	0.62
	100	5.36	3.87	2.63	2.02	1.67	1.43	1.24
Build 11	15	0.79	0.58	0.40	0.31	0.26	0.23	0.20
	50	2.63	1.93	1.34	1.05	0.88	0.76	0.67
	100	5.27	3.86	2.69	2.09	1.76	1.52	1.34
Build 12	15	0.74	0.55	0.39	0.31	0.26	0.22	0.20
	50	2.47	1.84	1.30	1.02	0.86	0.74	0.65
	100	4.95	3.68	2.60	2.04	1.71	1.49	1.31
Build 13	15	0.67	0.48	0.32	0.24	0.20	0.17	0.15
	50	2.25	1.60	1.07	0.81	0.67	0.56	0.49
	100	4.50	3.19	2.14	1.62	1.33	1.13	0.98
Build 14	15	0.62	0.45	0.30	0.23	0.19	0.16	0.14
	50	2.07	1.50	1.01	0.77	0.64	0.54	0.47
	100	4.15	2.99	2.03	1.55	1.28	1.09	0.94
Build 15	15	0.66	0.48	0.33	0.25	0.21	0.18	0.16
	50	2.21	1.60	1.09	0.84	0.70	0.60	0.52
	100	4.43	3.19	2.18	1.68	1.39	1.19	1.04
Build 16	15	0.63	0.46	0.32	0.24	0.20	0.17	0.15
	50	2.08	1.52	1.05	0.81	0.68	0.58	0.51
	100	4.17	3.05	2.10	1.63	1.35	1.16	1.01

Table C-8. Summary Table of Arrival Time for Distance Traveled for 7 Days Recharge

			Travel Distance						
			250 feet	500 feet	1000 feet	1500 feet	2000 feet	2500 feet	3000 feet
	Percentage of Maximum Arrival Concentration		Arrival Time (days)						
All Scenarios	15	Minimum	6	13	29	43	58	72	86
		Average	8	23	50	74	99	123	147
		Maximum	12	35	76	112	149	184	219
	50	Minimum	10	20	39	56	73	90	107
		Average	17	35	67	97	126	154	182
		Maximum	26	53	103	146	189	231	272
	100	Minimum	24	37	61	84	104	128	146
		Average	40	64	106	143	180	215	248
		Maximum	62	96	162	217	268	321	365

Table C-9. Summary Table of Concentration for Distance Traveled for 7 Days Recharge

			Travel Distance						
			250 feet	500 feet	1000 feet	1500 feet	2000 feet	2500 feet	3000 feet
	Percentage of Maximum Arrival Concentration		Concentration (mg/L)						
All Scenarios	15	Minimum	0.62	0.45	0.30	0.23	0.19	0.16	0.14
		Average	0.71	0.51	0.35	0.27	0.23	0.19	0.17
		Maximum	0.80	0.58	0.40	0.31	0.26	0.23	0.20
	50	Minimum	2.07	1.50	1.01	0.77	0.64	0.54	0.47
		Average	2.36	1.72	1.18	0.91	0.76	0.65	0.57
		Maximum	2.68	1.93	1.34	1.05	0.88	0.76	0.67
	100	Minimum	4.15	2.99	2.03	1.55	1.28	1.09	0.94
		Average	4.72	3.43	2.36	1.82	1.51	1.30	1.13
		Maximum	5.36	3.87	2.69	2.09	1.76	1.52	1.34

Attachment A: 14 Day Recharge Period Graphs

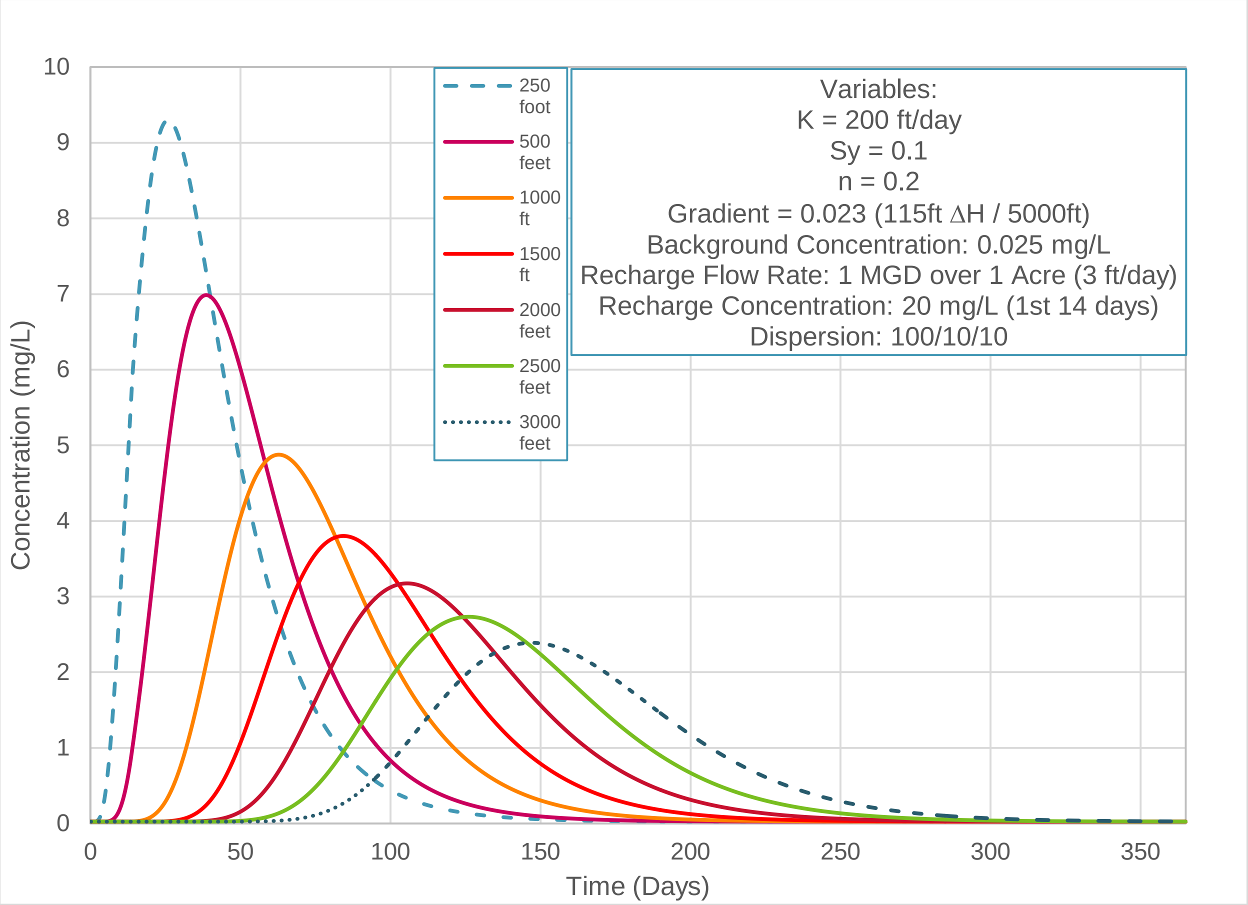

Figure 1. Breakthrough Curves for Build 1

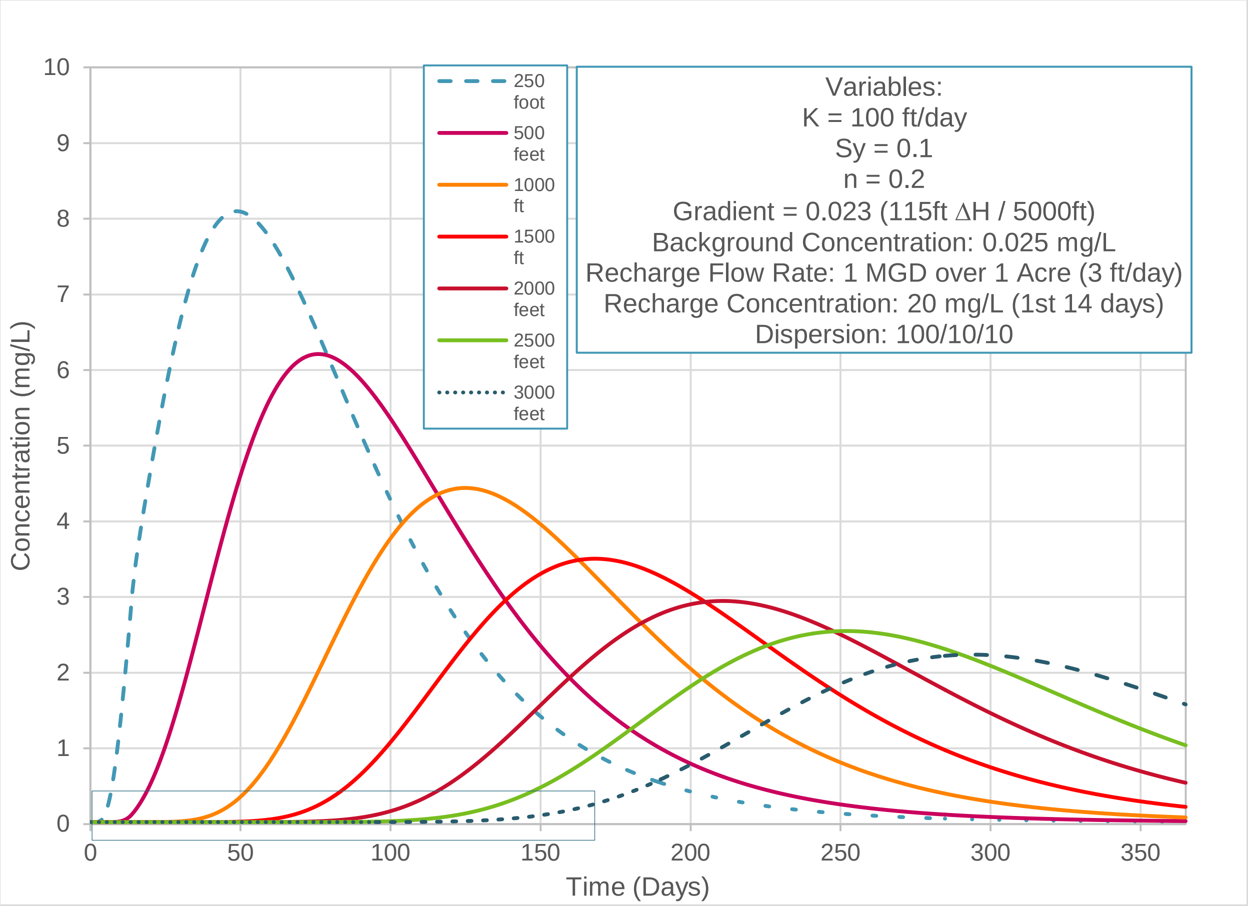

Figure 2. Breakthrough Curves for Build 2

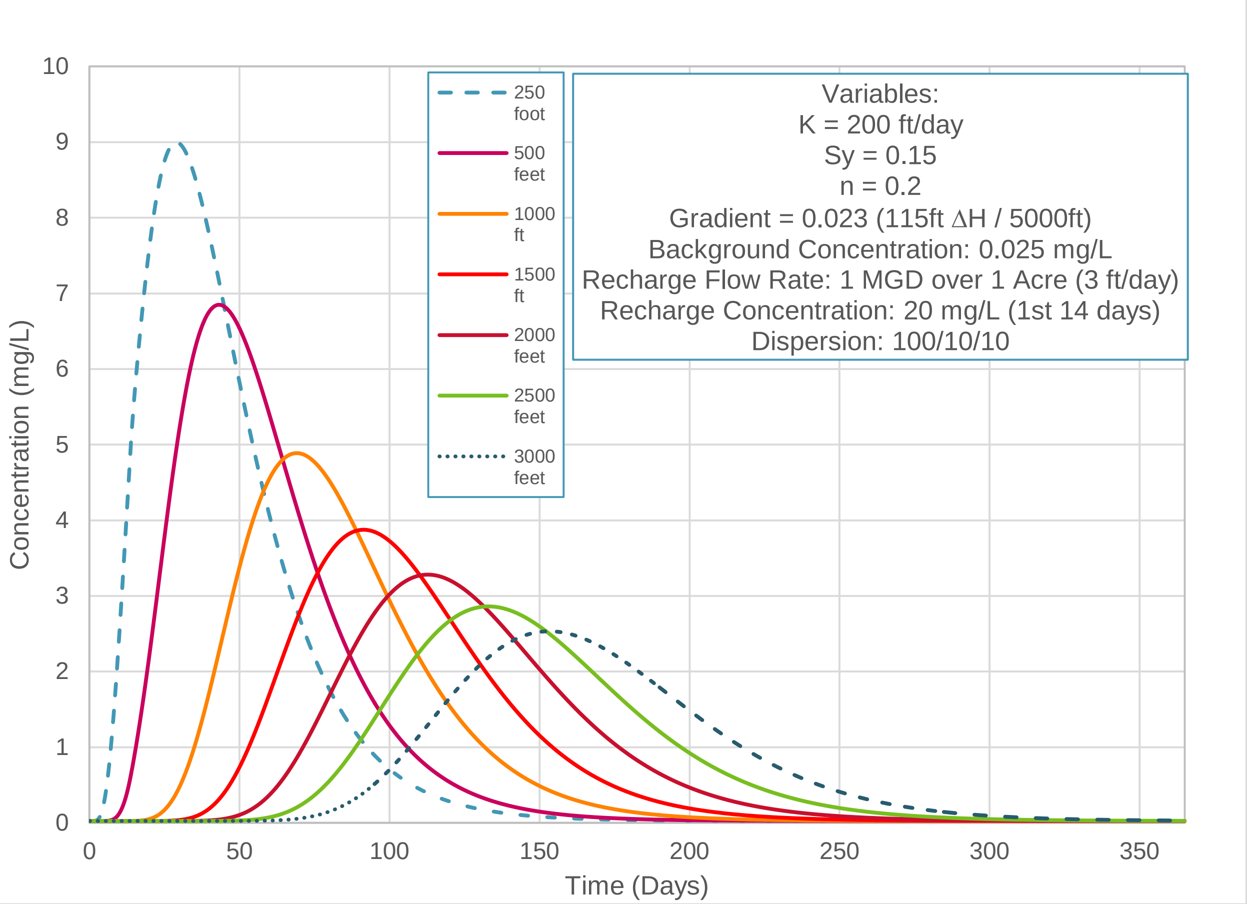

Figure 3. Breakthrough Curves for Build 3

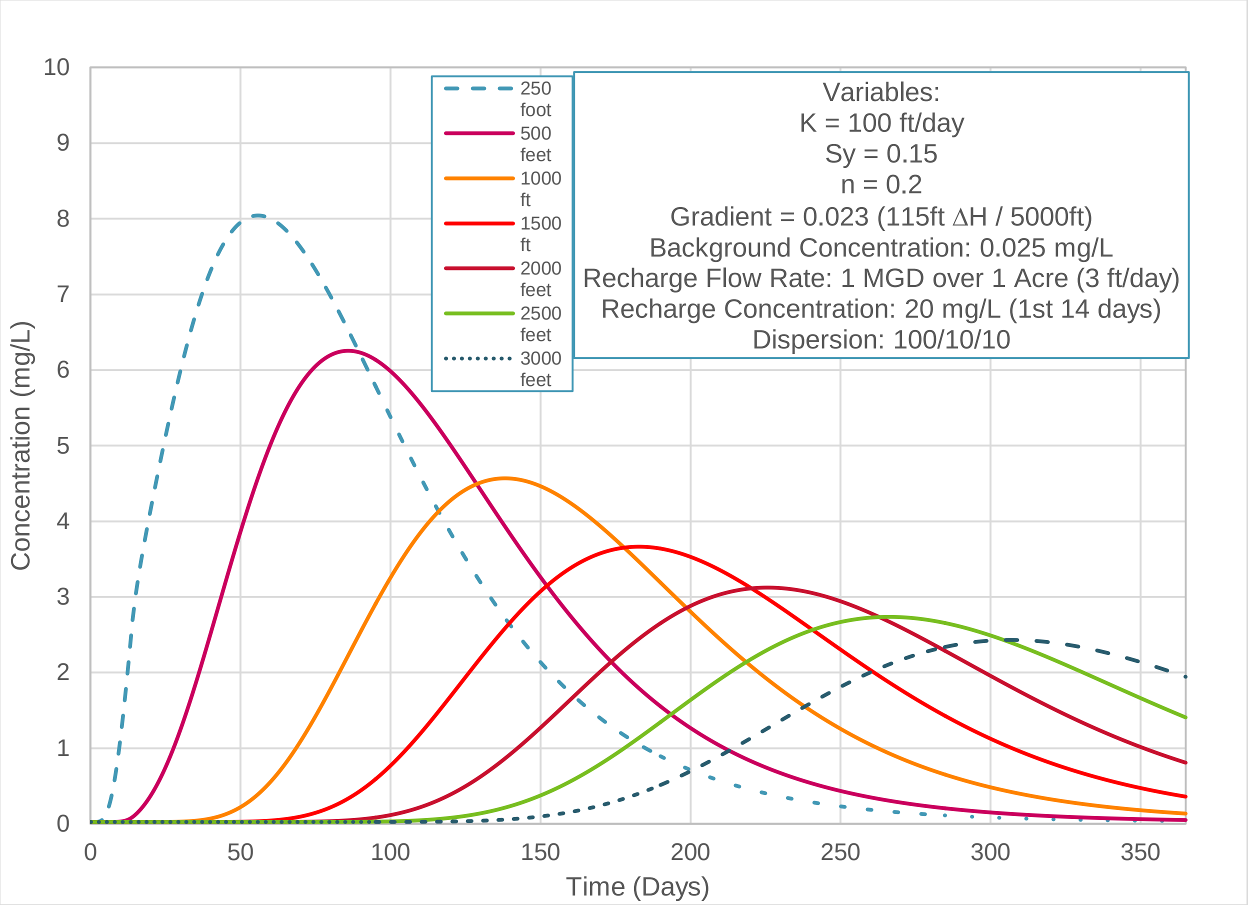

Figure 4. Breakthrough Curves for Build 4

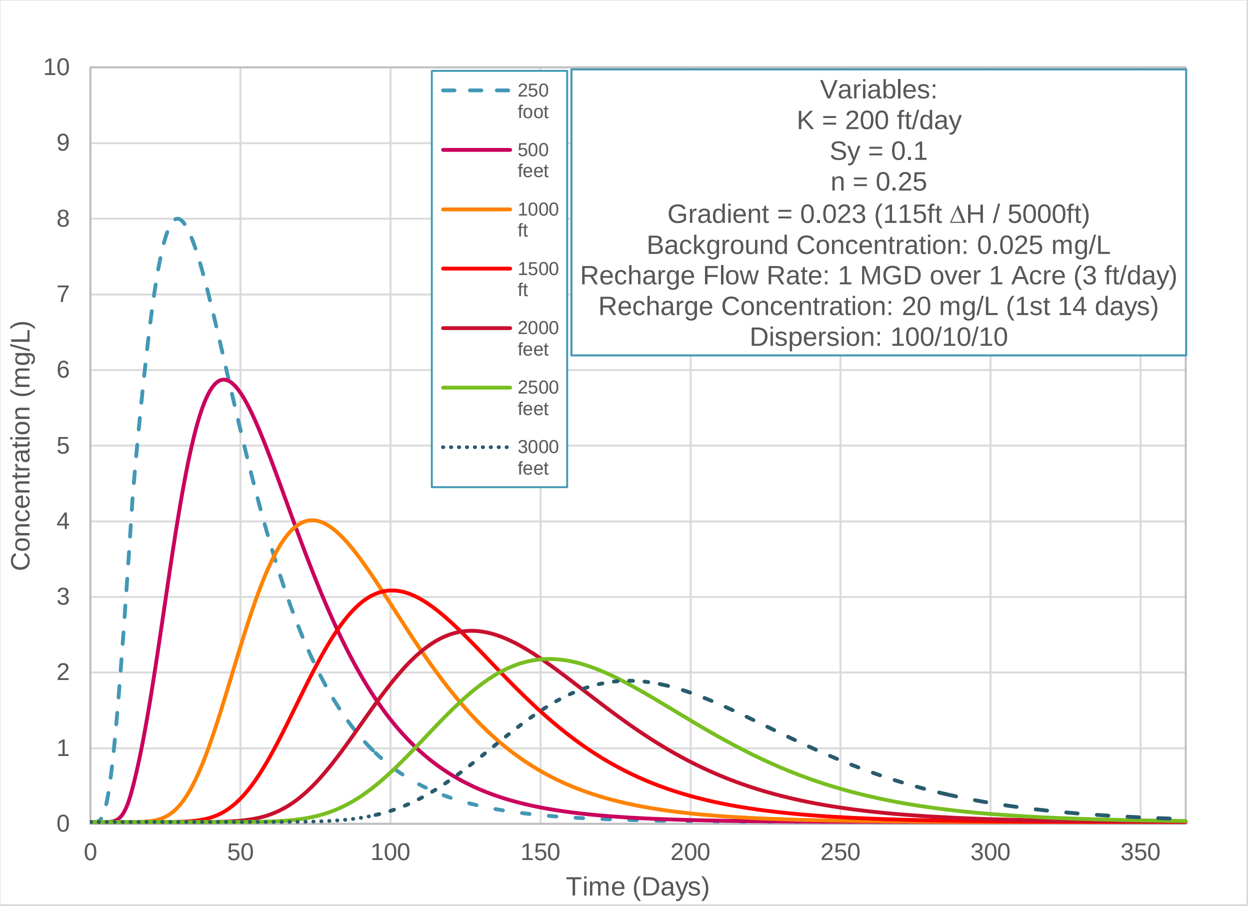

Figure 5. Breakthrough Curves for Build 5

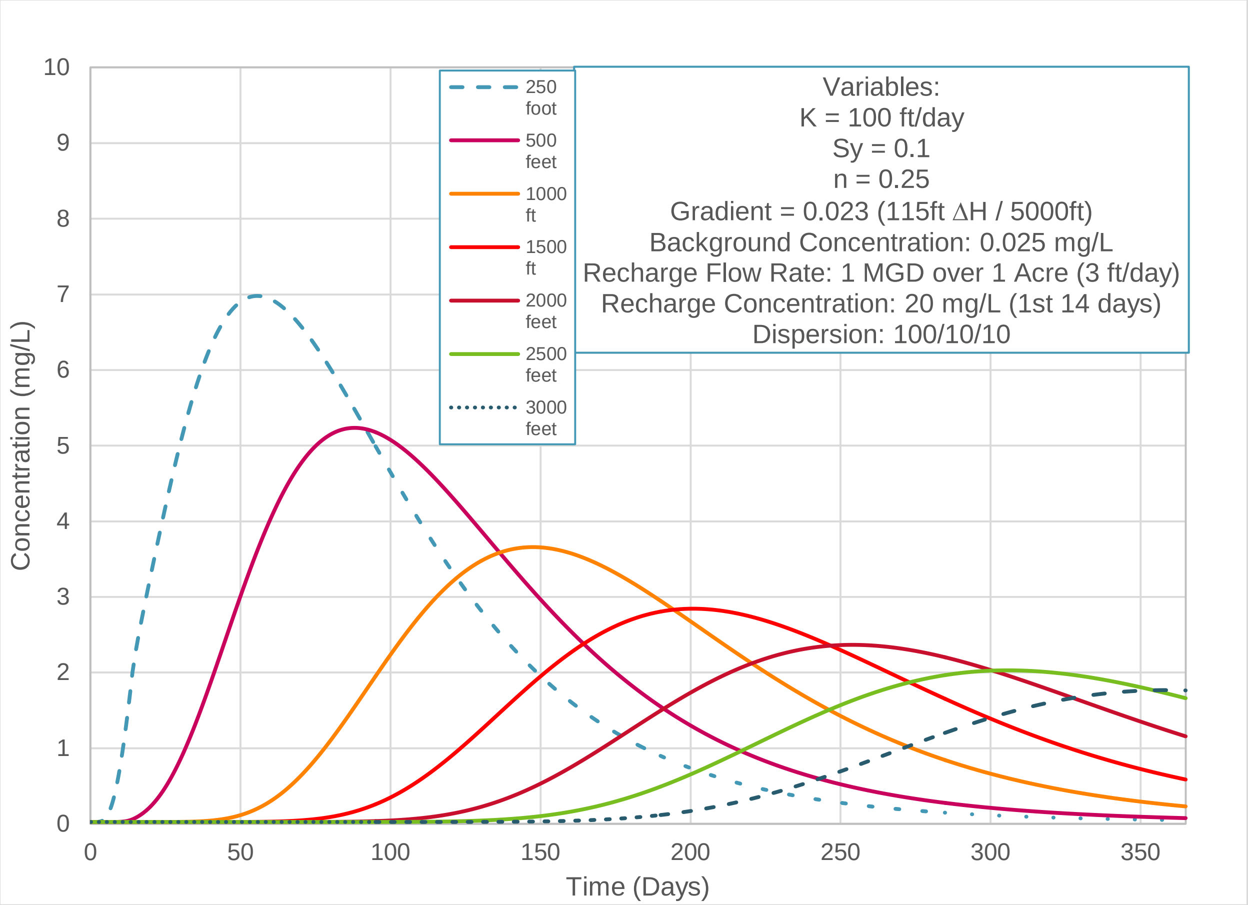

Figure 6. Breakthrough Curves for Build 6

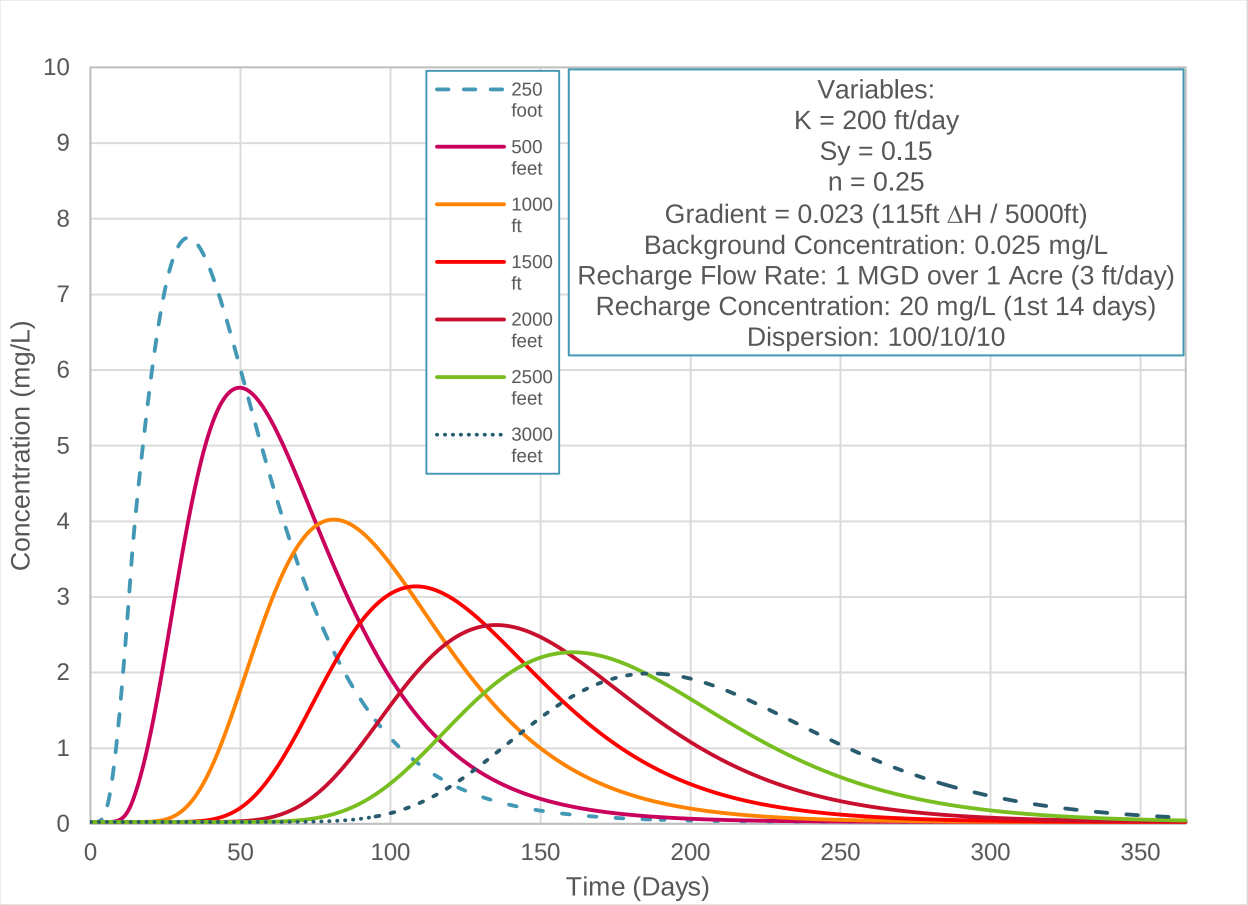

Figure 7. Breakthrough Curves for Build 7

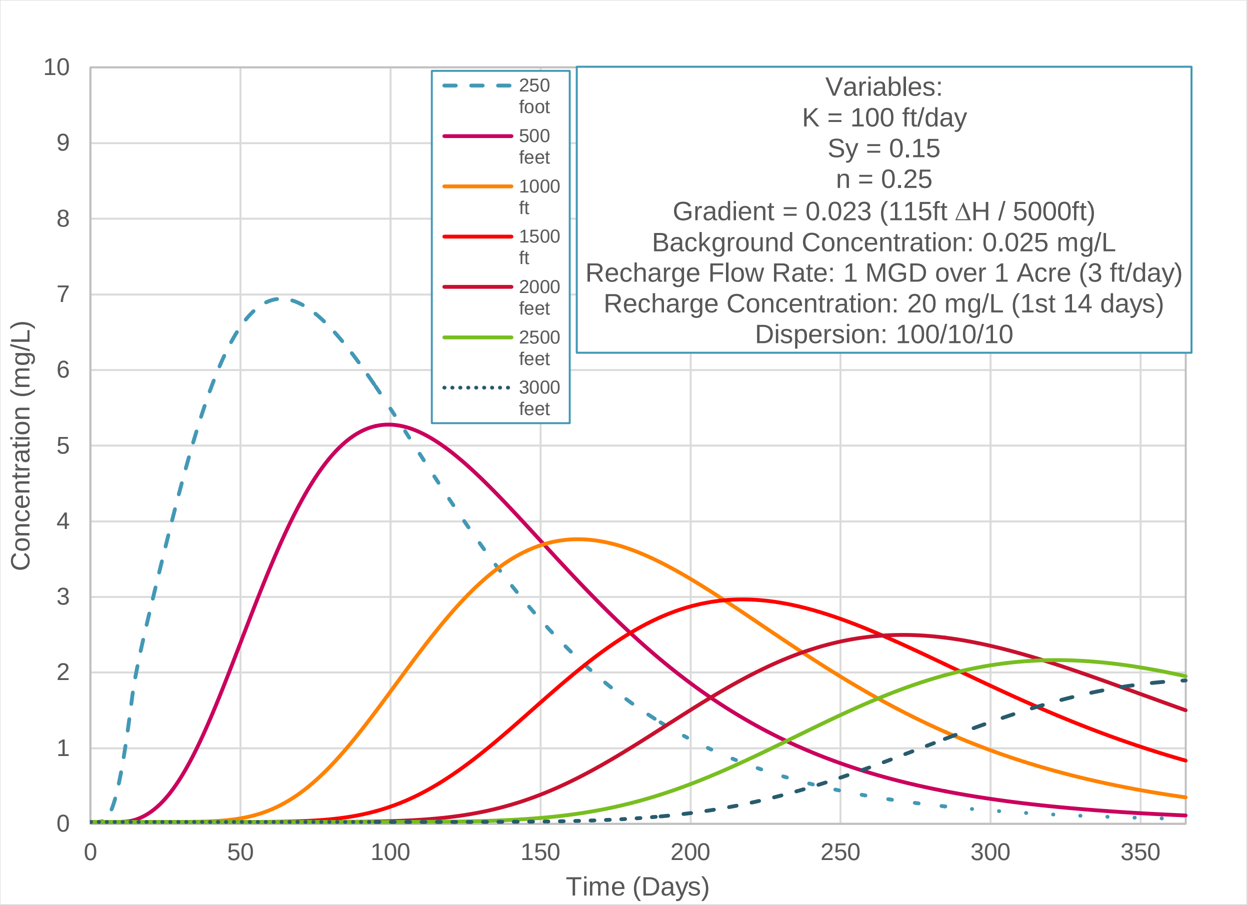

Figure 8. Breakthrough Curves for Build 8

Attachment B: 7 Day Recharge Period Graphs

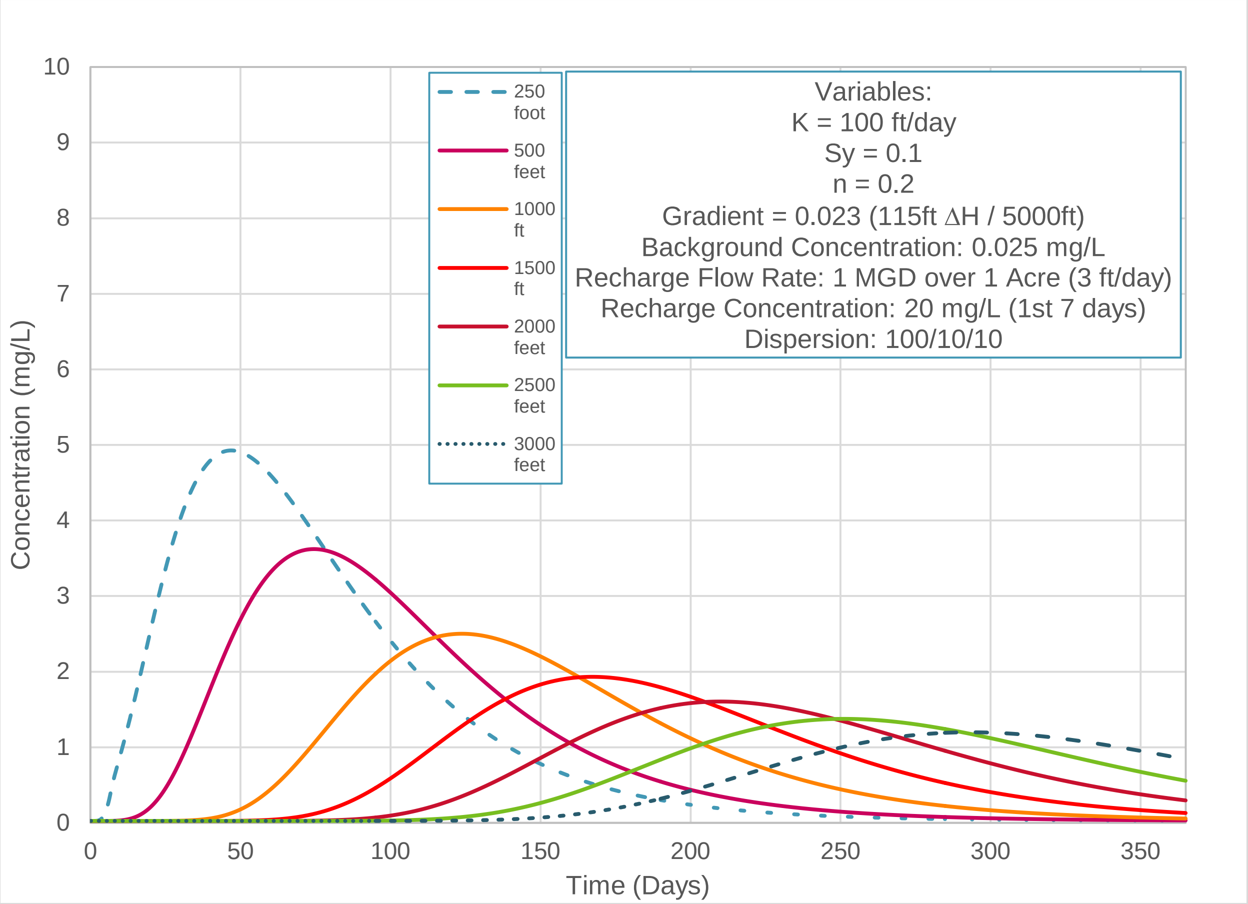

Figure 9. Breakthrough Curves for Build 9

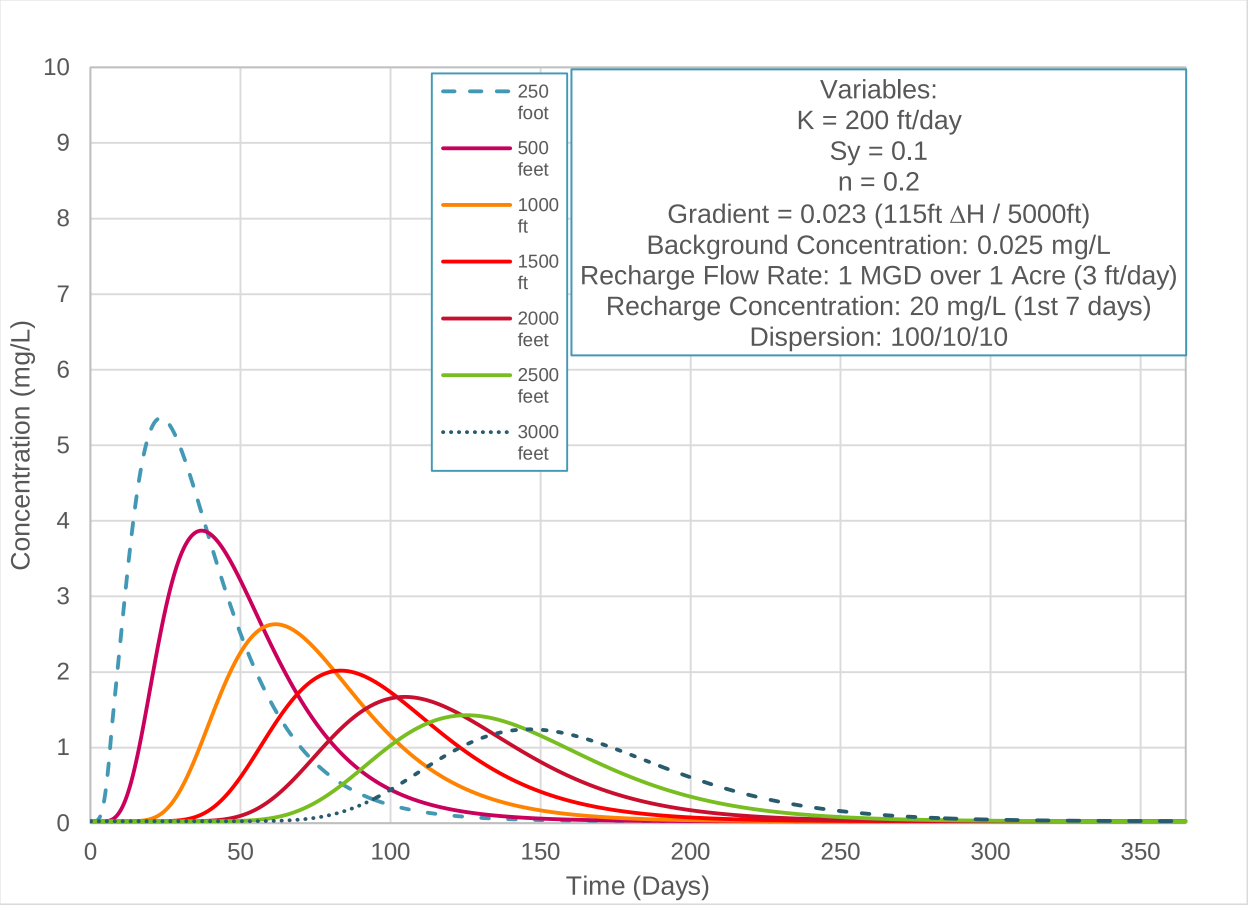

Figure 10. Breakthrough Curves for Build 10

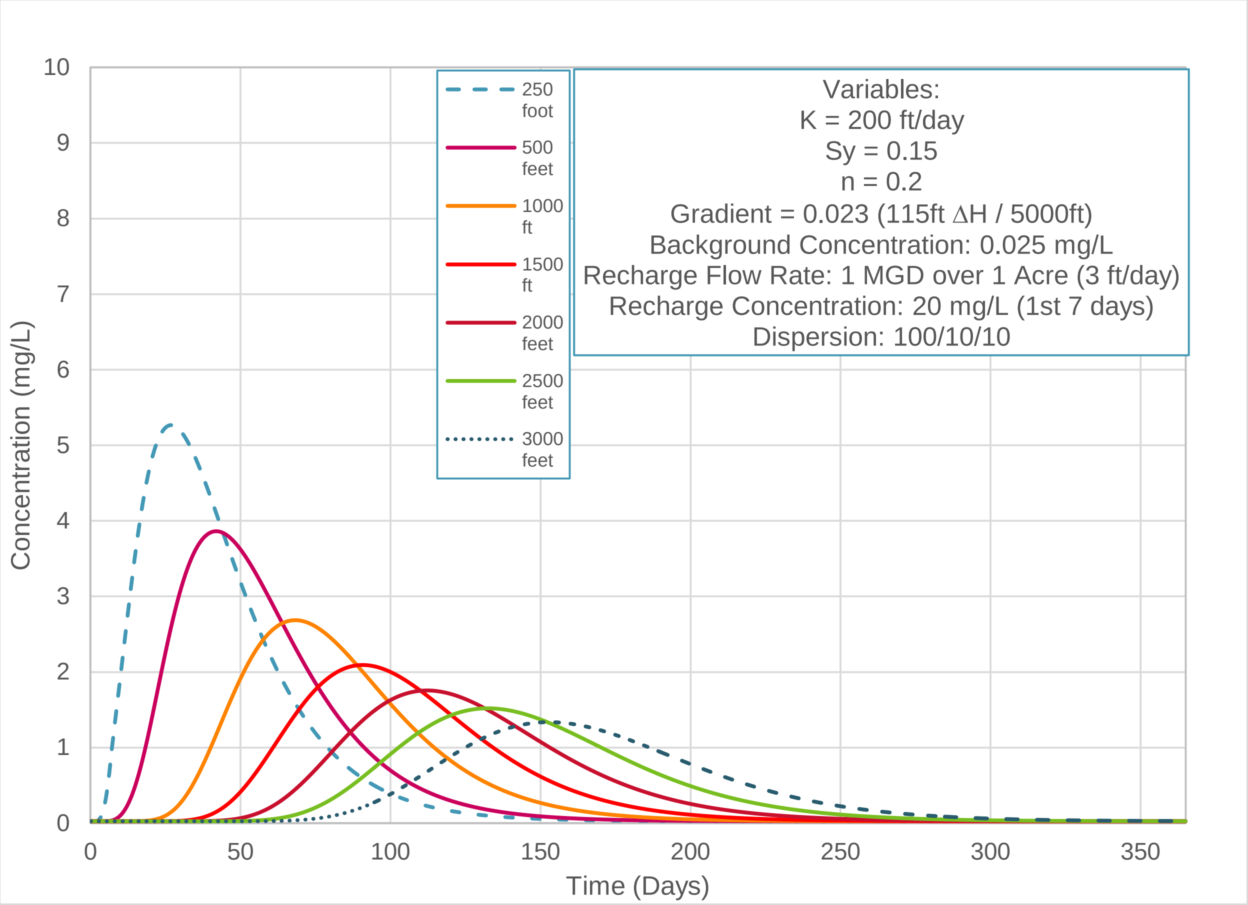

Figure 11. Breakthrough Curves for Build 11

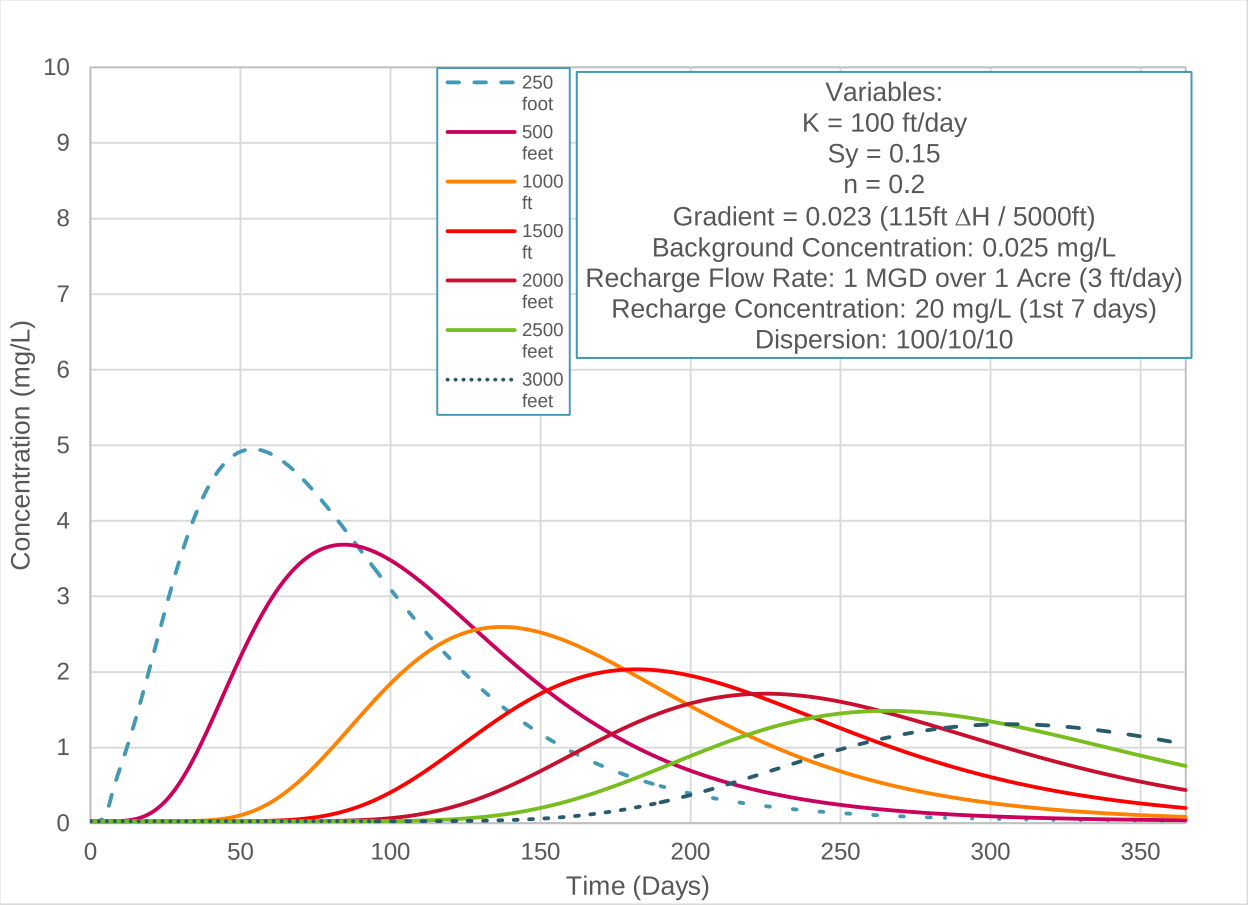

Figure 12. Breakthrough Curves for Build 12

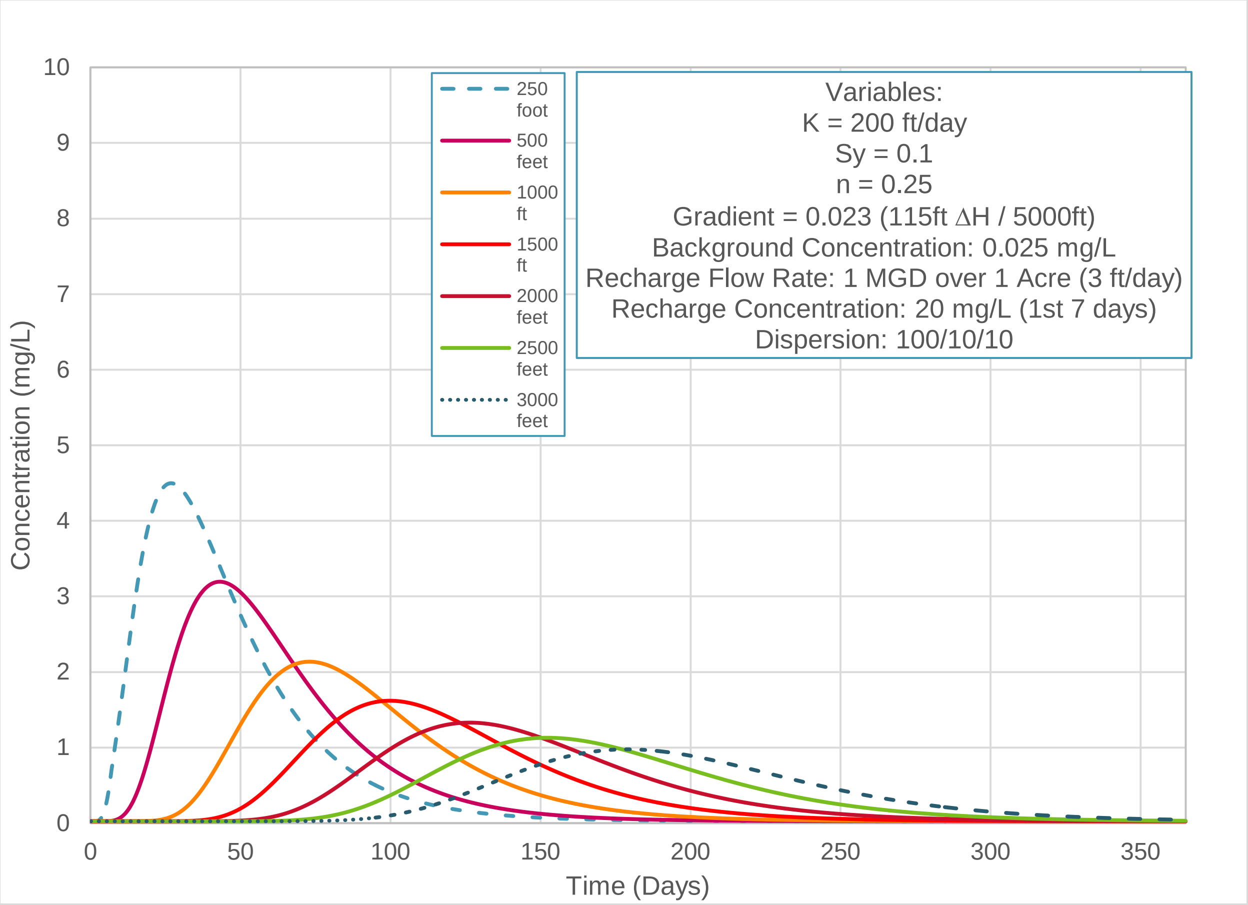

Figure 13. Breakthrough Curves for Build 13

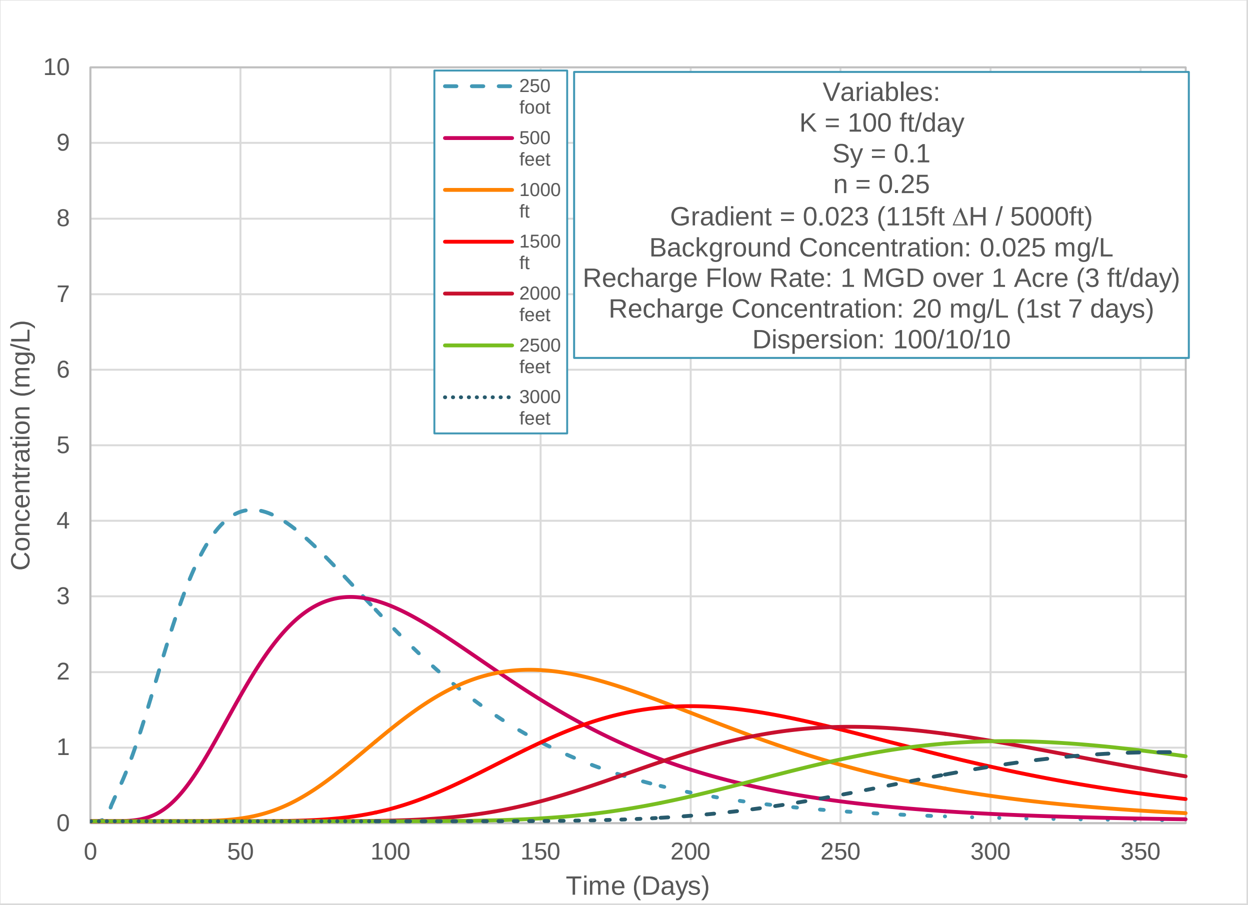

Figure 14. Breakthrough Curves for Build 14

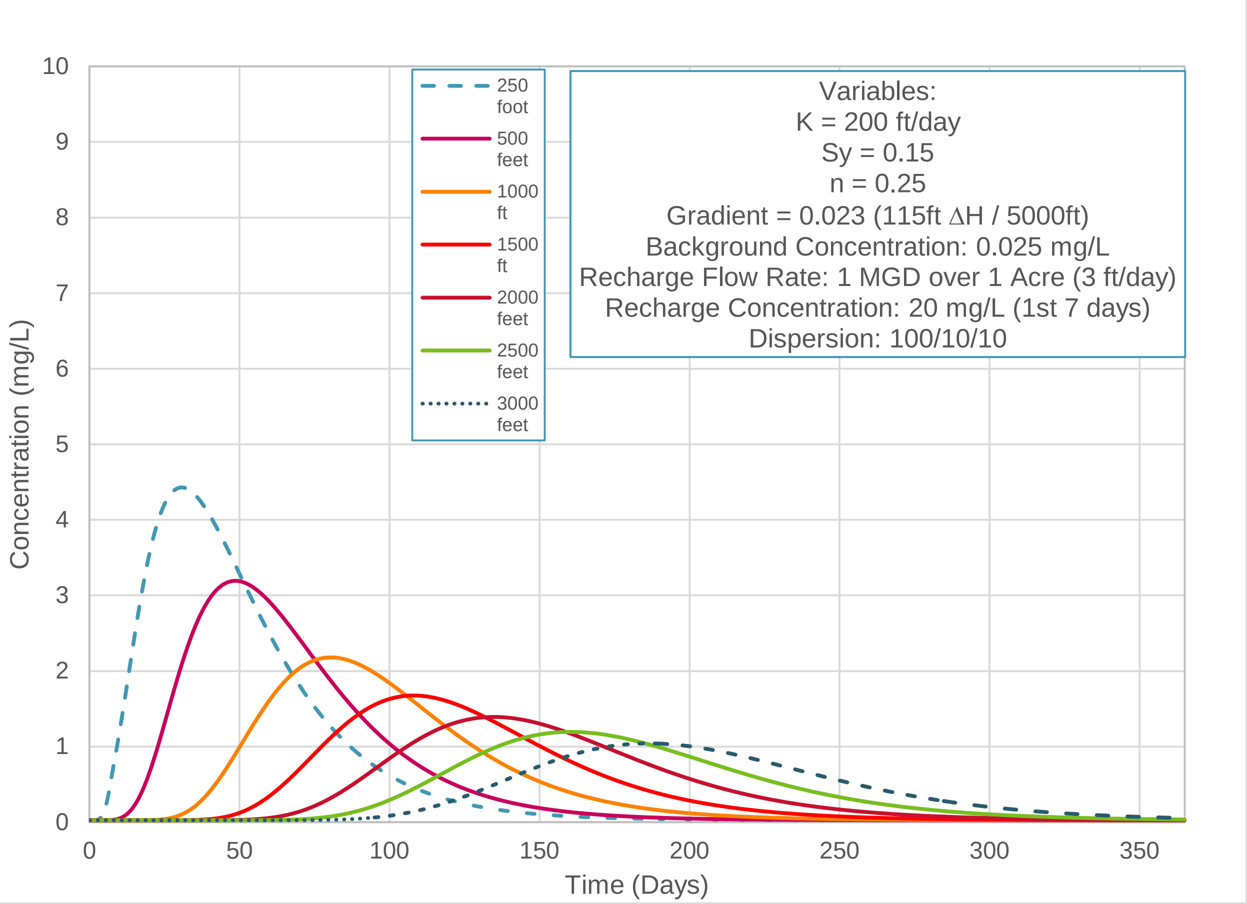

Figure 15. Breakthrough Curves for Build 15

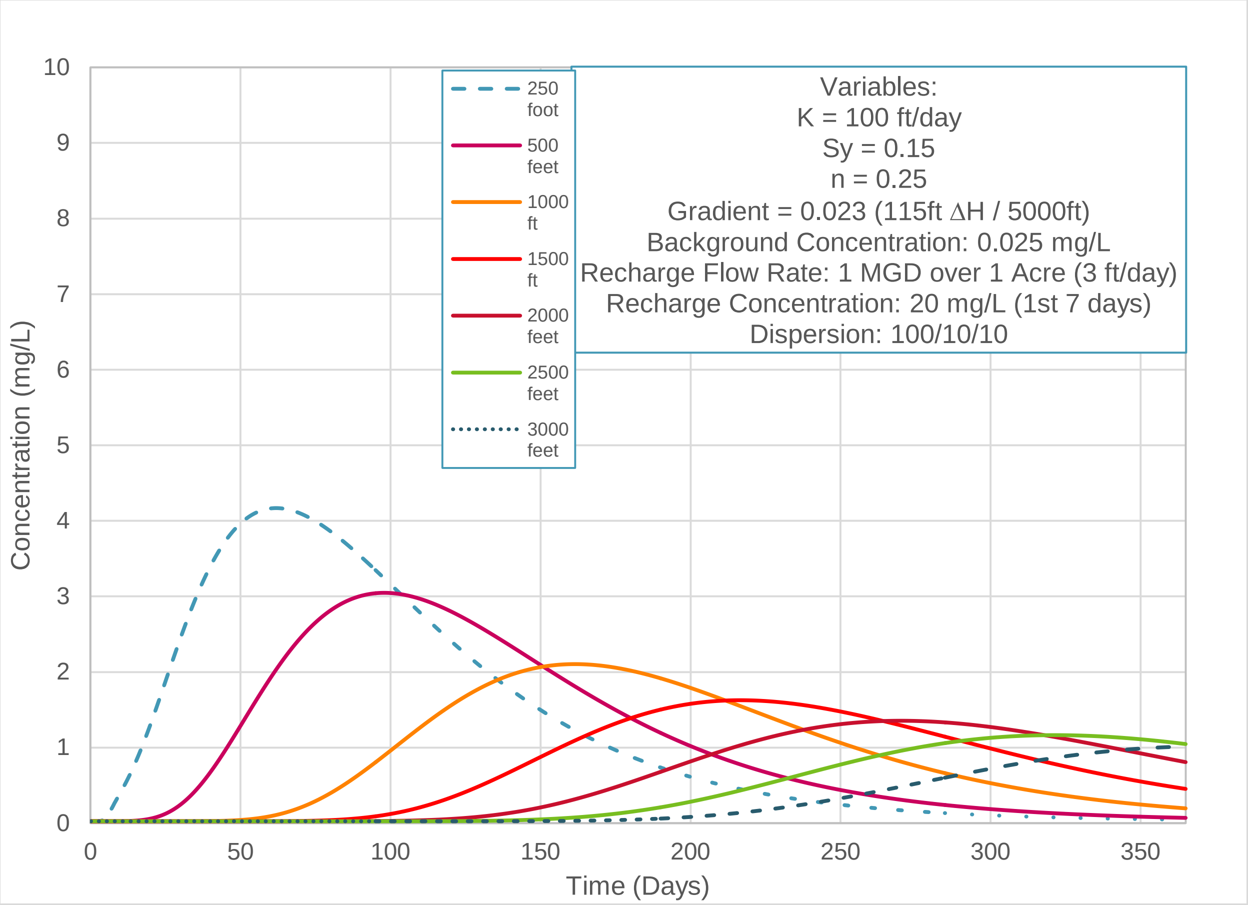

Figure 16. Breakthrough Curves for Build 16

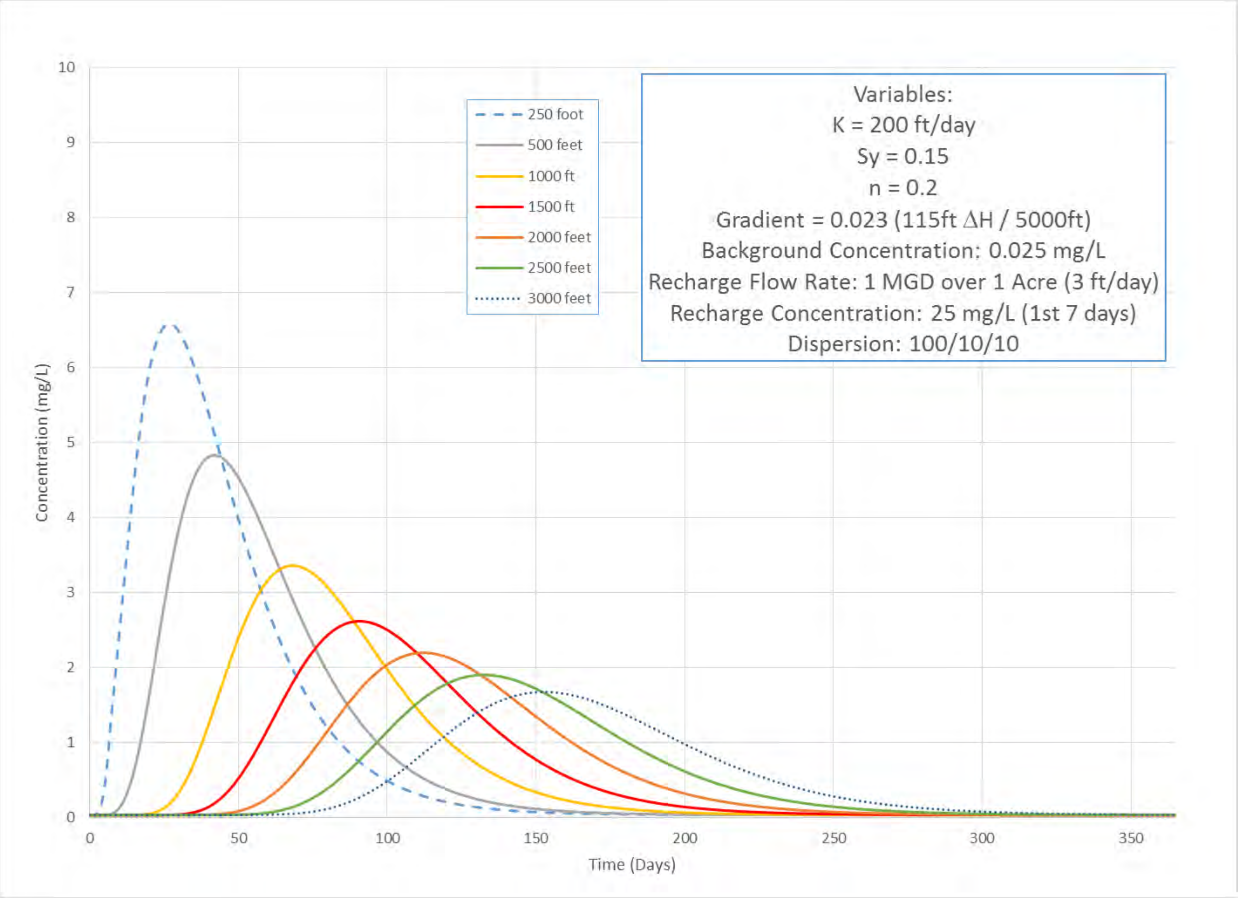

Figure 17. Breakthrough Curves for Build 11 (Modified for 25 mg/L)

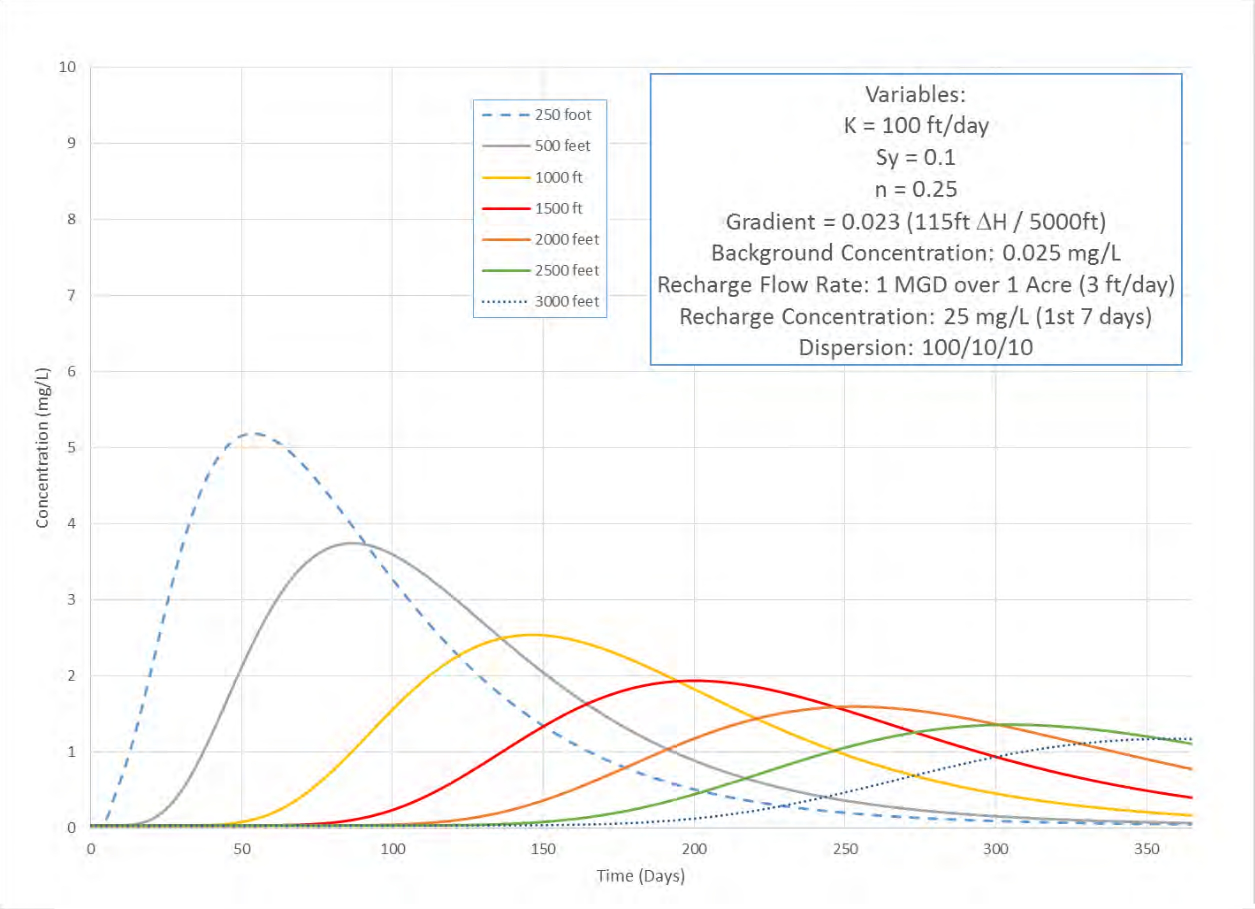

Figure 18. Breakthrough Curves for Build 14 (Modified for 25 mg/L)

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Appendix D – Water Quality Sampling Standard Operating Procedures

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APPENDIX D
GROUNDWATER AND VADOSE ZONE WATER SAMPLING STANDARD OPERATING PROCEDURE

1.0 SCOPE AND APPLICATION

This groundwater and vadose zone water sampling standard operating procedure (SOP) will be implemented when groundwater and vadose zone water samples are collected at the LOTT Hawks Prairie Site. Procedures for collecting samples of reclaimed water are also provided in this SOP. The objective of groundwater and vadose zone water sampling is to collect representative samples of water. To meet this objective, the sampling equipment, sampling method, monitoring well construction, monitoring well operation and maintenance, and sample handling procedures should not alter the chemistry of the sample.

Prior to sampling on the date selected, arrange with the contract laboratory for the proper sample bottles to be sent for the anticipated samples.

2.0 EQUIPMENT CHECKLIST

This section describes the equipment required for collecting samples of groundwater and vadose zone water at the LOTT Hawks Prairie site.

2.1 General Equipment

The following equipment list applies to both groundwater and vadose zone water sampling:

- Tool box – All needed tools for all site equipment used.
- Nitrile or latex gloves.
- Sample bottles, sample preservation supplies, sample labels, coolers, ice, and chain-of-custody forms.
- Well keys and map of monitoring well locations.
- Approved work plan.
- Well construction, field, and water quality data from the previous sampling event.
- Field logbook and calculator.

2.2 Groundwater Sampling Equipment

- Depth-to-water measuring device – An electronic water-level indicator with marked intervals of 0.01-foot.
- Groundwater sampling pump:
    - Dedicated submersible pumps (Grundfos Redi-Flo2) are already installed in some LOTT Hawks Prairie wells, including MW-1, MW-3a, MW-5, MW-8, MW-9, and MW-11. These pumps will be operated using a Grundfos control box and gasoline-powered generator.

    - Dedicated bladder pumps will be installed in monitoring wells listed in the work plan that do not already have a dedicated pump installed. Bladder pumps will be operated with a 12V portable air compressor and controller such as the Geotech GeoControl Pro, which has a maximum water sampling lift of 180 feet.
    - Pumps are to be constructed of inert materials, such as stainless steel. PTFE (Teflon®) materials will not be used to avoid potential interferences with laboratory analyses.

- Tubing – Polyethylene tubing will be used on all pumps for all samples. PTFE-lined tubing will not be used as it may interfere with analytical testing.
- Power source – If a combustion type (gasoline or diesel-driven) generator is used, it must be placed downwind of the sampling area.
- Flow measurement supplies – Flow meter or graduated cylinder, and a stop watch.
- Multi-parameter meter with flow-through cell – This can be one instrument or more contained in a flow-through cell. The water quality indicator parameters that are monitored are pH, dissolved oxygen (DO), specific conductance, oxidation reduction potential (ORP) and temperature. Calibration fluids for all instruments should be NIST-traceable and there should be enough for daily calibration throughout the sampling event. The inlet of the flow cell must be located near the bottom of the flow cell and the outlet near the top. The size of the flow cell should be kept to a minimum and a closed cell is preferred. The flow cell must not contain any air or gas bubbles when monitoring for the water-quality-indicator parameters.
- Groundwater sampling log forms. A suggested groundwater sampling log form is provided at the end of this SOP.
- Plastic sheeting.

2.3 Vadose Zone (Lysimeter) Water Sampling Equipment

- Vacuum pump with pressure gauge.
- Pressure pump with pressure gauge.
- Vadose zone sampling log forms. A suggested vadose zone water sampling log form is provided at the end of this SOP.
- Plastic sheeting.

3.0 GROUNDWATER SAMPLING PROCEDURES

The following describes the purging and sampling procedures of the low-flow method for the collection of groundwater samples. Water in the monitoring wells at the LOTT Hawks Prairie site is not contaminated; therefore purge water will be discharged directly to the ground.

3.1 Pre-Sampling Activities

1. Sampling must begin at the monitoring well with the least contamination, generally up-gradient or farthest from the site or suspected source. Then proceed systematically to

the monitoring wells with the most contaminated groundwater.

2. Check and record the condition of the monitoring well for damage or evidence of tampering.
3. Spread out clean plastic sheeting at work site.
4. Unlock well head. Record the location, time, date, and appropriate information in a field logbook and groundwater sampling log form.
5. Note wind direction. Stand upwind from the well to avoid contact with gases/vapors emanating from the well. When sampling with a Grundfos RediFlo2 submersible pump, place generator downwind of the well to be sampled.
6. Measure the depth to water (measured to nearest 0.01 foot) relative to a reference measuring point on the well casing with an electronic water level indicator or steel tape and record in field logbook and groundwater sampling log form. Measure the depth to water a second time to confirm initial measurement; measurement should agree within 0.01 foot or re-measure.

3.2 Purging and Sampling Activities

1. Record the depth of the pump intake on the groundwater sampling log form. Dedicated submersible Groundfos RediFlo2 pumps are already set in some wells and should not be moved. New dedicated bladder pumps will be installed in wells listed in the work plan, with the intake at mid-screen, or deeper if less than one-half of the well screen is submerged.
2. Measure the depth to water (measured to nearest 0.01 foot) and record the reading on the groundwater sampling log form. Leave water level indicator probe in the monitoring well.
3. Start pumping the well at a low flow rate (0.2 to 1.0 liter per minute) and slowly increase the speed. Check depth to water. Maintain a steady flow rate while maintaining a drawdown of less than 0.3 foot. If the minimum drawdown achieved exceeds 0.3 foot, but remains stable, continue purging.
4. Measure the discharge rate of the pump with a graduated cylinder and a stop watch. Also, measure the depth to water and record both flow rate and depth to water on the groundwater sampling log form. Continue purging, monitor and record depth to water and pump rate every three to five minutes during purging. Pumping rates should be kept at minimal flow to ensure minimal drawdown in the monitoring well.
5. During the purging, a minimum of one tubing volume (including the volume of water in the pump) must be purged prior to recording the water quality indicator parameters. At the LOTT Hawks Prairie site the volume of this initial purge at all wells is 1.5 gallons. Then monitor and record the water quality indicator parameters every three to five minutes. The water quality indicator parameters are pH, temperature, specific electrical conductance (conductivity), dissolved oxygen (DO), and oxidation/reduction potential (ORP). Readings will be recorded on the groundwater sampling log form. The stabilization criterion is based on three successive readings of the water quality indicator parameters; the following are the criteria which will be used:

Parameter	Stabilization Criteria
pH	+/- 0.1 pH unit
Temperature	3%
Specific Electrical Conductance (Conductivity)	3%
Dissolved Oxygen (DO)	10% for values greater than 0.5 mg/L; if values are less than 0.5 mg/L, consider values as stabilized
Oxidation/Reduction Potential (ORP)	+/- 10 mV

Source: USEPA, 2017

Once the criteria have been successfully met indicating that the water quality indicator parameters have stabilized, then sample collection can take place. If field parameters have not stabilized after purging three times the volume of water standing in the well, collect sample anyway. Note this on the sampling log.

6. In wells with partially submerged well screens, if a stabilized drawdown in the well can't be maintained, reduce the flow rate or turn the pump off (for 15 minutes) and allow for recovery. It should be noted whether or not the pump has a check valve. A check valve is required if the pump is shut off. Under no circumstances should the well be pumped dry. Begin pumping at a lower flow rate, and if drawdown again does not stabilize, turn pump off and allow for recovery. If two tubing volumes (including the volume of water in the pump and flow cell) have been removed during purging, then sampling can proceed the next time the pump is turned on. This information should be noted in the field logbook or groundwater sampling log form with a recommendation for a different purging and sampling procedure.
7. Maintain the same pumping rate or reduce slightly for sampling (0.2 to 1.0 liter per minute) in order to minimize disturbance of the water column. Disconnect the pump's tubing from the flow-through cell so that the samples are collected directly from the pump's discharge tubing. Don a new pair of nitrile or latex gloves. Filtered (dissolved) samples are collected last. All sample containers should be filled with minimal turbulence by allowing the groundwater to flow from the tubing gently down the inside of the container. When filling VOC sample vials, a meniscus must be formed over the mouth of the vial to eliminate the formation of air bubbles and head space prior to capping.
8. Immediately place all filled sample containers into a cooler with ice. Samples should not be exposed to sunlight after collection. Ensure that samples that are to be cooled remain at 4 degrees C, but do not allow any of the samples to freeze. Samples for constituents with short holding times are recommended to be shipped or delivered to the laboratory daily.
9. Disconnect the tubing that extends from the wellhead or cap.
10. Close and lock the well.
11. Decontaminate the water level measuring device. Decontamination steps will include

washing with an Alconox solution, wiping with clean paper towels, followed by a deionized water rinse and final wiping.

4.0 VADOSE ZONE WATER SAMPLING PROCEDURES

The following procedures will be used for collecting vadose zone water samples from lysimeters. A vadose zone water sampling log form is included at the end of this SOP.

4.1 Pre-Sampling Activities

1. Check and record the condition of the above-grade steel casing that houses the lysimeter tubing, and the PVC marker pipe, for damage or evidence of tampering.
2. Spread out clean plastic sheeting at work site.
3. Unlock steel casing that houses the lysimeter tubing. Record the location, time, date, and appropriate information in a field logbook and vadose zone water sampling log form.
4. Open the top of the PVC marker pipe. Measure the depth to water (measured to nearest 0.01 foot) relative to top of the PVC with an electronic water level indicator or steel tape and record in field logbook and vadose zone water sampling log form. Measure the depth to water a second time to confirm initial measurement; measurement should agree within 0.01 foot or re-measure.

4.2 Lysimeter Purging

To ensure the integrity of the samples, each lysimeter must be purged before sampled. The portable pressure pump is connected to the black polyethylene vacuum/pressure tube and a positive pressure is applied. This will clear any water that has entered the system between sampling events. When no further condensation evacuates the sampling tube, the sampling ball valve is closed.

4.3 Lysimeter Charging

Connect the portable vacuum pump to the black polyethylene vacuum/pressure tube, and run the vacuum pump to apply a vacuum until the pressure gauge reads approximately 20 psi (or as close as possible). Close the vacuum tube ball valve and turn off the vacuum pump. The lysimeter should remain charged at a negative pressure for as long as necessary to fill the 575 mL reservoir. The time for this will be determined by trial and error.

4.4 Lysimeter Sample Collection

To empty the lysimeter, attach the portable pressure pump to the black polyethylene vacuum/pressure tube, open both ball valves and apply a positive pressure. The water will flow up the clear tube to the surface. When no more fluid is ejected from the clear tube, power off the pump and close both valves.

One set of field water quality indicator parameter readings will be collected from purge water from the lysimeter. Due to the volume constraints of the lysimeter, it will likely not be possible to run the purge water through a flow-through cell. Instead, the purge water may be collected into a clean container and the water quality meter probes inserted into the container to collect the readings. The water quality indicator parameters are pH and specific electrical conductance (conductivity). These parameter readings will be recorded on the vadose zone water sampling log form. Charge the lysimeter again for sample collection.

For sample collection, don a new pair of nitrile or latex gloves, and insert the clear sampling tube into a clean, labeled sample container. The lysimeter reservoir holds 575 mL; additional cycles of charging and discharging may be required to fill the required sample containers. Immediately place all filled sample containers into a cooler with ice. Samples should not be exposed to sunlight after collection. Ensure that samples that are to be cooled remain at 4 degrees C, but do not allow any of the samples to freeze. Samples for constituents with short holding times are recommended to be shipped or delivered to the laboratory daily.

The vacuum pump does not come into contact with the sample water; therefore decontamination of the vacuum pump is not required between samples.

5.0 RECLAIMED WATER SAMPLING PROCEDURES

The following procedure will be used to collect samples of the reclaimed water at the LOTT Hawks Prairie Basin 4. Reclaimed water is pumped from Pond #5 to the recharge basins and discharged to the basins through holes drilled in black plastic pipe. Samples of the reclaimed water will be collected as the water flows from one of these holes into Basin 4. Sampling procedures are as follows:

1. The flows from the black plastic pipe will be inspected to determine if sample containers could be filled directly from one of the flows without assistance of a funnel. Pressure differences in the pipe may cause the recharge water to exit the pipe more forcefully from certain holes; samples will be collected from a hole exhibiting higher flow in order to avoid sampling water that has ran down the outside of the plastic pipe.
2. If none of the flows from the black plastic pipe are suitable for directly filling the sample containers without the water contacting the outside of the plastic pipe, a short length of decontaminated stainless steel pipe will be used as funnel. Decontamination procedures for the stainless steel funnel include scrubbing with an Alconox solution, rinsing with potable water, and rinsing with deionized water and wiped with clean paper towels. The funnel will be stored in a clean, dry plastic bag, and decontaminated prior to use.
3. Note in the field logbook the specific location the sample will be collected from, measured in feet from the west end of Basin 4.
4. Collect one set of field water quality indicator parameter readings using a water quality meter. Parameters are pH, temperature, specific electrical conductance (conductivity), dissolved oxygen (DO), and oxidation/reduction potential (ORP). Use of a flow-through cell will likely not be possible; instead, fill a clean container with reclaimed water and insert the water quality probes into the container to collect the readings. Record the parameter readings on a vadose zone water sampling log form.
5. Don a new pair of nitrile or latex gloves and fill the sample containers. Immediately place all filled sample containers into a cooler with ice. Samples should not be exposed to sunlight after collection. Ensure that samples that are to be cooled remain at 4 degrees C, but do not allow any of the samples to freeze. Samples for constituents with short holding times are recommended to be shipped or delivered to the laboratory daily.
6. If a stainless steel funnel is used, decontaminate the funnel as described above.

6.0 FIELD QUALITY CONTROL

The quality assurance (QA) targets for precision and accuracy of sampling programs are based on accuracy and precision guidelines established by the EPA. There are five primary areas of concern for QA in the collection of representative samples:

1. Obtaining a sample that is representative of water in the aquifer or vadose zone. Verify log documentation that the well or lysimeter was purged of the required volume. For groundwater sampling, verify that the water quality indicator parameters stabilized before samples were extracted.
2. Ensuring that the purging and sampling devices are made of materials and utilized in a manner that will not interact with or alter the analyses.
3. Generating results that are reproducible.
4. Preventing cross-contamination. Sampling should proceed from least to most contaminated wells, if known.
5. Ensuring that samples are properly preserved, packaged, and shipped. Place signed chain-of-custody forms inside the sample coolers, and place a custody seal on the cooler lid prior to shipping. If dropping off samples at the laboratory, a lab technician will sign the chain-of-custody acknowledging receipt of the samples.

Additional precautions to ensure accurate and representative sample collection are as follows:

- If the sample bottle contains no preservatives, the bottle should be rinsed with sample water, which is discarded before sampling. Bottles for sample analyses that require preservation should be prepared before they are taken to the well. Care should be taken to avoid overfilling bottles so that the preservative is not lost. The pH should be checked and more preservatives added to inorganic sample bottles, if needed. VOC sample vials that do not meet the pH requirements need to be discarded and new sample bottles with more preservative added should be prepared immediately.
- Clean sampling equipment should not be placed directly on the ground or other contaminated surfaces either prior to sampling or during storage and transport.

It is especially important to clean thoroughly the portion of the equipment that will be in contact with sample water. Prevent surface soils from coming in contact with the purging or sampling equipment. The effects of cross-contamination also can be minimized by sampling the least contaminated well first and progressing to the more contaminated ones.

6.1 Duplicate Samples

Duplicate samples are collected by taking separate samples as close to each other in time and space as practical. Duplicate samples are used to develop criteria for acceptable variations in the physical and chemical composition of samples that could result from the sampling procedure. Duplicate samples also serve as a check on laboratory analytical procedures.

Duplicate results are utilized by the QA officer and the project manager to give an indication of the precision of the sampling and analytical methods.

7.0 POST-SAMPLING ACTIVITIES

Several activities need to be completed and documented once groundwater and vadose zone water sampling has been completed. These activities include, but are not limited to:

- Ensuring that all field equipment has been decontaminated and returned to proper storage location.
- Compiling all field data for site records.
- Verifying all analytical data processed by the analytical laboratory against field sheets to ensure all data has been returned to sampler.
- Upon receipt of the final report from the contract laboratory check for accuracy and completeness based on what analyses were scheduled and expected. Input results into tracking worksheets.

HDR GROUNDWATER MONITORING / SAMPLING LOG FORM

Facility Name:	Sampler Name(s):
Monitoring Location:	Date/Time:
Sample Number:	Weather Conditions:
	Wellhead Conditions:

Visual Inspection:

1. Survey Mark Present: (Yes/No) ________
2. Collision/Vandalism Damage: (Yes/No) ________
3. Casing Degradation: (Yes/No) ________
4. Well Subsidence: (Yes/No) ________
5. Standing/Ponded Water (Yes/No) ________
6. Frost Heaving (Yes/No) ________
7. Lock in Place (Yes/No) ________

Groundwater Measurements and Purge data:

1. Static Water Level (±0.01 ft) ________
2. Bottom of casing (±0.01 ft) ________
3. Casing Diameter (inches) ________
4. Casing Volume (gal) ________
5. 3 X Casing Volume (gal) ________
6. Actual Volume of Water Purged (gal) ________

6a. Purge Water Characteristics: Odor ________
Color ________
Turbidity ________

7. Water Level Measuring Equipment ________
8. Purge Equipment Used ________
9. Dedicated? (Yes/No) ________
10. Intake depth (ft) ________
11. Purge rate (if pump used) ________ mL/min
12. Time to purge well ________
13. Drive Gas (Air/Nitrogen) ________
14. Notes: ________

Time	Total Volume Purged (gal)	Depth to Water (ft)	Temperature (˚C)	Conductivity (µS/cm)	pH	D.O. (mg/L)	ORP (mV)	Turbidity (NTU)

Well evacuated to dryness? (Yes/No) ________

Time to recharge ________ hrs. ________ min.

1. Sample Filtered? (Yes/No) ________
2. Sampling Equipment Used ________
3. Drive Gas (Air/Nitrogen) ________
4. Pump Rate ________ mL/min
5. Sample Appearance ________
   Odor ________
   Color ________
   Turbidity (High/Med/Low/Clear) ________
6. Method of Sample Preservation:

Notes:

Decontamination Procedures: ________

Instrument Type: ________
Instrument Calibration Date: ________
Instrument Calibration Time: ________
pH Standard (S.U.) ________
Reading (S.U.) ________
Adjustment (S.U.) ________
Conductivity Standard (µS/cm) ________
Reading (µS/cm) ________
ORP Standard (mV) ________
Reading (mV) ________
D.O. Standard Slope ________
Reading (mg/L) ________
Turbidity Standard (NTU) ________
Reading (NTU) ________

HDR VADOSE ZONE MONITORING / SAMPLING LOG FORM

Facility Name:	Sampler Name(s):
Monitoring Location:	Date/Time:
Sample Number:	Weather Conditions:
	Wellhead Conditions:

Visual Inspection:

1. Survey Mark Present: (Yes/No)
2. Collision/Vandalism Damage: (Yes/No)
3. Casing Degradation: (Yes/No)
4. Well Subsidence: (Yes/No)
5. Standing/Ponded Water (Yes/No)
6. Frost Heaving (Yes/No)
7. Lock in Place (Yes/No)

Water Measurements and Purge data:

1. Static Water Level (±0.01 ft)
2. Actual Volume of Water Purged (gal)
3. Purge Water Characteristics: Odor
   Color
   Turbidity
4. Water Level Measuring Equipment
5. Purge Equipment Used

Time	Total Volume Purged (gal)	Depth to Water (ft)	Temperature (˚C)		Conductivity (µS/cm)	pH	D.O. (mg/L)	ORP (mV)	Turbidity (NTU)

Well evacuated to dryness? (Yes/No)

Time to recharge hrs. min.

1. Sample Filtered? (Yes/No)
2. Sampling Equipment Used
3. Drive Gas (Air/Nitrogen)
4. Pump Rate mL/min
5. Sample Appearance
   Odor
   Color
   Turbidity (High/Med/Low/Clear)
6. Method of Sample Preservation:

Notes:

Decontamination Procedures:

Instrument Type:
Instrument Calibration Date:
Instrument Calibration Time:
pH Standard (S.U.)
Reading (S.U.)
Adjustment (S.U.)
Conductivity Standard (µS/cm)
Reading (µS/cm)
ORP Standard (mV)
Reading (mV)
D.O. Standard Slope
Reading (mg/L)
Turbidity Standard (NTU)
Reading (NTU)