GSI
Water Solutions, Inc.

Technical Memorandum

To: Elizabeth Sagmiller / City of Keizer
Kat LaFever / City of Keizer

From: Matt Kohlbecker, RG / GSI Water Solutions, Inc.
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REGISTERED
OREGON
MATTHEW V. KOHLBECKER
G2248
GEOLOGIST
EXP: 4/14

Date: November 18, 2013

Re: **Groundwater Protectiveness Demonstrations and Risk Prioritization for Underground Injection Control (UIC) Devices, City of Keizer, Oregon**

This technical memorandum (TM) presents a groundwater protectiveness demonstration (GWPD) for Underground Injection Control (UIC) devices in the City of Keizer (City), Oregon (Figure 1). The GWPD was conducted to support the City's 2013 UIC Water Pollution Control Facilities (WPCF) permit application.

1. Introduction

A UIC is device that infiltrates fluids into the subsurface. The City of Keizer (City) owns 86 UICs that manage stormwater mainly from public rights-of-way (ROW). The locations of the City's UICs are shown in Figure 2, and the City's UIC database is provided in Attachment A. The City uses horizontal UICs, vertical UICs, and UICs that consist of both vertical and horizontal elements (hybrid UICs):

- **Horizontal UICs.** Most of the City's UICs (72 of the 86, or 84%) are horizontal UICs. On average, horizontal UICs are 11-inch diameter pipes that are oriented parallel to the ground surface. The median length of a horizontal UIC in the City of Keizer is about 100 feet. Most horizontal UICs are perforated along the bottom to allow stormwater to infiltrate into the subsurface; however, a few are not perforated and dead-end into soil as an open pipe. The depth of the City's horizontal UICs ranges from 1 to 15 feet below ground surface.
- **Vertical UICs.** Relatively few of the City's UICs (11 of the 86, or 13%) are vertical UICs. Vertical UICs are 4 to 48-inch diameter cylindrical structures that are oriented perpendicular to the ground surface. Some vertical UICs have weep holes on the UIC

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wall that allow stormwater to infiltrate from the sides of the UIC, whereas others have solid walls and no bottom so that stormwater infiltrates from the bottom of the UIC. The depth of vertical UICs ranges from 2 to about 10 feet below ground surface.

- **Hybrid UICs.** Three of the City's 86 UICs are hybrid UICs. Hybrid UICs are interconnected horizontal and vertical UICs.

UICs are regulated by the Oregon Department of Environmental Quality (DEQ) under Oregon Administrative Rules (OAR) 340-044. In order to meet DEQ's basic requirements for rule authorization, the City cannot operate a UIC within 500 feet of a water well [OAR 340-044-0018(3)(a)(D)] or within the two year time of travel for a municipal supply well [OAR 340-044-0018(3)(a)(E)]. The City estimates that 59 of its 86 UICs are located within 500 feet of a tax lot containing a water well[1] and/or within the two year time of travel zone of a municipal supply well. Therefore, many of the City's UICs likely do not meet the basic conditions for rule-authorization. Because the City owns more than 50 UICs, the City must decommission UICs that do not meet the conditions for rule-authorization or manage its UICs under a permit (OAR 340-044-0018(3)(b)(A)(ii)). The City applied for a UIC WPCF permit (the permit) for its UICs on December 16, 2009. In July 2012, DEQ issued the *Draft Water Pollution Control Facilities Permit for Class V Stormwater Underground Injection Control Systems.* On August 6, 2013, the City received the applicant review draft for its UIC permit.

The permit is designed to protect groundwater to its highest beneficial use. As such, the permit stipulates that the City address UICs that are within 500 feet of a public drinking water or irrigation supply well, or inside the 2-year time of travel of a public water supply well. Options for addressing these UICs include developing a GWPD, retrofitting the UIC, or decommissioning the UIC. A GWPD is an evaluation of whether beneficial use of groundwater is adversely impacted by stormwater pollutants as a result of infiltration. The City has chosen to develop GWPD models to identify which UICs are protective of groundwater, and to prioritize future UIC decommissioning and retrofits based on the GWPD and other considerations (i.e., UIC functionality and other risk factors). This TM summarizes the GWPD models, which simulate attenuation of stormwater pollutants in the subsurface (i.e., after exfiltration from a UIC). Two GWPDs were conducted:

- **Unsaturated Zone GWPD**. The unsaturated zone GWPD is based on modeling pollutant fate and transport *vertically* through the *unsaturated* soils beneath a UIC. The objective of the unsaturated zone GWPD is to calculate the vertical distance required for pollutants to attenuate to background levels (which is considered to be the method reporting limit [MRL]), called the vertical protective separation distance. If the vertical separation distance at a UIC is greater than the protective separation distance, then the UIC is demonstrated to be protective and does not need to be retrofit or decommissioned. If the vertical separation distance at a UIC is less than the protective separation distance, then groundwater protectiveness must be demonstrated using a different method[2], the UIC must be retrofit, or the UIC must be decommissioned.

[1] As discussed in the City of Keizer UIC Systemwide Assessment (City of Keizer, 2013), the City identifies UICs that are potentially located within 500 feet of a water well using a conservative methodology. The precise location of a water well is typically uncertain (i.e., the most accurate driller logs provide only a tax lot for a water well's location, and often, driller logs provide far less accurate information such as a section or quarter section. Therefore, the City chose to classify a UIC as potentially being within 500 feet of a water well if the UIC was within 500 feet of a tax lot that contained a water well. Therefore, several of the 59 UICs within 500 feet of a tax lot containing a water well are likely more than 500 feet away from the actual water well.

[2] Other methods for demonstrating groundwater protectiveness include documentation that a water well is not being used for potable supply (e.g., well property connected to City water), evaluation of whether PCP is likely present within a UIC's drainage

- **Saturated Zone GWPD.** The saturated zone GWPD consists of modeling *horizontal* pollutant fate and transport through *saturated* soils. The model is used to demonstrate that that the UIC does not adversely impact groundwater users by delineating a waste management area (WMA) around the UIC. A WMA is the "area where waste or material that could become waste if released to the environment, is located or has been located" [OAR 340-040-0010(19)]. In the context of stormwater infiltration from a UIC, the WMA is the location where groundwater contains stormwater pollutants above background levels. The objective of the saturated zone GWPD is to calculate the horizontal distance required for pollutant concentrations to attenuate to background levels (i.e., the MRL), called the horizontal protective separation distance. This horizontal distance replaces the default horizontal separation distance in the permit template (i.e., 500 feet or 2-year time of travel).

Protective separation distance depends on the UIC configuration; therefore, protective separation distances depend on whether a UIC is horizontal, vertical, or a hybrid of the two. GWPDs have been conducted by several municipalities in Oregon, including the Cities of Gresham, Portland, Bend, Redmond, Eugene, Milwaukie, and Canby; Clackamas County Water Environment Services; and Lane County. Results of the GWPD models apply to stormwater with pollutant concentrations typical of stormwater runoff from urban ROWs, and do not apply to releases of pollutants to the environment (i.e., spills). The model results will be considered along with other relevant to groundwater protectiveness factors, permit requirements, and the City's goals and policies to develop a strategy for addressing the City of Keizer's UICs.

1.1 Objectives

The objectives of this TM are:

- Present technical documentation for the unsaturated zone and saturated zone GWPD models, and identify the protective vertical and horizontal separation distances for the City's horizontal, vertical and hybrid UICs.
- Identify whether each UIC is protective of groundwater, based on the protective separation distances calculated by the GWPD models.

The main text of this TM provides an overview of the City's UIC system and GWPD models. Additional technical details are provided in Attachment A (City of Keizer UIC database), Attachment B (technical documentation for the unsaturated zone GWPD model), Attachment C (technical documentation for the saturated zone GWPD model), and Attachment D (conservative assumptions for GWPD models).

2. Geology and Hydrogeology

Input parameters for the GWPD models are based on the physical characteristics of the soils in Keizer. This section summarizes the geologic and hydrogeologic characteristics of the soils with the objective of informing model input parameters.

basin (i.e., whether utility poles—the primary source of PCP—are present), or documentation that a water well is located upgradient and outside of the capture zone of a UIC.

The City is located in the Willamette Basin, which is topographic and structural trough between the foothills of the Coast Range to the west and Cascade Range to the east (Conlon et al., 2005). In the vicinity of Keizer, the basin is filled with unconsolidated alluvial deposits and basalts of the Columbia River Basalt Group (CRBG). Surficial geology within city limits is shown in Figure 3, and a cross section showing subsurface geology is shown in Figure 4. The Miocene CRBG is present at ground surface west of the Willamette River (unit Tcr), and is encountered at depths ranging from approximately 150 to over 400 feet below ground surface beneath the City[3]. Unconsolidated alluvial sediments overlie the CRBG, and become thicker towards the east. The unconsolidated alluvium includes the following geologic units, organized from youngest (shallowest) to oldest (deepest):

- **Floodplain Deposits of the Willamette River (Qalc on Figure 3).** Silts and sands deposited by the Willamette River and its tributaries. On the basis of boring logs presented in Golder Associates (1990), the Qalc is a "moderate brown silt." Based on driller's logs downloaded from OWRD (2013), the Qalc in Keizer is generally unsaturated, and ranges in thickness from about 10 to 30 feet, with an average thickness of about 18 feet. In local areas where the Qalc is saturated, private wells may pump groundwater for domestic purposes; however, most wells are completed in the underlying Troutdale Formation.

- **Catastropic Flood Deposits (Qff on Figure 3).** Silts and sands deposited by the one or more of the late Pleistocene catastrophic floods (Madin, 1990). Based on driller's logs downloaded from OWRD (2013), the Qff in Keizer is generally unsaturated, and ranges in thickness from about 10 to 40 feet, with an average thickness of about 30 feet. In local areas where the Qff is saturated, private wells may pump groundwater for domestic purposes; however, most wells are completed in the underlying Troutdale Formation.

- **Troutdale Formation.** Primarily sand and gravel with interbedded fine-grained sediment (silt and clay) that was deposited in Miocene to Pleistocene time (USGS, 1990). The Troutdale Formation is the primary water-bearing formation in Keizer, and all City wells pump groundwater from this unit. The Troutdale Formation is separated into a shallow and deep interval by a continuous silt and clay layer (shown by the black dashes within the Troutdale Formation in Figure 4). Aquifer test data in Golder Associates (1990) indicate that the silt is a semi-confining layer. The City's water wells pump from the deep Troutdale.

- **Sandy River Mudstone.** Fine-grained sediment (mudstone, siltstone, sand and claystone) that was deposited in Miocene to Pliocene times (USGS, 1990). The Sandy River Mudstone is not a significant source of groundwater in Keizer.

Conlon et al. (2005) groups these geologic units into four hydrogeologic units:

- **Willamette Silt Hydrogeologic Unit.** Includes the catastrophic flood deposits (Qff).

- **Upper Sedimentary Hydrogeologic Unit.** Includes the floodplain deposits of the Willamette River (Qalc).

- **Middle Sedimentary Hydrogeologic Unit.** Analagous to the Troutdale Formation (Tt) geologic unit.

[3] Based on pilot well logs TW-1, TW-2 and TW-5 (Golder Associates, 1990), and MARI 57704 (OWRD, 2013)

- **Lower Sedimentary Hydrogeologic Unit.** Analagous to the Sandy River Mudstone (Tsr) geologic unit.

As shown in Figure 3, the City's UICs are located in the Qalc geologic unit (i.e., the Upper Sedimentary Hydrogeologic Unit) and Qff geologic unit (i.e., the Willamette Silt Hydrogeologic Unit). The Qalc is more permeable than the Qff[4]; therefore, protective separation distance in the Qalc is larger than the protective separation distance in the Qff (i.e., because pollutants travel faster in the Qalc). Therefore, the protective separation distances calculated in this TM are conservatively determined using a model based on soil properties in the Qalc.

3. Groundwater Protectiveness Demonstrations

This section provides an overview of the unsaturated zone (Section 3.1) and saturated zone (Section 3.2) GWPD models.

The unsaturated and saturated zone models simulate pollutant fate and transport over time based on user-provided input parameters. During transport in the subsurface, pollutant concentrations are reduced by microbial action (biodegradation), dispersion, and sorption on aquifer solids. The objective of the modeling was to calculate the vertical and horizontal transport distances necessary to attenuate pollutants to below zero (i.e., the MRL). Pollutant fate and transport are simulated for organic pollutants pentachlorophenol (PCP); di(2-ethylhexyl)phthalate (DEHP); benzo(a)pyrene; and the metal lead. These pollutants are among the most mobile, toxic, and environmentally persistent in their respective chemical classes (GSI, 2008), and are the most likely pollutants in their respective chemical classes to exceed regulatory standards for stormwater at UICs (Kennedy/Jenks, 2009).

The following models were developed and run to calculate the protective separation distances:

- Unsaturated zone GWPD model for horizontal UICs
- Unsaturated zone GWPD model for vertical UICs
- Saturated zone GWPD model for horizontal UICs
- Saturated zone GWPD model for vertical UICs

Separate models were developed for horizontal and vertical UICs because the UIC configuration affects pollutant fate and transport (see Section 2.2.1 of Attachment B and Section 2.4.1 of Attachment C for technical details). A separate model was not developed for the City's three hybrid UICs because the protective separation distance at a hybrid UIC is determined using horizontal or vertical UIC model results.

Detailed technical documentation for input parameters, the governing equations, and conservative assumptions for the GWPD are provided in Attachment B (unsaturated zone GWPD) and Attachment C (saturated zone GWPD).

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4 According to a summary of hydraulic conductivities in the Willamette Valley (measured from aquifer tests, model calibrations, specific capacity tests, and cores) presented in Conlon et al., 2005, the horizontal hydraulic conductivity in the Willamette Silt ranges from 0.01 to 8 feet per day, and the horizontal hydraulic conductivity of the Upper Sedimentary Unit ranges from 0.03 to 24,500 feet per day.

3.1 Unsaturated Zone GWPD

This section presents the input parameters used in the unsaturated zone GWPD model, and the protective vertical separation distance calculated by the unsaturated zone GWPD model.

Model Setup and Input

The model is based on the 1-dimensional (1-D) advection dispersion equation, and is implemented in a Microsoft Excel spreadsheet. Model input parameters are summarized in Table 1 (soil properties) and Table 2 (pollutant properties). Soil properties for the horizontal UIC model and vertical UIC model are identical. Pollutant properties for the horizontal UIC model and vertical UIC model are identical with the exception of the distribution coefficient (K_d) and retardation factor (R) (see Section 2.2.1 of Attachment B for technical details).

The input parameters for the unsaturated zone GWPD are varied to evaluate two scenarios for pollutant fate and transport: (1) the average scenario, which is represented by the central tendency and is used for regulatory compliance, and (2) the reasonable maximum scenario, which is an upper bound on what could occur, but is considered unlikely to occur because of compounding conservatism.

Model Results

Table 3 presents the minimum protective vertical separation distances for vertical and horizontal UICs under the average and reasonable maximum scenarios of the unsaturated zone GWPD model. PCP migrates farther than the other pollutants that were modeled because it is more mobile in the environment. Therefore, the protective vertical separation distance at City UICs is conservatively based on PCP. Under the average scenario, PCP concentrations attenuate to below the MRL at 1.4 feet for vertical UICs and 2.1 feet for horizontal UICs. Protective vertical separation distances are larger for horizontal UICs because the organic carbon content of soil (i.e., f_{oc}) is lower for horizontal UICs.

When demonstrating groundwater protectiveness, we recommend adding 0.40 feet to the model-calculated vertical separation distances. The 0.4 feet is a measure of safety that accounts for natural variation of seasonal groundwater high elevations over time [5]. Therefore, we recommend using the following protective vertical separation distances for each UIC configuration:

- **Vertical UICs.** Use 1.8 feet for the minimum vertical separation distance (instead of the exact value of 1.4 feet)

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[5] The protective vertical separation distance is a separation from the seasonal high groundwater elevation. However, the seasonal high groundwater elevation fluctuates annually. The measure of safety accounts for these annual fluctuations in seasonal groundwater high, and was calculated using a prediction interval. A prediction interval contains a specified percent of the data from a distribution. For example, the upper 90% percent prediction interval for seasonal high groundwater elevation at a well contains 90% of the observed seasonal groundwater highs.

Groundwater elevation measurements from State of Oregon observation well MARI 6706 (located in T7S R2W Section 7DDD) were downloaded from the OWRD on-line groundwater elevation database. The period of record for MARI 6706 is 2001 to 2013. The well is completed in unconsolidated alluvium. The seasonal high groundwater elevation for each calendar year was identified, and one-sided nonparametric prediction interval was calculated using Equation 3.11 in Helsel and Hirsch (2002). Data from a calendar year was used only if data from at least one month during the January to May time period was available because this is the time period when the seasonal groundwater high typically occurs. The prediction interval was 0.41 feet above the median seasonal high groundwater elevation, respectively. Therefore, annual variation in seasonal high groundwater elevations is expected to be within 0.41 feet of the median seasonal high groundwater elevation 90% of the time.

- **Horizontal UICs and Hybrid UICs.** Use 2.5 feet for the minimum vertical separation distance (instead of the exact value of 2.1 feet)[6].

Vertical separation distance at the City UICs ranges from -1.45 feet (a wet feet UIC) to 63.4 feet, as shown in Attachment A. All but one of the City's 86 UICs have more than the protective vertical separation distance. The UIC that does not have the vertical protective separation distance (UIC 82) intersects the groundwater table, and is located next to Labish Creek in the SE ¼ of Section 26 of Township 6 South and Range 3 West (Figure 2).

The reasonable maximum scenario represents the worst-case conditions, and is characterized by compounding conservatism of input variables. The purpose of the reasonable maximum scenario is to evaluate model sensitivity, and it is not used for regulatory compliance. As is shown in Table 3, the protective separation distances under the worst-case "reasonable maximum scenario" are larger than the protective separation distances under the most likely "average scenario."

Model Verification

This section presents a verification of the unsaturated zone GWPD model. Model verification involves comparing the model result (i.e., PCP from UICs does not reach groundwater at 85 of the 86 City UICs) to observations (i.e., groundwater quality data) with the objective of confirming that model results are consistent with observations. Model results would be consistent with observations if PCP is not detected in groundwater beneath the City, and would be inconsistent with observations is a large-scale PCP plume was present in groundwater beneath the City.

The City collects groundwater quality samples from the City wells to fulfill requirements of the Safe Drinking Water Act (SDWA). The sampling includes collection of groundwater samples for analysis of PCP concentration. All samples are collected before treatment of the water. The City analyzes PCP at all wells every three years for two consecutive quarters (Pat Taylor, personal communication, 2013). PCP data were downloaded from the Oregon Health Authority on-line drinking water quality database (OHA, 2013), and results are tabulated in Table 4. PCP has not been detected in the City's public supply wells based on sampling conducted from 1993 to 2013, which is consistent with the results of the unsaturated zone GWPD model[7].

3.2 Saturated Zone GWPD

This section presents the input parameters used in the unsaturated zone GWPD model, and the protective vertical separation distance calculated by the unsaturated zone GWPD model.

Model Setup and Input

The conceptual model for the saturated zone GWPD assumes that the UIC intersects the seasonal high groundwater table such that the UIC extends 5 feet below the water table. The saturated zone GWPD model is based on a conservative, 3-D numerical groundwater model

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[6] Hybrid UICs contain elements of a vertical UIC and a horizontal UIC. The 2.5 feet of vertical separation distance that we recommend for hybrid UICs is based on model simulations of a horizontal UIC. We recommend using the 2.5 feet value for hybrid UICs because it is more conservative than using the1.8 feet that was calculated based on model simulations of a vertical UIC.

[7] The City wells are located in the lower Troutdale Formation, and are separated from the City's UICs by a continuous, low permeability silt and clay layer. Aquifer test data presented in Golder Associates (1990) indicates that the silt and clay layer is a leaky confining unit.

(MODFLOW) that is coupled with a pollutant fate and transport model (MT3D) to simulate pollutant attenuation by dilution, dispersion, biodegradation, and retardation. Model input parameters are summarized in Table 5 (soil properties) and Table 6 (pollutant properties).

Model Results

Table 7 presents the protective horizontal separation distances based on the saturated zone GWPD model. PCP migrates farther than the other pollutants that were modeled because it is more mobile and persistent in the environment. Therefore, the protective horizontal separation distances at City UICs are conservatively based on PCP. We recommend using the following protective horizontal separation distances for each UIC configuration:

- **Vertical UICs and Hybrid UICs.** Use 117 feet for the minimum protective horizontal separation distance.
- **Horizontal UICs.** Use 101 feet for the minimum protective horizontal separation distance[8].

If PCP is not present in a UIC drainage basin[9], then the protective horizontal separation distance should be based on DEHP (59 feet for vertical/hybrid UICs and 41 feet for horizontal UICs).

4. Conclusion and Recommendations

The GWPD models in this technical memorandum satisfy Condition 7(b) of Schedule A of the City's applicant review draft UIC WPCF permit, which requires that the City conduct a GWPD within one year of discovering a UIC within a default setback of water wells. According to these model-based GWPDs, a UIC is not protective if all three conditions are true:

- The UIC is located within a default water well setback, AND
- The vertical separation distance to seasonal high groundwater is less than 1.8 feet (vertical UIC) or 2.5 feet (horizontal and hybrid UIC), AND
- The horizontal separation distance between a UIC and water well is less than 117 feet (vertical and hybrid UIC for PCP) or 101 feet (horizontal UIC for PCP).

Based on the above criteria, all 86 UICs are protective of groundwater (see Attachment A). If additional UICs are identified or constructed in the future, they should be evaluated for protectiveness. UICs that are not protective according to the model-based GWPDs need to be retrofit or decommissioned, or groundwater protectiveness can be demonstrated using another method. Other methods for demonstrating groundwater protectiveness include documentation that a water well is not being used for potable supply (e.g., well property connected to City water), evaluation of whether PCP is likely present within a UIC's drainage basin (i.e., whether

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[8] Hybrid UICs contain elements of a vertical UIC and a horizontal UIC. The 117 feet of vertical separation distance that we recommend for hybrid UICs is based on model simulations of a vertical UIC. We recommend using the 117 feet value for hybrid UICs because it is more conservative than using the 101 feet that was calculated based on model simulations of a horizontal UIC.

[9] Most if not all PCP in stormwater is leached from treated wood utility poles (City of Portland, 2008). Therefore, PCP may not be present in UIC drainage basins that do not contain wood utility poles. Other potential sources of PCP are pesticide (e.g., lindane, hexachlorobenzene) breakdown products, insecticides, herbicides, fungicides, preservatives, glues, paper coatings, inks, and incineration of chlorine-containing wastes.

utility poles—the primary source of PCP—are present), or documentation that a water well is located upgradient and outside of the capture zone of a UIC.

The GWPD models were developed under conservative assumptions that are summarized in Appendix D. The process for demonstrating protectiveness using the GWPD models involves the following steps:

1. Determine whether the UIC is within the default setback to a water well, as specified in the City's UIC WPCF permit (500 feet from a water well or the two year time of travel of a municipal water well). Protectiveness only needs to be demonstrated if the UIC is within a default setback to a water well.
2. If the UIC is located within a default well setback, compare the vertical separation distance from seasonal high groundwater to the protective separation distances of 1.8 feet (vertical UICs) or 2.5 feet (horizontal or hybrid UICs). The UIC is protective of groundwater if the vertical separation distance at the UIC is greater than the protective separation distance.
3. If the vertical separation distance at the UIC is less than the protective separation distance of 1.8 feet (vertical UICs) or 2.5 feet (horizontal or hybrid UICs), compare the horizontal separation distance between the UIC and nearest water well to the protective horizontal separation distances of 117 feet (vertical or hybrid UICs) or 101 feet (horizontal UICs). The UIC is protective of groundwater if the horizontal separation distance between the UIC and water well is greater than the protective separation distance.
4. If the model results applied in 1-3 above do not demonstrate protectiveness, apply other protectiveness demonstrations, if applicable.
5. If the UIC is not protective of groundwater, the UIC needs to be retrofit or decommissioned over the 10 year term of the permit, or other methods for demonstrating groundwater protectiveness need to be employed within one year of discovery.

References

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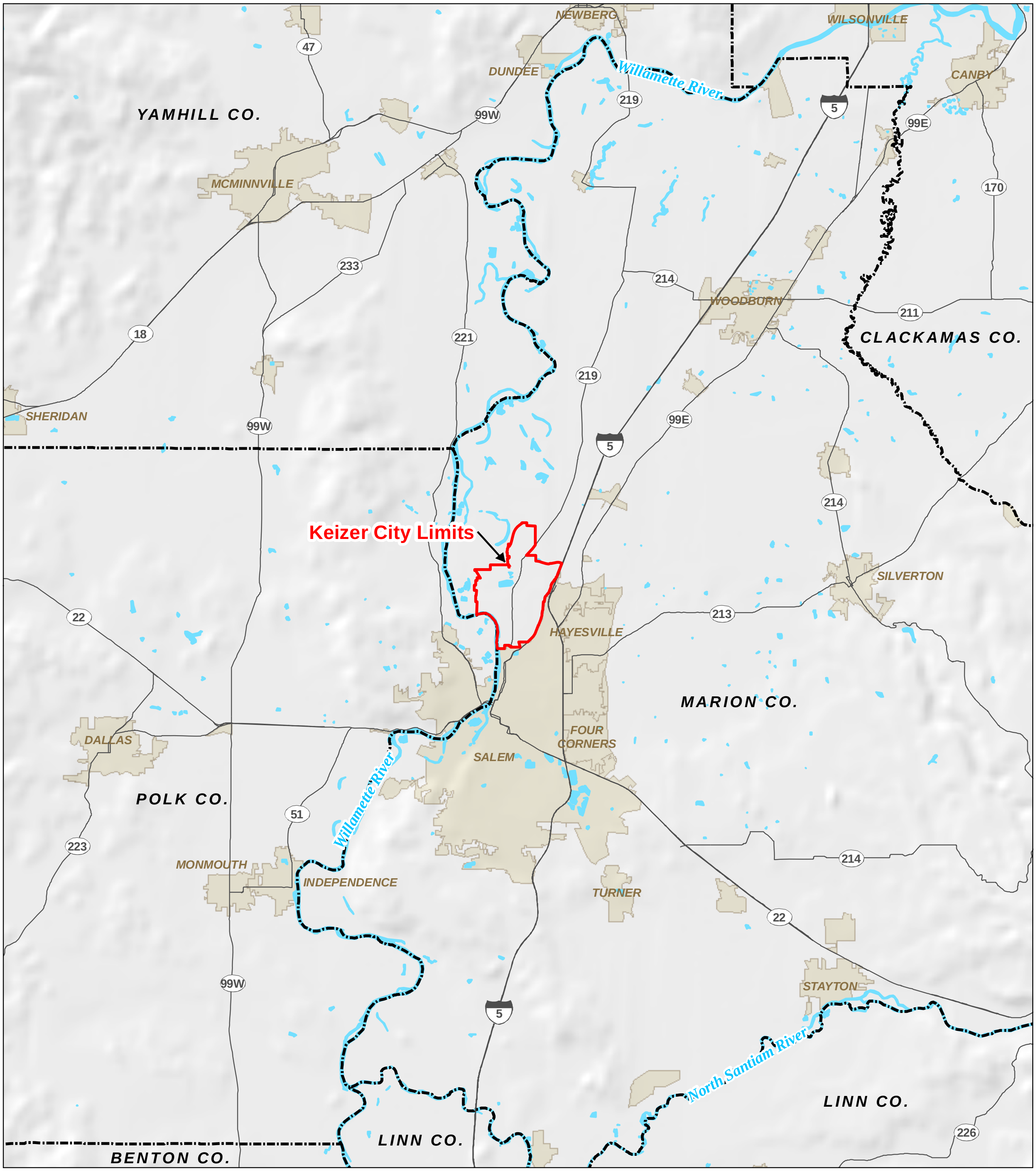
FIGURES



LEGEND

- Site Location
- Cities
- Counties
- Highways
- Major Waterbodies

MAP NOTES:
Date: September 9, 2013
Data Sources: OGIC, USGS, ESRI

FIGURE 1

Site Location
City of Keizer
Groundwater Protectiveness Demonstration

N

0 2.5 5
Miles

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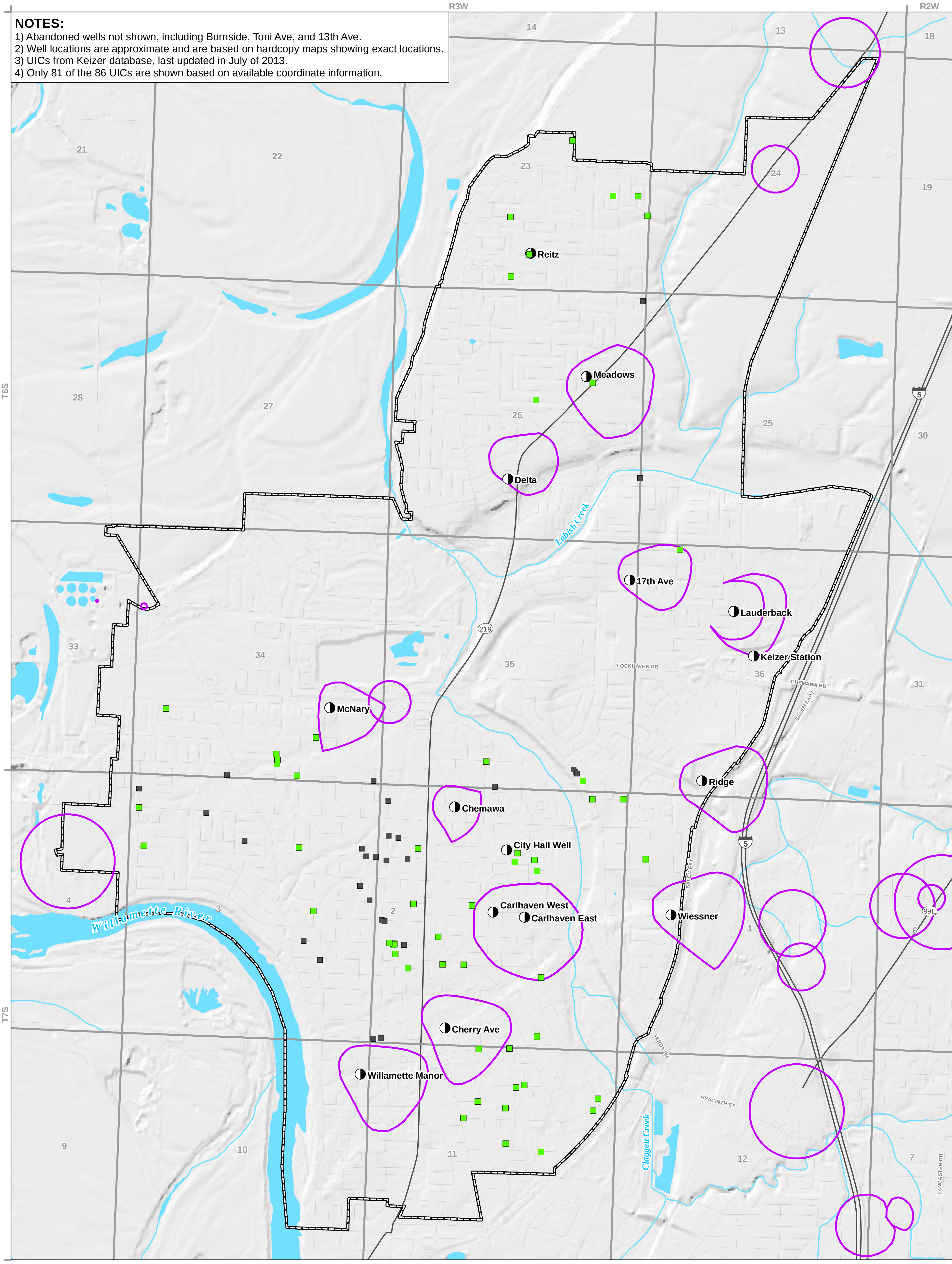
File Path: P:\Portland\150 - Keizer City\003 - UIC Services\Project_GIS\Project_mxds\Report_Figures\Figure1_Site_Location.mxd



LEGEND

- UICs Inside Well Setbacks (57 Total)
- UICs Outside Well Setbacks (29 Total)
- City Water Supply Wells
- 2 Year Time of Travel Zones

All Other Features

- Future City Limits
- Highways
- Roads
- Watercourses
- Waterbodies

N

0 1,000 2,000 3,000

Feet

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FIGURE 2

UICs and Municipal Supply Wells

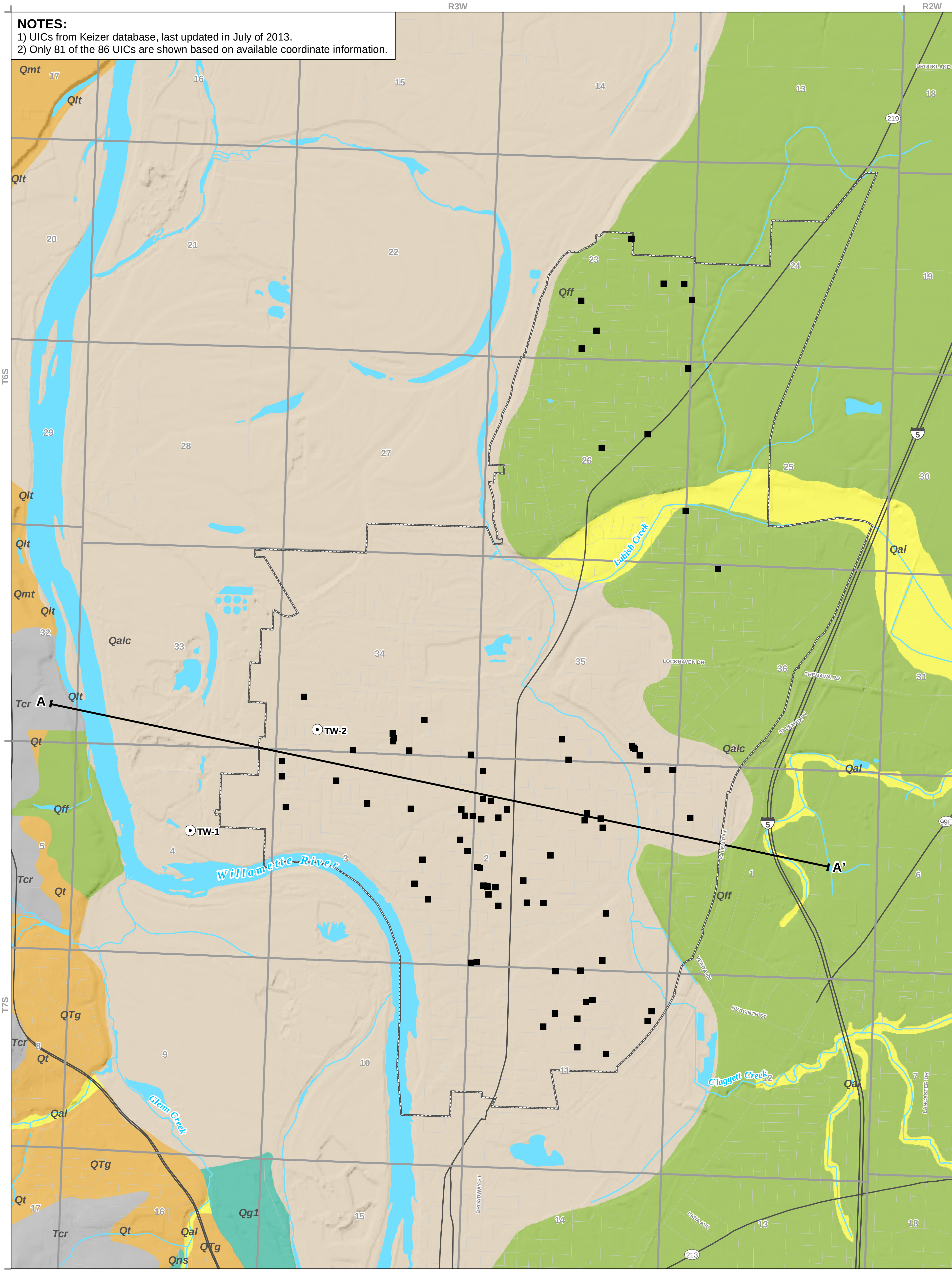
City of Keizer

Groundwater Protectiveness Demonstration

MAP NOTES:
Date: November 18, 2013
Data Sources: City of Keizer, OR DEQ, USGS, OGIC, ESRI

File Path: P:\Portland\150 - Keizer City\003 - UIC Services\Project_GIS\Project_mxds\Report_Figures\Figure2_UICs_and_Wells.mxd

NOTES:
1) UICs from Keizer database, last updated in July of 2013.
2) Only 81 of the 86 UICs are shown based on available coordinate information.



LEGEND

- ■ UIC Location

Surficial Geology

- Qal - Alluvium stream deposits
- Qalc - Floodplain deposits of the Willamette River and major tributaries
- Qff - Quaternary fine-grained deposits
- Qlt, Qmt, Qt, QTg - Terrace Deposits
- Qg1, Qns - Other Sedimentary Deposits
- Tcr - Columbia River Basalt Group

All Other Features

- Wells
- City Water Supply Wells
- Future City Limits
- Highways
- Roads
- Watercourses
- Waterbodies

MAP NOTES:
Date: November 18, 2013
Data Sources: City of Keizer, DOGAMI, USGS, OGIC, ESRI

N

0 1,250 2,500 3,750
Feet

FIGURE 3

Surficial Geology

City of Keizer
Groundwater Protectiveness Demonstration

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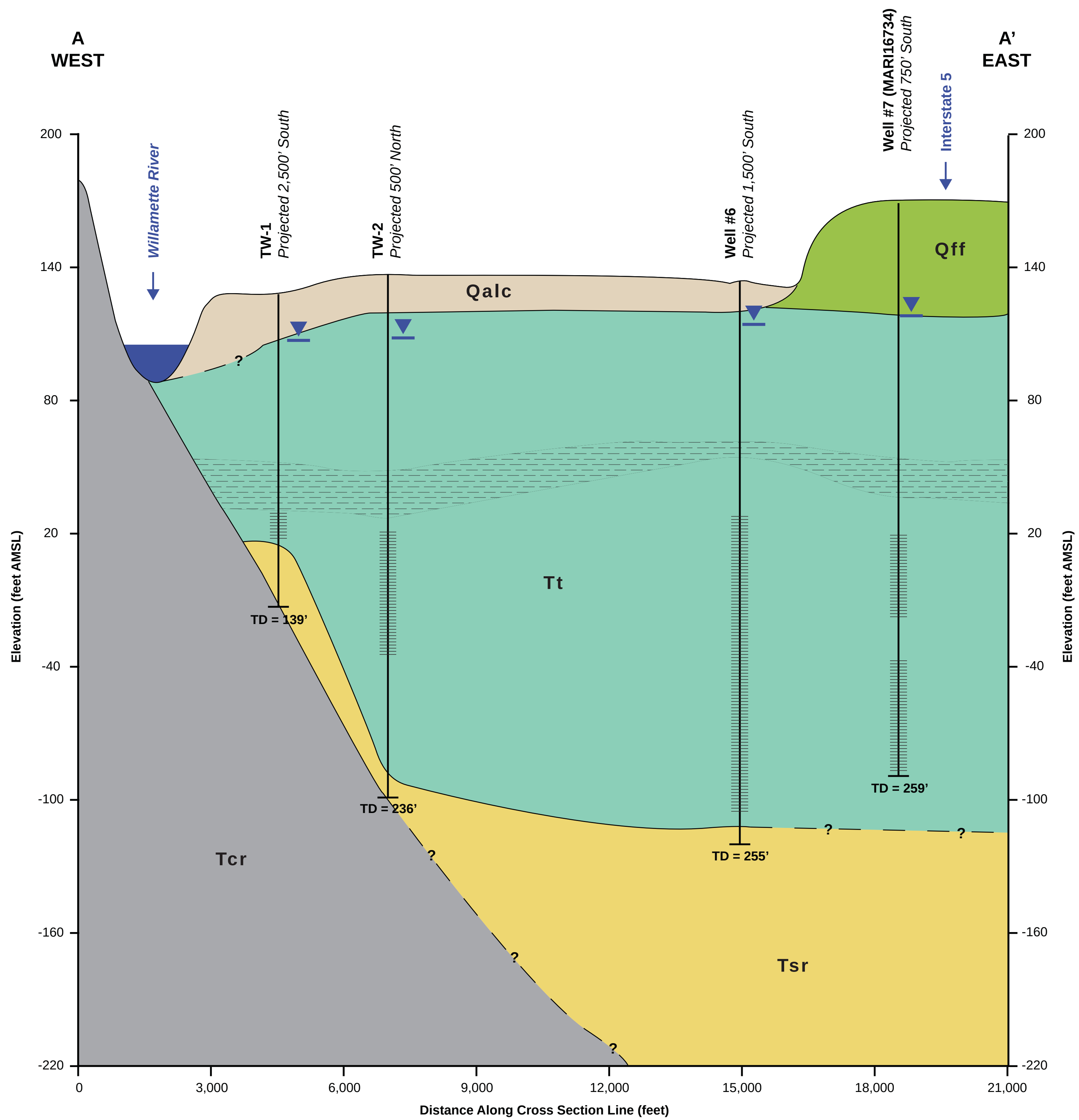

FIGURE 4

Cross Section A-A'

City of Keizer
Groundwater Protectiveness Demonstration

LEGEND

- Well
- Screen Interval
- Static Groundwater Level
- Qff, Fine Grained Facies of the Catastrophic Flood Deposits
- Qalc, Floodplain Deposits of the Willamette River
- Tt, Troutdale Formation (dashes indicate regional semiconfining silt and clay layer)
- Tsr, Sandy River Mudstone
- Tcr, Basalt of CRBG

NOTES

AMSL: Above Mean Sea Level
TD: Total Depth
CRBG: Columbia River Basalt Group

SCALE

Horizontal
1" = 3,000'

Vertical
1" = 60'

50X Vertical Exaggeration

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P:\Portland\150 - Keizer City\003 - UIC Services\Figures

TABLES

Table 1

Unsaturated Zone GWPD Model Input Parameters – Soil Properties

City of Keizer

Input Parameter	Units	Average Scenario	Reasonable Maximum Scenario	Data Source and Location of Technical Documentation
Total Porosity (η)	-	0.375	0.375	Midrange porosity for a sand, Freeze and Cherry (1979) Table 2.4. Appendix B, Section 2.1.1.
Effective Porosity (η_e)	-	0.20	0.20	Within the range of effective porosities for the Upper Sedimentary Unit in Conlon et al. (pg. 9, 2005)
Bulk Density (ρ_b)	g/cm^3	1.66	1.66	Calculated by equation 8.26 in Freeze and Cherry (1979). Appendix B, Section 2.1.2.
f_{oc}	-	0.005677 (Vertical) 0.003481 (Horizontal)	0.002087 (Vertical) 0.001278 (Horizontal)	Carbon loading from stormwater. Appendix B, Section 2.2.1.
Dispersivity (α)	m/d	5% of transport distance	5% of transport distance	Calculated based on Gelhar (1985). Appendix B, Section 2.1.3.
Pore Water Velocity (v)	m/d	0.20	1.45	Based on an effective porosity of 0.20 (Craner et al., 2005) and the median (average scenario) or maximum (reasonable maximum scenario) hydraulic conductivity measured from infiltration tests at City UICs. Appendix B, Section 2.1.4.

Notes

g/cm^3 = grams per cubic centimeter

m/d = meters per day

(-) = input parameter units are dimensionless

Table 2

Unsaturated Zone GWPD Model Input Parameters – Pollutant Properties

City of Keizer

Input Parameter	Units	Pollutant	Average Scenario	Reasonable Maximum Scenario	Data Source and Location of Technical Documentation
Initial Concentration	μg/L	PCP	10	10	Action Level in City of Keizer UIC WPCF Applicant Review Draft Permit No. 119546, dated August 6, 2013
		DEHP	300	300	Action Level in City of Keizer UIC WPCF Applicant Review Draft Permit No. 119546, dated August 6, 2013
		B(a)P	2	2	Action Level in City of Keizer UIC WPCF Applicant Review Draft Permit No. 119546, dated August 6, 2013
		Lead	500	500	Action Level in City of Keizer UIC WPCF Applicant Review Draft Permit No. 119546, dated August 6, 2013
Organic Carbon Partitioning Coefficient (K_{oc})	L/Kg	PCP	536.5	536.5	EPA (1996), assuming a pH of 6.95 based on groundwater pH measured at test wells underlying Keizer city limits. Appendix B, Section 2.3.1.
		DEHP	12,200	12,200	Calculated based on equations in Roy and Griffin (1985). Appendix B, Section 2.3.1.
		B(a)P	282,185	282,185	
Distribution Coefficient (K_d)	L/Kg	PCP	1.9 (Horizontal) 3.0 (Vertical)	0.7 (Horizontal) 1.1 (Vertical)	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		DEHP	43 (Horizontal) 69 (Vertical)	16 (Horizontal) 25 (Vertical)	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		B(a)P	980 (Horizontal) 1,600 (Vertical)	360 (Horizontal) 590 (Vertical)	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		Lead	1,200,000	535,000	Calculated based on Bricker (1998). Appendix B, Section 2.3.2.
Half Life (h)	d	PCP	31.4	49.9	Literature values. Appendix B, Section 2.3.3.
		DEHP	46.2	69.3	Literature values. Appendix B, Section 2.3.3.
		B(a)P	533	2,666	Literature values. Appendix B, Section 2.3.3.
Retardation Factor (R)	-	PCP	9.2 (Horizontal) 15 (Vertical)	4.0 (Horizontal) 5.9 (Vertical)	Calculated based on Equation (9.14) in Freeze and Cherry (1979). Appendix B, Section 2.3.4.
		DEHP	190 (Horizontal) 310 (Vertical)	70 (Horizontal) 110 (Vertical)	
		B(a)P	4,350 (Horizontal) 7,100 (Vertical)	1,600 (Horizontal) 2,600 (Vertical)	
		Lead	5,300,000	2,400,000	

Notes

d = days

L/Kg = Liters per Kilogram

mg/L = micrograms per liter

DEHP = di(2-ethylhexyl) phthalate

(-) = input parameter units are dimensionless

PCP = pentachlorophenol

B(a)P = benzo(a)pyrene

H = horizontal UIC

V = vertical UIC

GSI Water Solutions, Inc.

Table 3

Unsaturated Zone GWPD - Protective Vertical Separation Distances

City of Keizer

Pollutant	MRL (µg/L)	Minimum Protective Vertical Separation Distance [2] (feet)		
		Average Scenario	Reasonable Maximum Scenario	Recommended Value [3]
Vertical UICs				
Lead [1]	0.1	< 0.1	< 0.1	1.8
Benzo(a)pyrene	0.01	< 0.1	< 0.1	
PCP	0.04	1.4	24.0	
DEHP	1	< 0.1	1.3	
Horizontal UICs				
Lead [1]	0.1	< 0.1	< 0.1	2.5
Benzo(a)pyrene	0.01	< 0.1	< 0.1	
PCP	0.04	2.1	35.3	
DEHP	1	0.1	2.1	
Hybrid UICs				
Lead [1]	0.1	NC	NC	Depends on UIC configuration, See Page 6 of Text
Benzo(a)pyrene	0.01	NC	NC	
PCP	0.04	NC	NC	
DEHP	1	NC	NC	

Notes:

MRL = method reporting limit

µg/L = micrograms per liter

NC = not calculated

PCP = pentachlorophenol

DEHP = di(2-ethylhexyl)phthalate

[1] Metals transport simulations are longer than 12.86 days because metals do not biodegrade over time. Metals transport simulations assume 1000 years of transport at 12.86 days per year = 12,860 days of transport.

[2] The vertical separation distance in the unsaturated zone that is necessary for pollutant concentrations to attenuate to below the method reporting limit.

[3] "Recommended Value" is based on PCP, which migrates further than the other pollutants that were modeled. The Recommeded Value was calculated by adding the minimum protective vertical separation distance for PCP under the average scenario to a safety measure of 0.4 feet. The safety measure accounts for uncertainties in the seasonal high groundwater elevation contour map and natural variation of seasonal high groundwater elevations over time.

Table 4
Analysis of PCP in City Wells
City of Keizer

Sample ID	Sample Date	Chemical	Sample Point	Sample Point Name	Result
60222-21	21-Feb-96	Pentachlorophenol	A	EP FOR BURNSIDE PUMP	ND
40119-1	18-Jan-94	Pentachlorophenol	A	ENTRY POINT-BURNSIDE PUMP	ND
90226-2	23-Feb-99	Pentachlorophenol	AA	WELL #1 (BURNSIDE PUMP)	ND
30617-9	15-Jun-93	Pentachlorophenol	AA	WELL #1 (BURNSIDE PUMP) - WELL #1 (BUR	ND
30311-14	10-Mar-93	Pentachlorophenol	AA	WELL #1 (BURNSIDE PUMP) - WELL #1 (BUR	ND
60222-18	21-Feb-96	Pentachlorophenol	B	EP FOR CARLHAVEN EAST	ND
90226-11	24-Feb-99	Pentachlorophenol	BA	WELL #2 (CARLHAVEN EAST)	ND
31208-8	7-Dec-93	Pentachlorophenol	BA	WELL #2 (CARLHAVEN EAST) - WELL #2 (CA	ND
30617-11	15-Jun-93	Pentachlorophenol	BA	WELL #2 (CARLHAVEN EAST) - WELL #2 (CA	ND
30311-20	10-Mar-93	Pentachlorophenol	BA	WELL #2 (CARLHAVEN EAST) - WELL #2 (CA	ND
60222-14	21-Feb-96	Pentachlorophenol	C	EP FOR CARLHAVEN WEST	ND
90226-5	23-Feb-99	Pentachlorophenol	CA	WELL #3 (CARLHAVEN WEST)	ND
31208-14	7-Dec-93	Pentachlorophenol	CA	WELL #3 (CARLHAVEN WEST) - WELL #3 (CA	ND
30617-13	15-Jun-93	Pentachlorophenol	CA	WELL #3 (CARLHAVEN WEST) - WELL #3 (CA	ND
30311-17	10-Mar-93	Pentachlorophenol	CA	WELL #3 (CARLHAVEN WEST) - WELL #3 (CA	ND
90226-10	24-Feb-99	Pentachlorophenol	DA	WELL #4 (CHEMAWA)	ND
60222-22	21-Feb-96	Pentachlorophenol	DA	WELL #4 (CHEMAWA)	ND
31208-13	7-Dec-93	Pentachlorophenol	DA	WELL #4 (CHEMAWA) - WELL #4 (CHEMAWA)	ND
30617-4	15-Jun-93	Pentachlorophenol	DA	WELL #4 (CHEMAWA) - WELL #4 (CHEMAWA)	ND
30311-18	10-Mar-93	Pentachlorophenol	DA	WELL #4 (CHEMAWA) - WELL #4 (CHEMAWA)	ND
60222-15	21-Feb-96	Pentachlorophenol	E	EP FOR CHERRY AVE.	ND
90226-4	23-Feb-99	Pentachlorophenol	EA	WELL #5 (CHERRY AVENUE)	ND
31208-5	7-Dec-93	Pentachlorophenol	EA	WELL #5 (CHERRY AVENUE) - WELL #5 (CHE	ND
30617-14	15-Jun-93	Pentachlorophenol	EA	WELL #5 (CHERRY AVENUE) - WELL #5 (CHE	ND
30311-23	10-Mar-93	Pentachlorophenol	EA	WELL #5 (CHERRY AVENUE) - WELL #5 (CHE	ND
20718-32S	18-Jul-02	PENTACHLOROPHENOL	EP-A	INACTIVE EP FOR BURNSIDE PUMP	ND
20060608005-S	8-Jun-06	PENTACHLOROPHENOL	EP-B	INACTIVE EP FOR CARLHAVEN EAST	ND
50831-24S	30-Aug-05	PENTACHLOROPHENOL	EP-B	INACTIVE EP FOR CARLHAVEN EAST	ND
50413-3S	12-Apr-05	PENTACHLOROPHENOL	EP-B	INACTIVE EP FOR CARLHAVEN EAST	ND
20718-22S	18-Jul-02	PENTACHLOROPHENOL	EP-B	INACTIVE EP FOR CARLHAVEN EAST	ND
811180101-S	17-Nov-08	PENTACHLOROPHENOL	EP-C	INACTIVE EP FOR CARLHAVEN WEST	ND
808210101-S	20-Aug-08	PENTACHLOROPHENOL	EP-C	INACTIVE EP FOR CARLHAVEN WEST	ND
50719-49S	19-Jul-05	PENTACHLOROPHENOL	EP-C	INACTIVE EP FOR CARLHAVEN WEST	ND
50413-4S	12-Apr-05	PENTACHLOROPHENOL	EP-C	INACTIVE EP FOR CARLHAVEN WEST	ND
20718-23S	18-Jul-02	PENTACHLOROPHENOL	EP-C	INACTIVE EP FOR CARLHAVEN WEST	ND
305223215-S	22-May-13	PENTACHLOROPHENOL	EP-D	EP FOR CHEMAWA	ND
811180113-S	17-Nov-08	PENTACHLOROPHENOL	EP-D	EP FOR CHEMAWA	ND
808210114-S	20-Aug-08	PENTACHLOROPHENOL	EP-D	EP FOR CHEMAWA	ND
50719-61S	19-Jul-05	PENTACHLOROPHENOL	EP-D	EP FOR CHEMAWA	ND
50413-14S	12-Apr-05	PENTACHLOROPHENOL	EP-D	EP FOR CHEMAWA	ND
20718-29S	18-Jul-02	PENTACHLOROPHENOL	EP-D	EP FOR CHEMAWA	ND
305223206-S	22-May-13	PENTACHLOROPHENOL	EP-E	EP FOR CHERRY AVENUE	ND
811180102-S	17-Nov-08	PENTACHLOROPHENOL	EP-E	EP FOR CHERRY AVENUE	ND
808210102-S	20-Aug-08	PENTACHLOROPHENOL	EP-E	EP FOR CHERRY AVENUE	ND
50719-50S	19-Jul-05	PENTACHLOROPHENOL	EP-E	EP FOR CHERRY AVENUE	ND
50413-5S	12-Apr-05	PENTACHLOROPHENOL	EP-E	EP FOR CHERRY AVENUE	ND
20718-24S	18-Jul-02	PENTACHLOROPHENOL	EP-E	EP FOR CHERRY AVENUE	ND
50719-55S	19-Jul-05	PENTACHLOROPHENOL	EP-F	INACTIVE EP FOR ABANDONED DELTA	ND
50413-8S	12-Apr-05	PENTACHLOROPHENOL	EP-F	INACTIVE EP FOR ABANDONED DELTA	ND
20718-35S	18-Jul-02	PENTACHLOROPHENOL	EP-F	INACTIVE EP FOR ABANDONED DELTA	ND
305223213-S	22-May-13	PENTACHLOROPHENOL	EP-G	EP FOR LAUDERBACK	ND
811180109-S	17-Nov-08	PENTACHLOROPHENOL	EP-G	EP FOR LAUDERBACK	ND
808210110-S	20-Aug-08	PENTACHLOROPHENOL	EP-G	EP FOR LAUDERBACK	ND
50719-58S	19-Jul-05	PENTACHLOROPHENOL	EP-G	EP FOR LAUDERBACK	ND
50413-13S	12-Apr-05	PENTACHLOROPHENOL	EP-G	EP FOR LAUDERBACK	ND
20718-28S	18-Jul-02	PENTACHLOROPHENOL	EP-G	EP FOR LAUDERBACK	ND
305223204-S	22-May-13	PENTACHLOROPHENOL	EP-H	EP FOR McNARY	ND
811180103-S	17-Nov-08	PENTACHLOROPHENOL	EP-H	EP FOR McNARY	ND
808210104-S	20-Aug-08	PENTACHLOROPHENOL	EP-H	EP FOR McNARY	ND
50719-52S	19-Jul-05	PENTACHLOROPHENOL	EP-H	EP FOR McNARY	ND
50413-7S	12-Apr-05	PENTACHLOROPHENOL	EP-H	EP FOR McNARY	ND
20718-34S	18-Jul-02	PENTACHLOROPHENOL	EP-H	EP FOR McNARY	ND
20718-30S	18-Jul-02	PENTACHLOROPHENOL	EP-I	INACTIVE EP FOR TONI AVE.	ND
305223210-S	22-May-13	PENTACHLOROPHENOL	EP-J	EP FOR WIESSNER	ND
811180112-S	17-Nov-08	PENTACHLOROPHENOL	EP-J	EP FOR WIESSNER	ND
808210113-S	20-Aug-08	PENTACHLOROPHENOL	EP-J	EP FOR WIESSNER	ND

Table 4
Analysis of PCP in City Wells
City of Keizer

Sample ID	Sample Date	Chemical	Sample Point	Sample Point Name	Result
50719-60S	19-Jul-05	PENTACHLOROPHENOL	EP-J	EP FOR WIESSNER	ND
50413-2S	12-Apr-05	PENTACHLOROPHENOL	EP-J	EP FOR WIESSNER	ND
20718-21S	18-Jul-02	PENTACHLOROPHENOL	EP-J	EP FOR WIESSNER	ND
305223205-S	22-May-13	PENTACHLOROPHENOL	EP-K	EP FOR WILLAMETTE MANOR	ND
812101201-S	9-Dec-08	PENTACHLOROPHENOL	EP-K	EP FOR WILLAMETTE MANOR	ND
808210103-S	20-Aug-08	PENTACHLOROPHENOL	EP-K	EP FOR WILLAMETTE MANOR	ND
50719-51S	19-Jul-05	PENTACHLOROPHENOL	EP-K	EP FOR WILLAMETTE MANOR	ND
50413-6S	12-Apr-05	PENTACHLOROPHENOL	EP-K	EP FOR WILLAMETTE MANOR	ND
20718-31S	18-Jul-02	PENTACHLOROPHENOL	EP-K	EP FOR WILLAMETTE MANOR	ND
811180107-S	17-Nov-08	PENTACHLOROPHENOL	EP-L	EP FOR 13TH AVENUE	ND
808210108-S	20-Aug-08	PENTACHLOROPHENOL	EP-L	EP FOR 13TH AVENUE	ND
50901-22	31-Aug-05	PENTACHLOROPHENOL	EP-L	EP FOR 13TH AVENUE	ND
50413-11S	12-Apr-05	PENTACHLOROPHENOL	EP-L	EP FOR 13TH AVENUE	ND
20718-26S	18-Jul-02	PENTACHLOROPHENOL	EP-L	EP FOR 13TH AVENUE	ND
811180108-S	17-Nov-08	PENTACHLOROPHENOL	EP-M	EP FOR 17TH AVENUE	ND
808210109-S	20-Aug-08	PENTACHLOROPHENOL	EP-M	EP FOR 17TH AVENUE	ND
50901-23	31-Aug-05	PENTACHLOROPHENOL	EP-M	EP FOR 17TH AVENUE	ND
50413-12S	12-Apr-05	PENTACHLOROPHENOL	EP-M	EP FOR 17TH AVENUE	ND
20718-27S	18-Jul-02	PENTACHLOROPHENOL	EP-M	EP FOR 17TH AVENUE	ND
305223202-S	22-May-13	PENTACHLOROPHENOL	EP-N	EP FOR MEADOWS	ND
811180105-S	17-Nov-08	PENTACHLOROPHENOL	EP-N	EP FOR MEADOWS	ND
808210106-S	20-Aug-08	PENTACHLOROPHENOL	EP-N	EP FOR MEADOWS	ND
50719-54S	19-Jul-05	PENTACHLOROPHENOL	EP-N	EP FOR MEADOWS	ND
50413-9S	12-Apr-05	PENTACHLOROPHENOL	EP-N	EP FOR MEADOWS	ND
20718-25S	18-Jul-02	PENTACHLOROPHENOL	EP-N	EP FOR MEADOWS	ND
305223211-S	22-May-13	PENTACHLOROPHENOL	EP-O	EP FOR RIDGE DRIVE	ND
811180111-S	17-Nov-08	PENTACHLOROPHENOL	EP-O	EP FOR RIDGE DRIVE	ND
808210112-S	20-Aug-08	PENTACHLOROPHENOL	EP-O	EP FOR RIDGE DRIVE	ND
50719-59S	19-Jul-05	PENTACHLOROPHENOL	EP-O	EP FOR RIDGE DRIVE	ND
50413-1S	12-Apr-05	PENTACHLOROPHENOL	EP-O	EP FOR RIDGE DRIVE	ND
20718-20S	18-Jul-02	PENTACHLOROPHENOL	EP-O	EP FOR RIDGE DRIVE	ND
305223201-S	22-May-13	PENTACHLOROPHENOL	EP-P	EP FOR REITZ	ND
811180104-S	17-Nov-08	PENTACHLOROPHENOL	EP-P	EP FOR REITZ	ND
808210105-S	20-Aug-08	PENTACHLOROPHENOL	EP-P	EP FOR REITZ	ND
50719-53S	19-Jul-05	PENTACHLOROPHENOL	EP-P	EP FOR REITZ	ND
50413-10S	12-Apr-05	PENTACHLOROPHENOL	EP-P	EP FOR REITZ	ND
31014-30S	13-Oct-03	PENTACHLOROPHENOL	EP-P	EP FOR REITZ	ND
305223212-S	22-May-13	PENTACHLOROPHENOL	EP-Q	EP FOR KEIZER STATION	ND
811180110-S	17-Nov-08	PENTACHLOROPHENOL	EP-Q	EP FOR KEIZER STATION	ND
808210111-S	20-Aug-08	PENTACHLOROPHENOL	EP-Q	EP FOR KEIZER STATION	ND
706210501	20-Jun-07	PENTACHLOROPHENOL	EP-Q	EP FOR KEIZER STATION	ND
305223203-S	22-May-13	PENTACHLOROPHENOL	EP-R	EP FOR DELTA	ND
811180106-S	17-Nov-08	PENTACHLOROPHENOL	EP-R	EP FOR DELTA	ND
808210107-S	20-Aug-08	PENTACHLOROPHENOL	EP-R	EP FOR DELTA	ND
706210503	20-Jun-07	PENTACHLOROPHENOL	EP-R	EP FOR DELTA	ND
20060425007-S	25-Apr-06	PENTACHLOROPHENOL	EP-R	EP FOR DELTA	ND
305223209-S	22-May-13	PENTACHLOROPHENOL	EP-S	EP FOR CITY HALL	ND
812101202-S	9-Dec-08	PENTACHLOROPHENOL	EP-S	EP FOR CITY HALL	ND
808210115-S	20-Aug-08	PENTACHLOROPHENOL	EP-S	EP FOR CITY HALL	ND
305223207-S	22-May-13	PENTACHLOROPHENOL	EP-T	EP FOR CARLHAVEN WEST	ND
207311202-S	30-Jul-12	PENTACHLOROPHENOL	EP-T	EP FOR CARLHAVEN WEST	ND
109280702-S	27-Sep-11	PENTACHLOROPHENOL	EP-T	EP FOR CARLHAVEN WEST	ND
20101013049-S	13-Oct-10	PENTACHLOROPHENOL	EP-T	EP FOR CARLHAVEN WEST	ND
305223208-S	22-May-13	PENTACHLOROPHENOL	EP-U	EP FOR CARLHAVEN EAST	ND
207311201-S	30-Jul-12	PENTACHLOROPHENOL	EP-U	EP FOR CARLHAVEN EAST	ND
109280701-S	27-Sep-11	PENTACHLOROPHENOL	EP-U	EP FOR CARLHAVEN EAST	ND
20100803053-S	3-Aug-10	PENTACHLOROPHENOL	EP-U	EP FOR CARLHAVEN EAST	ND
305223214-S	22-May-13	PENTACHLOROPHENOL	EP-V	EP FOR 17TH AVENUE	ND
20120308017-S	8-Mar-12	PENTACHLOROPHENOL	EP-V	EP FOR 17TH AVENUE	ND
20120913026-S	13-Sep-12	PENTACHLOROPHENOL	EP-W	EP FOR LACEY COURT	ND
90226-3	23-Feb-99	Pentachlorophenol	FA	WELL #6 (DELTA PUMP)	ND
60222-13	21-Feb-96	Pentachlorophenol	FA	WELL #6 (DELTA PUMP)	ND
31208-11	7-Dec-93	Pentachlorophenol	FA	WELL #6 (DELTA PUMP) - WELL #6 (DELTA	ND
30617-8	15-Jun-93	Pentachlorophenol	FA	WELL #6 (DELTA PUMP) - WELL #6 (DELTA	ND
30311-10	10-Mar-93	Pentachlorophenol	FA	WELL #6 (DELTA PUMP) - WELL #6 (DELTA	ND
60222-23	21-Feb-96	Pentachlorophenol	G	EP FOR LAUDERBECK	ND

Table 4

Analysis of PCP in City Wells

City of Keizer

Sample ID	Sample Date	Chemical	Sample Point	Sample Point Name	Result
90226-9	24-Feb-99	Pentachlorophenol	GA	WELL #7 (LAUDERBECK)	ND
31208-3	7-Dec-93	Pentachlorophenol	GA	WELL #7 (LAUDERBECK) - WELL #7 (LAUDER	ND
30617-7	15-Jun-93	Pentachlorophenol	GA	WELL #7 (LAUDERBECK) - WELL #7 (LAUDER	ND
30311-9	10-Mar-93	Pentachlorophenol	GA	WELL #7 (LAUDERBECK) - WELL #7 (LAUDER	ND
90226-8	24-Feb-99	Pentachlorophenol	HA	WELL #8 (McNARY PUMP)	ND
60222-25	21-Feb-96	Pentachlorophenol	HA	WELL #8 (McNARY PUMP)	ND
31208-6	7-Dec-93	Pentachlorophenol	HA	WELL #8 (McNARY PUMP) - WELL #8 (McNAR	ND
30617-2	15-Jun-93	Pentachlorophenol	HA	WELL #8 (McNARY PUMP) - WELL #8 (McNAR	ND
30311-21	10-Mar-93	Pentachlorophenol	HA	WELL #8 (McNARY PUMP) - WELL #8 (McNAR	ND
60222-17	21-Feb-96	Pentachlorophenol	I	EP FOR TONI AVE.	ND
90226-1	23-Feb-99	Pentachlorophenol	IA	WELL #9 (TONI AVENUE)	ND
31208-4	7-Dec-93	Pentachlorophenol	IA	WELL #9 (TONI AVENUE) - WELL #9 (TONI	ND
30617-12	15-Jun-93	Pentachlorophenol	IA	WELL #9 (TONI AVENUE) - WELL #9 (TONI	ND
30311-19	10-Mar-93	Pentachlorophenol	IA	WELL #9 (TONI AVENUE) - WELL #9 (TONI	ND
90226-7	24-Feb-99	Pentachlorophenol	JA	WELL #10 (WIESSNER)	ND
60222-16	21-Feb-96	Pentachlorophenol	JA	WELL #10 (WIESSNER)	ND
31208-7	7-Dec-93	Pentachlorophenol	JA	WELL #10 (WIESSNER) - WELL #10 (WIESSNER	ND
30617-5	15-Jun-93	Pentachlorophenol	JA	WELL #10 (WIESSNER) - WELL #10 (WIESSNER	ND
30311-8	10-Mar-93	Pentachlorophenol	JA	WELL #10 (WIESSNER) - WELL #10 (WIESSNER	ND
60222-20	21-Feb-96	Pentachlorophenol	K	EP FOR WILLAMETTE MANOR	ND
90311-9	10-Mar-99	Pentachlorophenol	KA	WELL #11 (WILLAMETTE MANOR)	ND
31208-9	7-Dec-93	Pentachlorophenol	KA	WELL #11 (WILLAMETTE MANOR) - WELL #11 (	ND
30617-15	15-Jun-93	Pentachlorophenol	KA	WELL #11 (WILLAMETTE MANOR) - WELL #11 (	ND
30311-12	10-Mar-93	Pentachlorophenol	KA	WELL #11 (WILLAMETTE MANOR) - WELL #11 (	ND
90226-6	24-Feb-99	Pentachlorophenol	LA	WELL #12 (13th AVENUE)	ND
60222-19	21-Feb-96	Pentachlorophenol	LA	WELL #12 (13th AVENUE)	ND
31208-12	7-Dec-93	Pentachlorophenol	LA	WELL #12 (13th AVENUE) - WELL #12 (13th	ND
30617-10	15-Jun-93	Pentachlorophenol	LA	WELL #12 (13th AVENUE) - WELL #12 (13th	ND
30311-15	10-Mar-93	Pentachlorophenol	LA	WELL #12 (13th AVENUE) - WELL #12 (13th	ND
90226-12	24-Feb-99	Pentachlorophenol	MA	WELL #13 (17th AVENUE)	ND
60222-26	21-Feb-96	Pentachlorophenol	MA	WELL #13 (17th AVENUE)	ND
31208-10	7-Dec-93	Pentachlorophenol	MA	WELL #13 (17th AVENUE) - WELL #13 (17th	ND
30617-6	15-Jun-93	Pentachlorophenol	MA	WELL #13 (17th AVENUE) - WELL #13 (17th	ND
30311-13	10-Mar-93	Pentachlorophenol	MA	WELL #13 (17th AVENUE) - WELL #13 (17th	ND
90223-16	22-Feb-99	Pentachlorophenol	NA	WELL #14 (MEADOWS)	ND
60222-24	21-Feb-96	Pentachlorophenol	NA	WELL #14 (MEADOWS)	ND
50217-6	16-Feb-95	Pentachlorophenol	NA	WELL #14 (MEADOWS)	ND
41215-7	14-Dec-94	Pentachlorophenol	NA	WELL #14 (MEADOWS)	ND
40407-5	5-Apr-94	Pentachlorophenol	NA	WELL #14 (MEADOWS) - WELL #14 (MEADOWS)	ND

Table 5

Saturated Zone GWPD Model Input Parameters – Soil Properties

City of Keizer

Input Parameter	Units	Base Model	Data Source and Location of Technical Documentation
Total Porosity (η)	-	0.375	Midrange porosity for a sand, Freeze and Cherry (1979) Table 2.4. Appendix C, Section 2.4.1.
Effective Porosity (η_e)	-	0.20	Conlon et al. (pg. 9, 2005) for the Upper Sedimentary Unit. Appendix C, Section 2.4.1.
Hydraulic Conductivity (K)	ft/d	13	Median hydraulic conductivity calculated from infiltration tests in floodplain deposits of the Willamette River (Qalc). Appendix C, Section 2.4.1.
Hydraulic Gradient (h)	ft/ft	0.005	Based on water levels measured in City wells in the Troutdale gravels, and multiplied by a factor of 5 to conservatively account for the fact that the hydraulic gradient is likely higher in the lower permeability Qalc. Appendix C, Section 2.4.1.
Bulk Density (ρ_b)	g/cm^3	1.66	Calculated by equation 8.26 in Freeze and Cherry (1979). Appendix B, Section 2.1.2.
Longitudinal Dispersivity (α_L)	ft	17.93	Calculated using Xu and Eckstein (1995). aL = (3.28)(0.83)[log(Lp/3.28)]2.414. A transport distance (L_p) of 500 feet was used in the calculation). Appendix C, Section 2.4.1.
Transverse Dispersivity (y-direction)	ft	5.92	Calculated using EPA (1986). a_T = 0.33(a_L). Appendix C, Section 2.4.1.
Vertical Dispersivity (z-direction)	ft	1.79	Calculated using EPA (1986). a_v = 0.10(a_L). Appendix C, Section 2.4.1.

Notes

g/cm^3 = grams per cubic centimeter

ft/d = feet per day

ft = feet

DB Sensitivity Runs = Drainage Basin Sensitivity Runs

(-) = input parameter units are dimensionless

Table 6

Saturated Zone GWPD Model Input Parameters – Pollutant Properties

City of Keizer

Input Parameter	Units	Pollutant	Base Model - Near Vertical UIC	Base Model - Distal From Vertical UIC	Data Source and Location of Technical Documentation
Input Concentration	μg/L	PCP	10	10	Action Level in City of Keizer UIC WPCF Applicant Review Draft Permit No. 119546, dated August 6, 2013
		DEHP	300	300	Action Level in City of Keizer UIC WPCF Applicant Review Draft Permit No. 119546, dated August 6, 2013
		B(a)P	2	2	Action Level in City of Keizer UIC WPCF Applicant Review Draft Permit No. 119546, dated August 6, 2013
		Lead	500	500	Action Level in City of Keizer UIC WPCF Applicant Review Draft Permit No. 119546, dated August 6, 2013
Organic Carbon Partitioning Coefficient (K_{oc})	L/Kg	PCP	536.5	536.5	EPA (1996), assuming a pH of 6.95 based on groundwater pH measured at test wells within Keizer city limits. Appendix B, Section 2.3.1.
		DEHP	12,200	12,200	Calculated based on equations in Roy and Griffin (1985). Appendix B, Section 2.3.1.
		B(a)P	282,185	282,185	
Distribution Coefficient (K_d)	L/Kg	PCP	0.16 (Horizontal) 3.3 (Vertical)	0.97	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		DEHP	3.66 (Horizontal) 75.6 (Vertical)	22.3	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		B(a)P	84.7 (Horizontal) 1,750 (Vertical)	515	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		Lead	1,203,704	1,203,704	Calculated based on Bricker (1998). Appendix B, Section 2.3.2.
Half Life (h)	d	PCP	46	46	Literature values. Appendix C, Section 2.4.2.
		DEHP	10	10	Literature values. Appendix C, Section 2.4.2.
		B(a)P	587	587	Literature values. Appendix C, Section 2.4.2.
Retardation Factor (R)	-	PCP	0.17 (Horizontal) 15.7 (Vertical)	5.3	Calculated based on Equation (9.14) in Freeze and Cherry (1979). Appendix B, Section 2.3.4.
		DEHP	17.2 (Horizontal) 336 (Vertical)	100	
		B(a)P	376 (Horizontal) 7,746 (Vertical)	2,280	
		Lead	5,328,397	5,328,397	

Notes

d = days

L/Kg = Liters per Kilogram

mg/L = micrograms per liter

DEHP = di(2-ethylhexyl) phthalate

(-) = input parameter units are dimensionless

PCP = pentachlorophenol

B(a)P = benzo(a)pyrene

Table 7

Saturated Zone GWPD -- Protective Horizontal Separation Distance

City of Keizer

Pollutant	Minimum Protective Horizontal Separation Distance (feet)
Vertical UICs	
Lead	3
Benzo(a)pyrene	28
PCP	117
DEHP	59
Horizontal UICs	
Lead	<1
Benzo(a)pyrene	17
PCP	101
DEHP	41

Notes:

DEHP = di(2-ethylhexyl)phthalate

PCP = pentachlorophenol

Attachment A

City of Keizer UIC Database

City of Keizer, Oregon

Id	Instl_Date	Lat	Long	Dpst_leak	UIC_Type	Perf_Pipe	Diameter	1000TPD	Status	2_year_TOT	Vertical Separation Distance (feet)	Distance to Well (feet)	Protective?
1	1998	44 59'39.059"N	123 1'3.12"W	3' deep perf pipe	Horizontal	172'	6"	None	Active	City Hall	8.63245	90'	Yes
2	2004	44 59'54.46"N	123 0'47.479"W	5' deep perf pipe	Horizontal	13'	10"	Yes	Active		10.9795	74'	Yes
3	2004	44 59'58.198"N	123 0'50.427"W	4' invert to unknown depth perf pipe	Horizontal	360'	12"	Yes	Active		11.454165	350'	Yes
4	2004	45 0'0.133"N	123 0'52.701"W	5' deep perf pipe	Horizontal	18'	12"	Yes	Active		10.40803	710'	Yes
5	2004	45 0'0.594"N	123 0'53.335"W	5' deep perf pipe	Horizontal	13'	12"	Yes	Active		10.36056	810'	Yes
7	2004	44 59'45.533"N	123 1'47.311"W	7' deep perf manhole	Vertical	0	12"	None	Active		14.30795	790'	Yes
8	1989-1999	45 1'17.815"N	123 1'7.865"W	5.67' deep perf pipe	Horizontal	2,047'	10-15"	Yes	Active		60.65275	410'	Yes
9	1993	45 0'5.623"N	123 2'9.777"W	48" invert to unknown depth perf pipe	Horizontal	400'	12"	None	Active	McNary	13.7244	431'	Yes
10	1993	44 59'31.473"N	123 1'21.983"W	~7' deep perf pipe	Horizontal	2,147'	12-18"	Yes	Active		6.32885	188'	Yes
11	1961	44 59'56.939"N	123 1'52.31"W	6' bottomless manhole	Vertical	0	4'	None	Active		18.33105	796'	Yes
12	1961	44 59'52.794"N	123 1'47.692"W	12'+ bottomless manhole	Hybrid	179'	48' MH	None	Active		11.16805	684'	Yes
13	1970s	45 0'1.862"N	123 2'21.257"W	? feet buried perf manholes	Horizontal	0	10-12"	Yes	Active		14.10215	138'	Yes
14	1990-1994	45 0'10.685"N	123 2'54.229"W	7' deep perf pipe	Horizontal	1,788'	10-18"	Yes	Active		16.117	417'	Yes
15	1997-2000	44 59'49.801"N	123 3'1.366"W	7' deep perf pipe	Horizontal	1,693	10-12"	Yes	Active		18.83925	198'	Yes
16	1982	44 59'43.486"N	123 2'29.794"W	15' deep perf manhole	Hybrid	1,468'	4'	Yes	Active		18.09295	596'	Yes
17	1970s	44 59'31.393"N	123 1'39.391"W	2' invert to unknown	Horizontal	0	6"	None	Active		13.15095	116'	Yes
18	1982	44 59'49.093"N	123 2'41.416"W	10' deep perf manhole	Hybrid	0	4'	Yes	Active		16.17825	707'	Yes
19	1980s	44 59'57.192"N	123 2'35.604"W	? buried	Horizontal	0	12"	None	Active		17.7834	821'	Yes
20	1998	45 0'0.605"N	123 2'20.805"W	? buried	Horizontal	50'+	6"	None	Active		13.21075	185'	Yes
21	2004	44 59'54.653"N	123 0'38.202"W	7.5' invert at D48-494-202	Horizontal	1,094'	10-12"	Yes	Active		6.30045	178'	Yes
23	1996-2006	45 2'1.057"N	123 0'46.934"W	9.5' deep manhole control structure	Horizontal	1,904'	8-21"	Yes	Active		42.3245	70'	Yes
24	1998-2006	45 1'39.228"N	123 0'37.134"W	7' deep perf pipe	Horizontal	534'	10"	Yes	Active		35.16185	545'	Yes
25	1990	45 1'21.773"N	123 0'51.239"W	4' deep perf pipe	Horizontal	1,841'	10-12"	Yes	Active	Meadows	41.17935	50'	Yes
27	1997	45 1'57.128"N	123 0'36.496"W	4' deep perf pipe	Horizontal	195+	6"	None	Active		47.28725	330'	Yes
28	1997	45 2'1.19"N	123 0'39.462"W	5' deep perf pipe in swale	Horizontal	478'	15"	None	Active		49.0143	290'	Yes
30	2005	44 59'22.916"N	123 2'11.454"W	5' deep perf pipe	Horizontal	31'	12"	None	Active		16.90875	780'	Yes
31	1971	44 59'42.421"N	123 2'13.714"W	4' deep perf pipe ?	Horizontal	77	8"	None	Active		23.40205	410'	Yes
32	1958	44 59'29.236"N	123 2'8.843"W	6' deep perf (?) manhole	Vertical	0	6"	None	Active		18.2127	341'	Yes
34	2005	44 59'3.028"N	123 1'47.753"W	5' deep perf pipe	Horizontal	24'	10"	None	Active		22.58285	622'	Yes
35	2005	44 59'2.801"N	123 1'49.987"W	5' deep perf pipe	Horizontal	20'	10"	None	Active		22.471	610'	Yes
36	1992-2000	44 58'49.157"N	123 1'10.276"W	~5 feet deep perf pipe	Horizontal	1526'	8-10"	None	Active		10.92705	97'	Yes
38	2004	44 59'18.909"N	123 1'30.139"W	5' deep perf pipe	Horizontal	14'	10"	None	Active		22.9917	127'	Yes
39	2004	44 59'18.962"N	123 1'23.955"W	5' deep perf pipe	Horizontal	10'	12"	None	Active		14.65715	179'	Yes
40	2003	44 59'41.408"N	123 1'3.98"W	5' deep perf pipe	Horizontal	20'	8"	None	Active	City Hall	6.5435	155'	Yes
41	2004	44 59'59.751"N	123 0'52.224"W	5' deep perf pipe	Horizontal	18'	12"	Yes	Active		10.44803	670'	Yes
43	1998	44 59'20.737"N	123 1'44.284"W	5' deep perf pipe	Horizontal	30'	10"	None	Active		16.5192	388'	Yes

Attachment A

City of Keizer UIC Database

City of Keizer, Oregon

Id	Instl_Date	Lat	Long	Dpst_leak	UIC_Type	Perf_Pipe	Diameter	1000TPD	Status	2_year_TOT	Vertical Separation Distance (feet)	Distance to Well (feet)	Protective?
44	1966	44 59'23.019"N	123 1'46.139"W	4' deep bottomless catchbasin	Vertical	0	12	None	Active		19.0696	409'	Yes
45	1994	44 59'22.926"N	123 1'44.952"W	5' deep perf pipe	Horizontal	70'	12"	Yes	Active		16.86745	462'	Yes
46	2003	44 59'22.772"N	123 1'44.629"W	5' deep perf pipe	Horizontal	70'	12"	Yes	Active		16.621	445'	Yes
47	1970s	44 59'22.693"N	123 1'41.803"W	5' deep bottomless catchbasin	Vertical	0	0	None	Active		16.0516	630'	Yes
48	1950s	44 59'27.793"N	123 1'48.577"W	approx 5'	Vertical	0	6"	None	Active		17.6696	610'	Yes
49	1950s	44 59'27.581"N	123 1'47.694"W	approx 5'	Vertical	0	6"	None	Active		17.1587	600'	Yes
50	1950s	44 59'16.742"N	123 1'0.973"W	5' deep perf pipe	Horizontal	48'	8"	None	Active	arlhaven East and We	10.32545	270'	Yes
51	1997	44 59'1.715"N	123 1'9.61"W	7'	Horizontal	222'	12"	Yes	Active	Cherry Ave	10.6279	73'	Yes
53	1978	44 59'4.447"N	123 1'1.722"W	2' invert to?	Horizontal	85'	8"	None	Active		10.9785	289'	Yes
54	2006	44 59'1.345"N	123 1'18.725"W	10' deep	Horizontal	248'	12"	Yes	Active	Cherry Ave	11.87955	70	Yes
55	1990s	44 59'59.864"N	123 2'20.966"W	<5'	Horizontal	0	12"	None	Active		13.56625	256'	Yes
56	1978	44 58'41.735"N	123 1'9.888"W	7' deep perf manhole	Vertical	0	10"	None	Active		8.277	160'	Yes
57	1970s	44 58'50.341"N	123 1'18.506"W	~5' based on similiar systems	Horizontal	100'	12"	None	Active		14.2393	295'	Yes
58	1995	44 58'53.599"N	123 1'7.341"W	7.5' deep perf pipe	Horizontal	300'	10"	Yes	Active		14.2216	156'	Yes
59	1980	44 58'54.133"N	123 1'4.94"W	9.5' perf manhole	Vertical	0	8"	None	Active		17.85895	140'	Yes
60	1998	44 58'49.18"N	123 0'44.451"W	2' invert to ~5' deep	Horizontal	15'	10"	None	Active		5.2201	425'	Yes
61	1995	44 58'51.734"N	123 0'43.054"W	2.5' invert to ~5' deep perf pipe	Horizontal	45'	12"	None	Active		4.640495	210'	Yes
62	1999	44 59'34.782"N	123 1'55.323"W	4' deep perf pipe	Horizontal	160'	12"	None	Active		19.02615	600'	Yes
63	1995	44 59'41.029"N	123 1'53.747"W	~5' deep	Horizontal	38'	8"	None	Active		19.72235	685'	Yes
64	1995	44 59'40.981"N	123 1'50.9"W	1.4' invert to ~5' deep	Horizontal	24'	8"	None	Active		18.60845	875'	Yes
65	1970	44 59'40.274"N	123 1'47.739"W	4' deep perf manhole	Horizontal	20'	12"	None	Active		16.57585	730'	Yes
66	1990s	44 59'24.631"N	123 1'31.691"W	3.5' deep	Horizontal	335'	10"	None	Active		13.76035	270'	Yes
67	1997-2000	45 1'48.294"N	123 1'11.007"W	13.79' deep perf pipe	Horizontal	7,279'	21"	None	Active	No TOT for Reitz	61.5199	68'	Yes
69	2007	45 1'56.005"N	123 1'17.063"W	14.50' deep perf pipe	Horizontal	2,622'	15"	None	Active	No TOT for Reitz	62.1988	80'	Yes
72	2003	44 59'45.097"N	123 1'44.463"W	4' perforated manhole	Horizontal	43'	10"	None	Active		15.1408	550'	Yes
76	1996	44 59'17.871"N	123 1'40.47"W	4'	Horizontal	246'	10"	None	Active		18.19715	464'	Yes
79	?	44 59'18.982"N	123 2'6.469"W	3'	Vertical	0	4"	None	Active		17.12635	678'	Yes
81	?	45 0'1.694"N	123 1'19.144"W	2'	Vertical	0	8"	None	Active		10.74685	430'	Yes
82	1990's	45 1'2.106"N	123 0'36.289"W	2' invert to ~5' deep	Horizontal	13'	10"	None	Active		-1.455499	1655'	Yes
83	1994	44 59'56.471"N	123 1'16.432"W	9' deep perf pipe	Horizontal	469'	10"	None	Active		2.98615	643'	Yes
84	2002	44 59'40.823"N	123 1'9.838"W	4' deep perf pipe	Horizontal	374'	10"	None	Active	City Hall well	9.5407	95'	Yes
88	?	44 59'53.739"N	123 3'1.511"W	3.5' deep perf pipe	Horizontal	45'	10"	None	Active		24.3277	725'	Yes
89	?	44 59'31.856"N	123 1'52.382"W	~5?	Horizontal	11'	10"	None	Active		18.65515	1100'	Yes
90	?	1 21'54.812"N	20 42'24.633"E	24" invert to unknown depth drain rock	Horizontal	171'	12"	Yes	Active		16.28555	96'	Yes
91	1998	1 23'36.142"N	20 42'7.71"E	8.5' inv at D48-508-211	Horizontal	255'	21"	Yes	Active		47.04945	411'	Yes
92	1993	44 59'42.636"N	123 1'55.124"W	? ~5	Horizontal	56'	12"	None	Active		21.8576	667'	Yes

GSI Water Solutions, Inc.

Attachment A

City of Keizer UIC Database

City of Keizer, Oregon

Id	Instl_Date	Lat	Long	Dpst_leak	UIC_Type	Perf_Pipe	Diameter	1000TPD	Status	2_year_TOT	Vertical Separation Distance (feet)	Distance to Well (feet)	Protective?
93	1993	44°59'42.987"N	123°1'38.532"W	4' @ north mh	Horizontal	200'	10"	None	Active		13.8532	957'	Yes
94	?	44°59'41.776"N	123°2'59.539"W	4' perf pipe	Horizontal	46'	12"	None	Active		29.3402	128'	Yes
95	?	44°59'42.255"N	123°0'31.18"W	4.6' deep perf pipe	Horizontal	874'	12"	None	Active		21.6127	377'	Yes
96	1997	44°59'42.648"N	123°1'9.013"W	~5'	Horizontal	~100'	10"	None	Active	City Hall	4.5296	20'	Yes
97	1998	44°58'46.857"N	123°1'22.644"W	4.89' deep perf pipe at D45-488-210	Horizontal	243'	10"	Yes	Active		15.9218	234'	Yes
99	?	45°2'12.484"N	123°0'59.332"W	<5' deep perf pipe	Horizontal	30'	10"	None	Active		53.93065	64'	Yes
100	?	44°59'40.833"N	123°1'41.515"W	~5' deep perf pipe	Horizontal	23'	10"	None	Active		14.41015	902'	Yes
101	1997	44°58'40.203"N	123°0'59.441"W	3'	Horizontal	706	12"	None	Active		9.3946	37'	Yes
103	1994	45°0'47.351"N	123°0'23.833"W	6.5' deep at D51-500-225	Horizontal	200'	10"	Yes	Active	17th	23.1568	921'	Yes
104	?	44°59'57.493"N	123°2'14.954"W	?	Horizontal	139'	12"	None	Active		16.0988	478'	Yes
105	?	1°21'37.083"N	20°42'1.5"E	~1' deep	Horizontal	15'	4"	Yes	Active	No	14.38206	885'	Yes
107	?	1°21'46.194"N	20°42'19.776"E	~5' perf pipe	Horizontal	20'	8"	Yes	Active	No	19.76885	73'	Yes
108	1990's	45°1'43.532"N	123°1'16.273"W	11.80' at MH D45-506-203	Horizontal	2365	18	No	Active	No TOT for Reitz	63.4008	185	Yes
110	?			~5'	Horizontal		10	Yes	Active	No	22.3672	501	Yes

Attachment B – Technical Documentation for the Unsaturated Zone GWPD

1 Pollutant Fate and Transport Processes

An Underground Injection Control (UIC) device allows stormwater to infiltrate into the unsaturated zone (i.e., variably saturated soils above the water table). The stormwater is transported downward by matric forces that hold the water close to mineral grain surfaces. During transport, pollutant concentrations are attenuated by the following processes:

- **Volatilization.** Volatilization is pollutant attenuation by transfer from the dissolved phase to the vapor phase. Because soil pores in the unsaturated zone are only partially filled with water, chemicals with a high vapor pressure volatilize into the vapor phase. The propensity of a pollutant to volatilize is described by the Henry's constant. Because volatilization is not significant at depths below most UIC bottoms (USEPA, 2001), volatilization is not included in the unsaturated zone Groundwater Protectiveness Demonstration (GWPD).

- **Adsorption.** Adsorption is pollutant attenuation by partitioning of substances in the liquid phase onto the surface of a solid substrate. Physical adsorption is caused mainly by Van der Waals forces and electrostatic forces between the pollutant molecule and the ions of the solid substrate molecule's surface. For organic pollutants, the unsaturated zone GWPD simulates adsorption is a function of f_{oc} (fraction organic compound) and K_{oc} (organic carbon partitioning coefficient). For metals, the unsaturated zone GWPD uses stormwater analytical data to estimate adsorption.

- **Degradation.** Degradation is pollutant attenuation by biotic and abiotic processes. Abiotic degradation includes hydrolysis, oxidation-reduction, and photolysis. Biotic degradation involves microorganisms metabolizing pollutants through biochemical reactions.

- **Dispersion.** Dispersion describes pollutant attenuation from pore water mixing, which occurs because of differences in subsurface permeability.

2 Pollutant Fate and Transport Input Parameters

The unsaturated zone GWPD consists of a one dimensional analytical model that simulates the effects of adsorption, degradation, and dispersion based on user-specified input parameters from scientific references and available regulatory guidance. Input parameters to the unsaturated zone GWPD model include soil properties, organic carbon content in the subsurface, and pollutant properties, as described in the following sections:

- Soil properties
  - Total porosity and effective porosity (Section 2.1.1)
  - Soil bulk density (Section 2.1.2)
  - Dispersion coefficient and dispersivity (Section 2.1.3)
  - Average linear pore water velocity (Section 2.1.4)
- Organic carbon content of the subsurface
  - Fraction organic carbon (Section 2.2.1)
- Pollutant properties
  - Organic carbon partitioning coefficient (Section 2.3.1)
  - Distribution coefficient (Section 2.3.2)
  - Degradation rate constant and half life (Section 2.3.3)
  - Retardation factor (Section 2.3.4)

2.1 Soil Properties

Soil properties include total porosity, effective porosity, soil bulk density, dispersivity/dispersion coefficient, and average linear pore water velocity.

2.1.1 Total Porosity (η) and Effective Porosity (η_e)

Total porosity is the percent of pore space in a material. Porosities are correlated with soil type (e.g., sand, silt, gravel), and were estimated from Table 2.4 of Freeze and Cherry (1979). Specifically, the midrage porosity of a sand was used based on the lithology of the Floodplain Deposits of the Willamette River (Qalc). Boring logs in Golder Associates (1990) indicate that the Qalc is a silt. However, infiltration testing at City UICs indicates that the Qalc likely contains higher permeability sand lenses. Therefore, the porosity used in the model was based on the porosity of a sand. Effective porosity is the percent of pore space through which flow occurs, as was estimated as 0.20 for the Upper Sedimentary Hydrogeologic Unit, which is within the range of effective porosities presented in Conlon et al. (pg. 9, 2005).

2.1.2 Soil Bulk Density (ρ_b)

Bulk density is the density of a soil, including soil particles and pore space. According to Freeze and Cherry (1979), bulk density is calculated from total porosity by the following formula:

$$\rho_b = 2.65(1-\eta) \qquad \text{(B.1)}$$

2.1.3 Dispersion Coefficient (D) and Dispersivity (α)

Dispersion is the spreading of a pollutant plume caused by differential advection. The dispersion coefficient, D, is defined as:

$$D = \alpha\ v \qquad \text{(B.2)}$$

where:

v is average linear pore water velocity (L/T), and
α is longitudinal dispersivity (L).

The dispersivity (and therefore the dispersion coefficient) is a scale-dependent parameter. According to a review of tracer tests conducted under saturated conditions, dispersivity is estimated as (Gelhar et al., 1992):

$$\alpha \leq \frac{L}{10} \tag{B.3}$$

where:

L is the length scale of transport (L).

However, according to a review of tracer tests conducted in the unsaturated zone, dispersivity can be significantly less than would be estimated by Equation (B.3) (Gehlar et al., 1985):

$$\frac{L}{10} \leq \alpha \leq \frac{L}{100} \tag{B.4}$$

Because the unsaturated zone under the UICs is at near-saturated conditions, this technical memorandum assumes that $\alpha = \frac{L}{20}$, which is conservatively less than saturated dispersivity, but is on the high end of the reported range in unsaturated dispersivity.

2.1.4 Average Linear Pore Water Velocity (*v*)

Average linear pore water velocity is the rate that water moves vertically through the unsaturated zone, and is directly proportional to soil moisture content (i.e., pore water velocity increases as soil moisture content increases). Soil moisture content is the percent of water in soil, and is equal to or less than porosity. The unsaturated zone GWPD conservatively assumes that soils are fully saturated, which is likely representative of actual conditions because of the near-constant infiltration of water during the rainy season.

Darcy's Law is (Stephens, 1996):

$$v = -K_u \left(\frac{\partial \psi}{\partial y} + \frac{\partial y}{\partial y} \right) \tag{B.5}$$

where:

v is specific discharge (L/T),
K_u is unsaturated hydraulic conductivity (L/T),
$\left(\frac{\partial \psi}{\partial y} \right)$ is the pressure gradient (L/L), and
$\left(\frac{\partial y}{\partial y} \right)$ is the head gradient (L/L).

In the unsaturated zone, $\left(\frac{\partial y}{\partial y}\right)$ = 1. When the unsaturated zone is stratified and pressure head is averaged over many layers (which is the case in sediments in the vicinity of Keizer), $\left(\frac{\partial \psi}{\partial y}\right)$ = 0. Under these conditions, equation (B.5) reduces to (Stephens, 1996):

$$v = -K_u \tag{B.6}$$

Average linear pore water velocity is calculated by dividing Equation B.6 by 0.20, which is within the range of effective porosity of the Upper Sedimentary Hydrogeologic Unit as indicated on page 9 of Conlong et al. (2005).

2.2 Organic Carbon Content in the Subsurface

The organic carbon content in the subsurface is parameterized by fraction organic carbon, a dimensionless measure of the quantity of organic carbon in soil (i.e., g_{carbon} / g_{soil}). Carbon in unsaturated soil beneath a UIC is derived from two sources:

- Organic carbon incorporated into sediments during deposition
- Particulate matter (e.g., degraded leaves, pine needles, and pollen) that is filtered out of stormwater and accumulates in unsaturated soil adjacent to UICs as stormwater infiltrates from the UIC

The unsaturated zone GWPD conservatively only considers organic carbon that accumulates in the unsaturated zone soils due to filtering of particulate matter from stormwater.

2.2.1 Fraction Organic Carbon (f_{oc})

As stormwater infiltrates into the unsaturated zone surrounding the UIC, the organic carbon is filtered out of solution and the f_{oc} in soil increases over time because of the ongoing addition of organic carbon. An estimate of f_{oc} based on the accumulation of carbon in unsaturated soil was derived by calculating the grams of organic carbon added to unsaturated materials surrounding the UIC during a 10-year period. A 10-year accumulation period is conservative because literature evaluating the longevity of organic material in bioretention cells indicates that it lasts about 20 years before it begins to degrade (Weiss et al, 2008). The following equations were used in the analysis:

$$I = (A)(p)(1-e) \tag{B.7}$$

$$CL = (I)(C)(t)\left(\frac{1\,\text{liter}}{1{,}000\,\text{cm}^3}\right)\left(\frac{1\,\text{gram}}{1{,}000\ \text{milligrams}}\right) \tag{B.8}$$

$$\rho_{oc} = \frac{CL}{SV} \tag{B.9}$$

$$f_{oc} = \frac{\rho_{oc}}{\rho_b + \rho_{oc}} \tag{B.10}$$

where:

- I = Average annual stormwater infiltration volume (cubic feet per year)
- A = Area of a typical UIC catchment (square feet)
- p = Precipitation (feet per year)
- e = Evaporative loss factor (dimensionless). The infiltration volumes assumed an evaporative loss factor of 24 percent based on the value presented in Snyder (1994) for the Portland Basin.
- CL = Organic carbon loaded into the unsaturated zone beneath a UIC during a 10-year period (grams)
- C = Average TOC concentration in stormwater (milligrams per liter)
- t = Time of carbon loading (years)
- ρ_{oc} = Organic carbon weight per unit unsaturated zone material volume (grams per cubic centimeter)
- SV = Material volume into which the organic carbon would accumulate because of filtration and adsorption (cubic centimeters). This volume is different for horizontal and vertical UICs.
- f_{oc} = Fraction organic carbon (dimensionless)
- ρ_b = Bulk density (grams per cubic centimeter)

The value of SV is different for horizontal and vertical UICs because of their different sizes:

- For vertical UICs, SV is assumed to be the volume of soil from 3 feet above the UIC bottom to 5 feet below the base of the UIC, extending 1 foot from the radius of the UIC (i.e., SV is about 5,000,000 cubic centimeters). The radius of vertical UICs in Keizer ranges from 2 to 24 inches. A radius of 24 inches was used to calculate f_{oc} because a larger radius results in a lower f_{oc} concentration. Therefore, using a 24 inch radius for vertical UICs is conservative.
- For horizontal UICs, SV is assumed to be one-half of the volume of soil within a 1 foot radius of the perforated pipe (using the average pipe diameter of 11 inches, and the median pipe length of 100 feet, SV is about 8,700,000 cubic centimeters). One half of the volume of soil is used because the perforated pipe is assumed to be half full during stormwater infiltration.

Because SV at horizontal UICs is larger than SV at vertical UICs, the ρ_{oc} (and f_{oc}) at horizontal UICs is lower than the ρ_{oc} (and f_{oc}) at vertical UICs (see Equation B.9).

Calculations of f_{oc}, based on the filtering of TOC for the average and reasonable maximum scenarios, are shown in Tables B-1 through B-3. First, the average annual precipitation was calculated from rain gages (Table B-1) and used to calculate the volume of stormwater that infiltrates into a UIC (Table B-2) by Equation (B.7). Next, an average TOC concentration was calculated and was used to calculate the grams of carbon added to the unsaturated zone surrounding the UIC during a 10-year period by Equation (B.8), mass of organic carbon per unit volume of material surrounding the UIC (ρ_{oc}) by Equation (B.9), and convert ρ_{oc} to f_{oc} by Equation (B.10) (Table B-3). The average TOC concentration in stormwater was calculated on the basis of 14 stormwater grab samples collected at City of Keizer UICs. Samples were collected in October 2012, March 2013 and April 2013, and analytical results are summarized in Table B-4.

2.3 Pollutant Properties

Pollutant properties include the organic carbon partitioning coefficient, distribution coefficient, degradation rate constant/half life, and retardation factor.

2.3.1 Organic Carbon Partitioning Coefficient (K_{oc})

The organic carbon partitioning coefficient (K_{oc}) is pollutant specific, and governs the degree to which the pollutant will partition between the organic carbon and water phases. Higher K_{oc} values indicate that the pollutant has a higher tendency to partition in the organic carbon phase, and lower K_{oc} values indicate that the pollutant will have a higher tendency to partition in the water phase.

K_{oc} was assigned differently for PCP and other organic pollutants, according to the following criteria:

- **PCP.** The K_{oc} for PCP is pH dependent, so K_{oc}s for the average and reasonable maximum scenarios were estimated on the basis of groundwater pH of shallow groundwater presented in Golder Associates (1990). Golder Associates (1990) measured pH at different depths during the installation of four water supply test wells. The shallowest-measured pHs from test wells TW1, TW2, TW3 and TW4 were averaged together. The average groundwater pH at test wells drilled within the city limits was 6.95.

- **All Organic Pollutants except PCP.** For the average scenario, K_{oc} was estimated from empirical regression equations relating K_{oc} to the octanol water partitioning coefficient (K_{ow}) and/or pollutant solubility. For the reasonable maximum scenario, K_{oc} was assumed to be either the lowest-reported literature value or the K_{oc} calculated by empirical equations, which ever was lower (i.e., more conservative).

2.3.2 Distribution Coefficient (K_d)

For organic pollutants, the distribution coefficient, K_d, was estimated from the following equation (e.g., Watts, 1998):

$$K_d = f_{oc}K_{oc} \qquad \text{(B.11)}$$

For metals, K_d was estimated from equations in Bricker (1998). The most important solid phases for sorption of metals in environmental porous media are clays, organic matter, and iron/manganese oxyhydroxides (Langmuir et al., 2004). The distribution of a trace metal between dissolved and sorbed phases is described by the following equation:

$$K_d = \frac{C_s}{C_w} \qquad \text{(B.12)}$$

where:

C_s is the concentration of the metal adsorbed on the solid phase (M/L^3), and
C_w is the dissolved concentration (M/L^3).

The value of K_d for metals can depend on a number of environmental factors, including the nature and abundance of the sorbing solid phases, dissolved metal concentration, pH, redox conditions, and water chemistry. Measured K_d values for a given metal range over several orders of magnitude depending on the environmental conditions (Allison and Allison, 2005). Therefore, site-specific K_d values are preferred for metals over literature-reported K_ds. K_d values can be determined empirically for a particular situation from Equation (B.12) (Bricker, 1998). The partitioning coefficients were estimated from total and dissolved metals concentrations and total suspended solids (TSS) data in stormwater collected in 2012 by the City of Milwaukie. Sorbed concentrations were calculated by normalizing the particulate metals concentrations to the concentration of TSS. For each sample, an apparent K_d value was calculated for each metal from the following equation:

$$K_d = \frac{\left([Me]_t - [Me]_d\right)}{[Me]_d \times TSS} \times 10^6 \qquad \text{(B.13)}$$

where:

$[Me]_t$ is total metals concentration (M/L^3), and
$[Me]_d$ is dissolved metal concentration (M/L^3)

Note that in Equation (B.13), metals concentrations are in micrograms per liter, and TSS are in units of milligrams per liter.

Although the K_ds are determined from systems containing lower concentrations of sorbing particle surfaces than is typical of stormwater infiltrating through a soil column, this is considered to be conservative because (1) the low levels of suspended solids in the stormwater may result in nonlinear sorption regime, in which case calculated K_d values may be significantly lower than would be expected in a higher surface area environment (i.e., the unsaturated zone), and (2) site-specific K_ds calculated in the stormwater already account for the effect of dissolved organic carbon, which could lower apparent K_d values by complexing with trace metals, and thereby shifting the partitioning to the solution.

2.3.3 Degradation Rate Constant (*k*) and Half Life (*h*)

Degradation rate is a chemical-specific, first-order rate constant, and depends on whether the unsaturated zone is aerobic or anaerobic. The organic pollutants evaluated in the unsaturated zone GWPD are biodegradable under aerobic conditions (Aronson et al., 1999; MacKay, 2006); therefore, it is expected that these compounds will biodegrade to some extent within the unsaturated zone after discharging from the UIC. Metals are not discussed in this section because they do not undergo biodegradation.

Aerobic biodegradation rate constants were compiled from a review of the scientific literature, including general reference guides as well as compound-specific studies. The review included degradation in soils, surface water, groundwater, and sediment. Soil aerobic degradation rates were considered to be most representative of UIC field conditions. First-order rate constants are generally appropriate for describing biodegradation under conditions where the substrate is limited and there is no growth of the microbial population (reaction rate is dependent on substrate concentration rather than microbial growth). Because of the low concentrations of the organic pollutants detected in stormwater, it is appropriate to consider biodegradation as a pseudo-first-order rate process for the UIC unsaturated zone scenario.

The ranges of biodegradation rates representative of conditions expected to be encountered in the unsaturated zone beneath UICs are summarized in Table B-5. Summary statistics provided in Table B-5 include number of measurements, minimum, maximum, mean, 25^{th}, and 50^{th} percentile (median) values. For the average scenario, the median biodegradation rate (benzo(a)pyrene and DEHP) or ten percent of the average biodegradation rate (PCP) was used. For the reasonable maximum, the 25^{th} percentile biodegradation rate (benzo(a)pyrene and DEHP) or the minimum biodegradation rate (PCP) was used.

The half-life of a pollutant is the time required for pollutant concentration decline to one half of its initial value. Half-life is calculated by the following formula:

$$h = \frac{\ln(2)}{k} \tag{B.14}$$

where:

k is the first-order rate constant (T^{-1}), and
h is the half-life (T)

2.3.4 Retardation Factor (*R*)

The retardation factor, *R*, is the ratio between the rate of pollutant movement and the rate of pore water movement. For example, a retardation factor of 2 indicates that pollutants move twice as slow as pore water. The retardation factor is estimated by equation 9.14 of Freeze and Cherry (1979):

$$R = 1 + \frac{(\rho_b)(K_d)}{\eta} \tag{B.15}$$

where:

ρ_b is soil bulk density (M/L^3),
K_{oc} is the organic carbon partitioning coefficient (L^3/M),
f_{oc} is fraction organic carbon (dimensionless), and
η is total porosity (dimensionless).

3 Governing Equation for Unsaturated Zone GWPD

A one-dimensional pollutant fate and transport equation was used to estimate the magnitude of pollutant attenuation during transport through the unsaturated zone. This constant source Advection-Dispersion Equation (ADE) incorporates adsorption, degradation (biotic and abiotic), and dispersion to estimate pollutant concentration at the water table (e.g., Watts, 1998). This equation is provided below:

$$\frac{C(y,t)}{C_0} = \frac{1}{2}\left[\left(e^{A_1}\right)erfc(A_2) + \left(e^{B_1}\right)erfc(B_2)\right] \tag{B.16}$$

where:

$$A_1 = \left(\frac{y}{2D'}\right)\left(v' - \sqrt{(v')^2 + 4D'k'}\right)$$

$$A_2 = \frac{y - t\sqrt{(v')^2 + 4D'k'}}{2\sqrt{D't}}$$

$$B_1 = \left(\frac{y}{2D'}\right)\left(v' + \sqrt{(v')^2 + 4D'k'}\right)$$

$$B_2 = \frac{y + t\sqrt{(v')^2 + 4D'k'}}{2\sqrt{D't}}$$

$$v' = \frac{v}{R}$$

$$D' = \frac{D}{R}$$

$$k' = \frac{k}{R}$$

and:

y is distance in the vertical direction (L),
v is average linear pore water velocity (L/T),
D is the dispersion coefficient (L^2/T),
R is the retardation factor (dimensionless),
k is the first-order degradation constant (T^{-1}),
t is average infiltration time (T),
C_0 is initial pollutant concentration (M/L^3),
C(y, t) is pollutant concentration at depth *y* and time *t* (M/L^3), and
erfc is complementary error function used in partial differential equations

Equation (B.16) is an exact solution to the one-dimensional ADE. The exact solution can be used for both short (i.e., less than 3.5 meters) and long transport distances (greater than 35 meters; Neville and Vlassopoulos, 2008). An approximate solution to the 1-dimensional ADE has also been developed, and can only be used for long transport distances. The unsaturated zone GWPD uses the exact solution to the ADE.

With the exception of infiltration time (*t*), the input parameters were described in Section 2. Infiltration time is the length of time during the year that stormwater infiltrates into a UIC and, therefore, migrates downward through the unsaturated zone. Because stormwater infiltrates into UICs only when the precipitation rate exceeds a threshold value, the infiltration time is dependent on the occurrence of rain events equal to or greater than this amount. The DEQ (2005) permit fact sheet for the City of Portland assigns a threshold precipitation rate of 0.08 inch/hour for stormwater to infiltrate into UICs. The unsaturated zone GWPD conservatively assumes that stormwater infiltrates into UICs at one-half of the threshold precipitation rate (i.e., 0.04 inch/hour). Precipitation and infiltration times from 2003 to 2011 in the City are shown in Table B-1.

The key assumptions in applying this equation include:

- Transport is one-dimensional vertically downward from the bottom of the UIC to the water table (Note: water at some City exfiltrates from holes in the side of the UIC, as well as from the bottom).
- The stormwater infiltration rate into the UIC is constant and maintains a constant head within the UIC to drive the water into the unsaturated soil. (Note: stormwater flows are highly variable, short duration, and result in varying water levels within the UIC dependent on the infiltration capacity of the formation.)
- Pollutant concentrations in water discharging into the UIC are uniform and constant throughout the period of infiltration (Note: concentrations are variable seasonally and throughout storm events).
- The pollutant undergoes equilibrium sorption (instantaneous and reversible) following a linear sorption isotherm.
- The pollutant is assumed to undergo a first-order transformation reaction involving biotic degradation.
- The pollutant does not undergo transformation reactions in the sorbed phase (i.e., no abiotic or biotic degradation).
- There is no portioning of the pollutant to the gas phase in the unsaturated zone.
- The soil is initially devoid of the pollutant.

4 Method for Calculating Average Linear Pore Water Velocity

The City conducted infiltration tests at vertical UICs to estimate hydraulic conductivity (a proportionality constant that is used to calculate pore water velocity [see Equation B.6]). Figure B-1 shows a conceptual diagram of a UIC during an infiltration test.

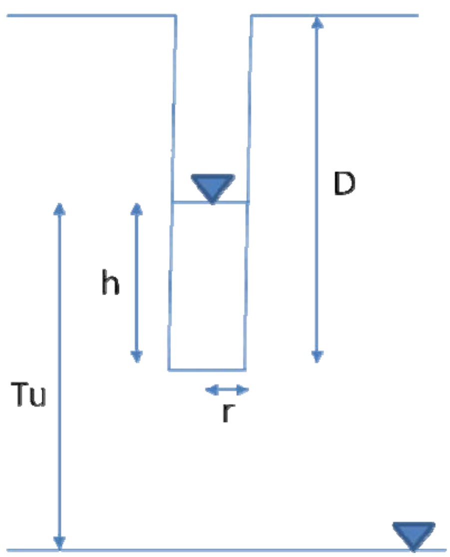

Figure B-1. Infiltration test conceptual model.

Infiltration tests consist of injecting water into a UIC at a known rate until the water level in the UIC stabilizes. The horizontal hydraulic conductivity is calculated based on the stable water level, injection rate, physical characteristics of the UIC, and depth to groundwater. According to USDI (1993), horizontal hydraulic conductivity in the unsaturated zone is calculated from an infiltration test by the following formulae:

$K_s =$

$$\frac{\left[\ln\left(\frac{h}{r}+\sqrt{\left(\frac{h}{r}\right)^2+1}\right)-1\right]Q}{2\pi h^2} \quad \text{if } T_u \geq 3h \qquad \text{(B.17)}$$

$$\left[\frac{3\ln\left(\frac{h}{r}\right)}{\pi h\left(h+2T_U\right)}\right]Q \quad \text{if } 3h \geq T_u \geq h \qquad \text{(B.18)}$$

where:

K_s is saturated hydraulic conductivity (L/T),
h is the height of the stable water level above the UIC bottom (L),
D is the depth of the UIC from ground surface to bottom (L)
T_u is the separation distance between the water table and stable water level in the UIC (L),
Q is the rate water enters the UIC when the water level is stable (L^3/T), and
r is the radius of the UIC (L).

Pore water velocity is then calculated based on the following assumptions:

- **Saturated hydraulic conductivity (K_s) can be used to approximate unsaturated hydraulic conductivity (K_u).** Equations B.17 and B.18 calculate saturated hydraulic conductivity, but Equation B.6 calculates pore water velocity based on unsaturated hydraulic conductivity. Therefore, we make the assumption that $K_s = K_u$ and substitute K_s into Equation B.6 when calculating pore water velocity. This is a conservative assumption because unsaturated hydraulic conductivity is smaller than saturated hydraulic conductivity (usually by several orders of magnitude) because of the tortuosity of unsaturated flow paths.

- **The ratio of horizontal to vertical anisotropy in hydraulic conductivity is 100:1.** Equations B.17 and B.18 calculate horizontal hydraulic conductivity. Because water is transported vertically through the unsaturated zone, the horizontal hydraulic conductivity calculated from the infiltration test must be converted to a vertical hydraulic conductivity. Horizontal hydraulic conductivity was converted to vertical hydraulic conductivity by assuming a horizontal to vertical anisotropy of 100:1 (Freeze and Cherry, 1979).

- **Effective porosity is 0.20 (Conlon et al., 2005).**

The City selected UICs for infiltration testing based on the following criteria:

- The UIC is completed in the Floodplain Deposits of the Willamette River (Qalc)
- The UIC is vertical (i.e., as shown in the conceptual model for pump-in tests in Figure B.1)
- There is no standing water in the UIC
- The UIC is perforated
- The UIC construction allows a minimum water column height in the UIC during testing. The water column height that a UIC can accommodate is determined by the distance between the UIC bottom and any conveyance piping at the top of the UIC. The height must exceed 2.35 feet if Equation B.17 is used, and must exceed 2.0 feet if Equation B.18 is used. If minimum water column heights cannot be achieved, Equations B.18 and B.17 will produce a negative value for *K* when the UIC radius is 2 feet.

On the basis of these criteria, three UICs were identified for testing. The test results are summarized in Table B-6. The horizontal hydraulic conductivities in the Qalc ranged from 2.4 to 95 ft/day. These hydraulic conductivities are slightly higher than the published range for hydraulic conductivities of a silt [which range from less than 1 ft/day to 10 ft/day in Anderson and Woessner (Table 3.3, pg. 40, 1992)], which may indicate that the Qalc contains interbedded, higher permeability lenses (i.e., sands) in the areas where infiltration tests were conducted.

5 Unsaturated Zone GWPD Results

The unsaturated zone GWPD model input, calculations and results are provided in Table B-7 (protective vertical separation distance at vertical UICs) and Table B-8 (protective vertical separation distance at horizontal UICs).

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Table B-1

Precipitation, 2003 - 2011

City of Keizer

Year	**Annual Precipitation** (feet)	**Annual Precipitation** (inches)	**Precipitation exceeding 0.04 inch/hr** (inches)	**Hours With ≥ 0.04 inches/hr intensity** (hours)	**Days With ≥ 0.04 inches/hr intensity** (days)
2011	2.78	33.4	22.3	303	12.6
2009	2.72	32.6	24.9	270	11.3
2008	2.24	26.9	17.8	247	10.3
2007	2.82	33.8	24.4	339	14.1
2006	3.33	40.0	31.0	354	14.8
2003	3.19	38.3	28.1	356	14.8
Maximum	*2.58*	*40.0*	*31.0*	*356*	*14.8*
Minimum	*1.48*	*26.9*	*17.8*	*247*	*10.3*
Average	*2.06*	*34.2*	*24.8*	*312*	*13.0*
Median	*2.06*	*33.6*	*24.7*	*321*	*13.4*
Geomean	***2.83***	***33.9***	***24.4***	***308.6***	***12.9***

Notes

Data is from "SALEM_RG4" (2003) located at River Road Park and "SALEM_RG16" (2006 - 2009, 2011) located at Clearlake RD NE and Wheatland Road N. If over six days of precipitation data were missing in a calendar year, the year was excluded from the analysis. Three years were excluded (2004, 2005 and 2010), and the amount of missing data ranged from 1 month (2004) to 8 months (2010).

Table B-2

Unsaturated Zone GWPD Stormwater Infiltration Volume

City of Keizer

Impervious Area, *A* (ft^2)	**Annual Precipitation, *P*** (Geometric Mean, 2003 - 2011) (ft/yr)	**Evaporative Loss Factor, *e*** (-)	**Infiltration Volume, *I*** (ft^3/yr)	**Infiltration Volume, *I*** (cm^3/yr)
17,109 (1)	2.83 (2)	0.24 (3)	36,738 (4)	1.04E+09 (4)

Notes

(1) Median impervious area for N=95 City of Keizer UIC drainage basins

(2) Excludes 2004, 2005, and 2010 due to missing data in these years

(3) From Snyder et al. (1994) for the Portland vicinity

(4) Calculated by the following equation from Snyder (1994): $I = (A)(P)(1\text{-}e)$

ft = feet

cm = centimeters

yr = year

Table B-3

Unsaturated Zone GWPD Fraction Organic Carbon

City of Keizer

	CL Calculation					*SV Calculation*						ρ_{oc} *Calculation*	f_{oc} Calculation	
	Infiltration Volume (cm^3/yr)	**Carbon Concentration** (mg TOC/1000 cm^3)	**Time** (years)	**Conversion Factor for ug to g**	**CL**	**UIC radius** (cm)	**Radius of Carbon Accumulation + UIC radius** (cm)	**3' Above base volume** (cm^3)	**5' Below base volume** (cm^3)	**UIC Length** (cm)	**Total Volume** (cm^3)	ρ_{oc} (g TOC per cm^3 soil)	**Bulk Density** (g/cm^3)	f_{oc}
Vertical UIC														
Average Scenario	1.04E+09	4.86	10	1,000,000	50,559	60.96	91.44	1,333,723	4,001,170		5,334,894	0.009477123	1.66	0.005677
Reasonable Maximum Scenario	1.04E+09	1.78	10	1,000,000	18,518	60.96	91.44	1,333,723	4,001,170		5,334,894	0.003471045	1.66	0.002087
Horizontal UIC														
Average Scenario	1.04E+09	4.86	10	1,000,000	50,559	13.92	44.39			3,126	8,719,309	0.005798561	1.66	0.003481
Reasonable Maximum Scenario	1.04E+09	1.78	10	1,000,000	18,518	13.92	44.39			3,126	8,719,309	0.002123753	1.66	0.001278

Notes

cm = centimeters

mg = milligrams

ug = micrograms

g = grams

yr = year

Average scenario uses the average TOC concentration, reasonable maximum scenario uses the minimum TOC concentration

Horizontal UIC calculations assume 1 feet of radial transport for TOC accumulation

Equations:

$$CL = (I)(C)(t)\left(\frac{1\text{ liter}}{1{,}000\text{ cm}^3}\right)\left(\frac{1\text{ gram}}{1{,}000\text{ milligrams}}\right)$$

$$\rho_{oc} = \frac{CL}{SV}$$

$$f_{oc} = \frac{\rho_{oc}}{\rho_b + \rho_{oc}}$$

CL = Organic carbon loaded into the unsaturated zone beneath a UIC during a 10-year period

I = Average annual stormwater infiltration volume

C = TOC concentration in stormwater

t = time of carbon loading

ρ_{oc} = Organic carbon weight per unit unsaturated zone material volume

SV = material volume into which the organic carbon would accumulate because of filtration and adsorption

f_{oc} = fraction organic carbon

ρ_b = bulk density

Table B-4

Total Organic Carbon in Stormwater

City of Keizer

Sample Collection Date	Sample ID	TOC (mg/L)
10/31/2012	TOC A	2.1
10/31/2012	TOC B	11
10/31/2012	TOC C	8.73
10/31/2012	TOC D	3.86
10/31/2012	TOC E	2.66
3/18/2013	TOC F	2.55
3/18/2013	TOC G	3.86
3/18/2013	TOC H	2.73
3/18/2013	TOC I	3.23
3/18/2013	TOC J	1.78
4/10/2013	TOC K	4.45
4/10/2013	TOC L	3.99
4/10/2013	TOC M	11.7
4/10/2013	TOC O	5.4
Average (Average Scenario)		***4.86***
Minimum (Reasonable Maximum Scenario)		***1.78***

Notes:

mg/L = milligrams per liter

TOC = total organic carbon

Table B-5

Unsaturated Zone GWPD Biodegradation Rates

City of Keizer

Compound	First-Order Biodegradation Rate (day^{-1})					
	N	*Median*	*Mean*	*Maximum*	*25 th percentile*	*Minimum*
Benzo(a)pyrene [1]	38	0.0013	0.0021	0.015	0.00026	ND
Di-(2-ethylhexyl)phthalate [2]	34	0.015	0.021	0.082	0.01	0.004
PCP [3]	10	0.206	0.221	0.361	0.1695	0.139

Notes

[1] Rate constants under aerobic conditions in soil were compiled from Aronson et al. (1999) Ashok et al. (1995); Bossart and Bartha (1986); Carmichael and Pfaender (1997); Coover and Sims (1987); Deschenes et al. (1996); Grosser et al. (1991); Grosser et al. (1995); Howard et al. (1991); Keck et al. (1989); Mackay et al. (2006); Mueller et al. (1991); Park et al. (1990); and Wild and Jones (1993).

[2] From Dorfler et al. (1996); Efroymson and Alexander (1994); Fairbanks et al. (1985); Fogel et al. (1995); Maag and Loekke (1990); Mayer and Sanders (1973); Ruedel et al. (1993); Schmitzer et al. (1988); Scheunert et al. (1987) and Shanker et al. (1985).

[3] From Schmidt et al. (1999) and D'Angelo and Reddy (2000)

Table B-6

Hydraulic Conductivity Summary

City of Keizer

N	Minimum Horizontal Hydraulic Conductivity, K_H (ft/day)	Maximum Horizontal Hydraulic Conductivity, K_H (ft/day)	Median Horizontal Hydraulic Conductivity, K_H (ft/day)	95% UCL Horizontal Hydraulic Conductivity, K_H (ft/day)
Infiltration Tests in Floodplain Deposits of the Willamette River (Qalc)				
3	2.4	95	13	ND
Published Values for a Site (Table 3.3, pg. 40, Anderson and Woessner, 1992)				
NG	0.075	10	0.1	NG

Notes

ft/day = feet per day

UCL = upper confidence limit, calculated using the 95% H-UCL and the EPA's ProUCL software

ND = insufficient number of data points

NG = Not given

Table B-7. Pollutant Fate and Transport

Groundwater Protectiveness Demonstration, City of Keizer, Vertical UIC

	Parameter	Symbol	Units	Metals		PAHs		SVOCs			
				Lead		Benzo(a)pyrene		PCP		di-(2-ethylhexyl) phthalate	
				Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Distance Needed to Reach MRLs	y	m	0.00144	0.0236	0.00082	0.0164	0.41	7.31	0.0198	0.3908
		y	ft	0.00471	0.077	0.00270	0.05378	1.35	23.99	0.065	1.28
	Concentration	C_0	mg/L	0.50 [1]	0.50 [1]	0.002 [1]	0.002 [1]	0.01 [1]	0.01 [1]	0.30 [1]	0.30 [1]
	Infiltration Time	t	d	12,860 [2]	12,860 [2]	12.86 [3]	12.86 [3]	12.86 [3]	12.86 [3]	12.86 [3]	12.86 [3]
Pollutant Properties	First-Order Rate Constant	k	d^{-1}			1.30E-03 [4]	2.60E-04 [5]	2.21E-02 [6]	1.39E-02 [7]	1.50E-02 [4]	1.00E-02 [5]
	Half-Life	h	d			533.2 [8]	2666.0 [8]	31.4 [8]	49.9 [8]	46.2 [8]	69.3 [8]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.375 [9]	0.375 [9]	0.375 [9]	0.375 [9]	0.375 [9]	0.375 [9]	0.375 [9]	0.375 [9]
	Soil Bulk density	ρ_b	g/cm^3	1.66 [10]	1.66 [10]	1.66 [10]	1.66 [10]	1.66 [10]	1.66 [10]	1.66 [10]	1.66 [10]
	Fraction Organic Carbon	f_{oc}	-			0.0057 [11]	0.0021 [11]	0.0057 [11]	0.0021 [11]	0.0057 [11]	0.0021 [11]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg			282,185 [12]	282,185 [12, 13]	536.5 [14]	536.5 [14]	12,200 [12]	12,200 [12, 13]
	Distribution Coefficient	K_d	L/kg	1,203,704 [15]	535,040 [16]	1,603 [17]	589 [17]	3.0 [17]	1.1 [17]	69.3 [17]	25.5 [17]
	Vertical Hydraulic Conductivity	K_v	m/d	0.04 [18]	0.29 [18]	0.04 [18]	0.29 [18]	0.04 [18]	0.29 [18]	0.04 [18]	0.29 [18]
	Effective Porosity	η_e	-	0.20 [19]	0.20 [19]	0.20 [19]	0.20 [19]	0.20 [19]	0.20 [19]	0.20 [19]	0.20 [19]
	Pore Water Velocity	v	m/d	0.20	1.45	0.20	1.45	0.20	1.45	0.20	1.45
Calculations	Retardation Factor	R	-	5,316,360	2,363,094	7,080	2,602	14.5	5.9	307	113
	Dispersion Coefficient	D	m^2/d	1.42E-05	1.71E-03	8.16E-06	1.19E-03	4.08E-03	5.29E-01	1.96E-04	2.83E-02
	Normalized Dispersion	D'	m^2/d	2.68E-12	7.24E-10	1.15E-09	4.56E-07	2.82E-04	8.90E-02	6.37E-07	2.49E-04
	Normalized Velocity	v'	m/d	3.73E-08	6.13E-07	2.80E-05	5.56E-04	1.37E-02	2.44E-01	6.45E-04	1.28E-02
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	1.84E-07	9.99E-08	1.53E-03	2.34E-03	4.89E-05	8.81E-05
	A_1	-	-	0.00E+00	0.00E+00	-5.41E-06	-2.94E-06	-4.58E-02	-7.00E-02	-1.50E-03	-2.70E-03
	A_2	-	-	2.58E+00	2.58E+00	1.91E+00	1.91E+00	1.95E+00	1.94E+00	2.00E+00	2.00E+00
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.55E-01	9.32E-01	9.99E-01	9.97E-01
	$erfc(A_2)$	-	-	2.62E-04	2.63E-04	7.03E-03	7.00E-03	5.85E-03	5.99E-03	4.65E-03	4.65E-03
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.01E+01	2.00E+01	2.00E+01
	B_2	-	-	5.16E+00	5.16E+00	4.86E+00	4.86E+00	4.89E+00	4.89E+00	4.90E+00	4.90E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08	5.08E+08	5.20E+08	4.86E+08	4.86E+08
	$erfc(B_2)$	-	-	2.83E-13	2.84E-13	6.20E-12	6.18E-12	4.77E-12	4.64E-12	4.22E-12	4.22E-12
	Concentration Immediately Above Water Table	C	mg/L	1.00E-04	1.00E-04	1.00E-05	1.00E-05	4.00E-05	4.00E-05	1.00E-03	1.00E-03
MRL		C	mg/L	1.00E-04	1.00E-04	1.00E-05	1.00E-05	4.00E-05	4.00E-05	1.00E-03	1.00E-03
Action Level		C	mg/L	5.00E-01 [20]		2.00E-03 [20]		1.00E-02 [20]		3.00E-01	

NOTES *(SEE APPENDIX B FOR CITATIONS)*

[1] Equal to the Action Level from Table 1 of the City of Keizer Applicant Review Draft UIC Permit No. 119546 (August 6, 2013)

[2] Infiltration time for lead is 1,000 years (1,000 years at 12.86 days per year = 12,860 days)

[3] Infiltration time is the number of hours (converted to days) during the year that stormwater infiltrates into the UIC. Stormwater infiltration is conservatively assumed to occur when the precipitation rate is $\geq$ 0.04 inches/hour.

[4] Median biodegradation rate from a review of scientific literature (see Table B-7 for references).

[5] 25th percentile biodegradation rate from a review of scientific literature (seeTable B-7 for references).

[6] 10 percent of the average biodegradation rate of PCP under aerobic conditions (see Table B-7 for references).

[7] 10 percent of the minimum biodegradation rate of PCP under aerobic conditions (see Table B-7 for references).

[8] Calculated from the following formula: $C_t = C_0e^{-kt}$, where C_t is concentration at time t, C_0 is initial concentration, t is time, and k is biodegradation rate.

[9] Midrange of porosity for sand in Freeze and Cherry (Table 2.4, pg. 37, 1979)

[10] Calculated by formula 8.26 in Freeze and Cherry (1979): $\rho_b = 2.65(1-\eta)$.

[11] Estimate of f_{oc} based on loading of TOC in stormwater; see Table B-6 for details.

[12] Calculated from the equation of Roy and Griffin (1985), which relates K_{oc} (soil organic carbon-water partitioning coefficient) to water solubility and K_{ow} (octanol-water partitioning coefficient) as presented in Fetter (1994).

[13] Because the K_{oc}s reported in field studies were all higher than K_{oc}s calculated from K_{ow} (i.e., field-study K_{oc}s were less conservative), the reasonable maximum scenario uses the K_{oc} calculated by Roy and Griffin (1985)

[14] The Koc for PCP is pH-dependent. pH has been measured at test wells installed in the sedimentary units that underly Keizer (Golder Associates, 1990). The average pH at the wells was 6.95. When pH = 6.95, the Koc for PCP is 536.5 L/kg. See text for details.

[15] Median K_d for lead, calculated using stormwater analytical data collected by the City of Milwaukie in spring of 2012 and an equation from Brickner (1998)

[16] 10th percentile K_d for lead, calculated using stormwater analytical data collected by the City of Milwaukie in spring of 2012 and an equation from Brickner (1998)

[17] K_d calculated from the following equation: Kd = $(f_{oc})(K_{oc})$ (e.g., Watts, pg. 279, 1998).

[18] Hydraulic conductivity is the median (average scenario) or maximum (reasonable maximum scenario) from infiltration tests at UICs.

[19] The effective porosity of the Upper Sedimentary Unit is summarized in Conlon et al. (pg. 9, 2005), and ranges from 0.003 to 0.20.

[20] Action Levels from Table 1 of the City of Keizer Applicant Review Draft UIC Permit No. 119546 (August 6, 2013)

Table B-8. Pollutant Fate and Transport

Groundwater Protectiveness Demonstration, City of Keizer, Horizontal UIC

	Parameter	Symbol	Units	Metals		PAHs		SVOCs			
				Lead		Benzo(a)pyrene		PCP		di-(2-ethylhexyl) phthalate	
				Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Distance Needed to Reach MRLs	y	m	0.00144	0.0236	0.00134	0.0267	0.64	10.77	0.0322	0.6336
		y	ft	0.00471	0.077	0.00441	0.08764	2.11	35.32	0.106	2.08
	Concentration	C_0	mg/L	0.50 [1]	0.50 [1]	0.002 [1]	0.002 [1]	0.01 [1]	0.01 [1]	0.30 [1]	0.30 [1]
	Infiltration Time	t	d	12,860 [2]	12,860 [2]	12.86 [3]	12.86 [3]	12.86 [3]	12.86 [3]	12.86 [3]	12.86 [3]
Pollutant Properties	First-Order Rate Constant	k	d^{-1}			1.30E-03 [4]	2.60E-04 [5]	2.21E-02 [6]	1.39E-02 [7]	1.50E-02 [4]	1.00E-02 [5]
	Half-Life	h	d			533.2 [8]	2666.0 [8]	31.4 [8]	49.9 [8]	46.2 [8]	69.3 [8]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.375 [9]	0.375 [9]	0.375 [9]	0.375 [9]	0.375 [9]	0.375 [9]	0.375 [9]	0.375 [9]
	Soil Bulk density	ρ_b	g/cm^3	1.66 [10]	1.66 [10]	1.66 [10]	1.66 [10]	1.66 [10]	1.66 [10]	1.66 [10]	1.66 [10]
	Fraction Organic Carbon	f_{oc}	-			0.0035 [11]	0.0013 [11]	0.0035 [11]	0.0013 [11]	0.0035 [11]	0.0013 [11]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg			282,185 [12]	282,185 [12, 13]	536.5 [14]	536.5 [14]	12,200 [12]	12,200 [12, 13]
	Distribution Coefficient	K_d	L/kg	1,203,704 [15]	535,040 [16]	982 [17]	361 [17]	1.9 [17]	0.7 [17]	42.5 [17]	15.6 [17]
	Vertical Hydraulic Conductivity	K_v	m/d	0.04 [18]	0.29 [18]	0.04 [18]	0.29 [18]	0.04 [18]	0.29 [18]	0.04 [18]	0.29 [18]
	Effective Porosity	η_e	-	0.20 [19]	0.20 [19]	0.20 [19]	0.20 [19]	0.20 [19]	0.20 [19]	0.20 [19]	0.20 [19]
	Pore Water Velocity	v	m/d	0.20	1.45	0.20	1.45	0.20	1.45	0.20	1.45
Calculations	Retardation Factor	R	-	5,316,360	2,363,094	4,339	1,596	9.2	4.0	189	70
	Dispersion Coefficient	D	m^2/d	1.42E-05	1.71E-03	1.33E-05	1.93E-03	6.37E-03	7.79E-01	3.19E-04	4.59E-02
	Normalized Dispersion	D'	m^2/d	2.68E-12	7.24E-10	3.07E-09	1.21E-06	6.89E-04	1.93E-01	1.69E-06	6.55E-04
	Normalized Velocity	v'	m/d	3.73E-08	6.13E-07	4.57E-05	9.07E-04	2.14E-02	3.59E-01	1.05E-03	2.07E-02
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	3.00E-07	1.63E-07	2.39E-03	3.45E-03	7.95E-05	1.43E-04
	A_1	-	-	0.00E+00	0.00E+00	-8.82E-06	-4.80E-06	-7.15E-02	-1.03E-01	-2.44E-03	-4.38E-03
	A_2	-	-	2.58E+00	2.58E+00	1.91E+00	1.91E+00	1.94E+00	1.94E+00	2.00E+00	2.00E+00
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.31E-01	9.02E-01	9.98E-01	9.96E-01
	$erfc(A_2)$	-	-	2.62E-04	2.63E-04	7.02E-03	7.02E-03	6.00E-03	6.20E-03	4.64E-03	4.66E-03
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.01E+01	2.01E+01	2.00E+01	2.00E+01
	B_2	-	-	5.16E+00	5.16E+00	4.86E+00	4.86E+00	4.89E+00	4.89E+00	4.90E+00	4.90E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08	5.21E+08	5.38E+08	4.86E+08	4.87E+08
	$erfc(B_2)$	-	-	2.83E-13	2.84E-13	6.19E-12	6.19E-12	4.63E-12	4.48E-12	4.21E-12	4.21E-12
	Concentration Immediately Above Water Table	C	mg/L	1.00E-04	1.00E-04	1.00E-05	1.00E-05	4.00E-05	4.00E-05	1.00E-03	1.00E-03
MRL		C	mg/L	1.00E-04	1.00E-04	1.00E-05	1.00E-05	4.00E-05	4.00E-05	1.00E-03	1.00E-03
Action Level		C	mg/L	5.00E-01 [20]		2.00E-03 [20]		1.00E-02 [20]		3.00E-01	

NOTES *(SEE APPENDIX B FOR CITATIONS)*

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[3] Infiltration time is the number of hours (converted to days) during the year that stormwater infiltrates into the UIC. Stormwater infiltration is conservatively assumed to occur when the precipitation rate is $\geq$ 0.04 inches/hour.

[4] Median biodegradation rate from a review of scientific literature (see Table B-7 for references).

[5] 25th percentile biodegradation rate from a review of scientific literature (seeTable B-7 for references).

[6] 10 percent of the average biodegradation rate of PCP under aerobic conditions (see Table B-7 for references).

[7] 10 percent of the minimum biodegradation rate of PCP under aerobic conditions (see Table B-7 for references).

[8] Calculated from the following formula: $C_t = C_0e^{-kt}$, where C_t is concentration at time t, C_0 is initial concentration, t is time, and k is biodegradation rate.

[9] Midrange of porosity for sand in Freeze and Cherry (Table 2.4, pg. 37, 1979)

[10] Calculated by formula 8.26 in Freeze and Cherry (1979): $\rho_b = 2.65(1-\eta)$.

[11] Estimate of f_{oc} based on loading of TOC in stormwater; see Table B-6 for details.

[12] Calculated from the equation of Roy and Griffin (1985), which relates K_{oc} (soil organic carbon-water partitioning coefficient) to water solubility and K_{ow} (octanol-water partitioning coefficient) as presented in Fetter (1994).

[13] Because the K_{oc}s reported in field studies were all higher than K_{oc}s calculated from K_{ow} (i.e., field-study K_{oc}s were less conservative), the reasonable maximum scenario uses the K_{oc} calculated by Roy and Griffin (1985)

[14] The Koc for PCP is pH-dependent. pH has been measured at test wells installed in the sedimentary units that underly Keizer (Golder Associates, 1990). The average pH at the wells was 6.95. When pH = 6.95, the Koc for PCP is 536.5 L/kg. See text for details.

[15] Median K_d for lead, calculated using stormwater analytical data collected by the City of Milwaukie in spring of 2012 and an equation from Brickner (1998)

[16] 10th percentile K_d for lead, calculated using stormwater analytical data collected by the City of Milwaukie in spring of 2012 and an equation from Brickner (1998)

[17] K_d calculated from the following equation: $Kd = (f_{oc})(K_{oc})$ (e.g., Watts, pg. 279, 1998).

[18] Hydraulic conductivity is the median (average scenario) or maximum (reasonable maximum scenario) from infiltration tests at UICs.

[19] The effective porosity of the Upper Sedimentary Unit is summarized in Conlon et al. (pg. 9, 2005), and ranges from 0.003 to 0.20.

[20] Action Levels from Table 1 of the City of Keizer Applicant Review Draft UIC Permit No. 119546 (August 6, 2013)

Attachment C – Technical Documentation for the Saturated Zone GWPD

This attachment provides technical documentation of the methods used to delineate waste management areas (WMA) for Underground Injection Control (UIC) devices in the City of Keizer (City). A WMA is the "area where waste or material that could become waste if released to the environment, is located or has been located" [Oregon Administrative Rules (OAR) 340-040-0010(19)]. In the context of stormwater infiltration from a UIC, the WMA is the location where groundwater contains stormwater pollutants above background levels (i.e., which is considered to be the method reporting limit [MRL]). The waste management areas will be used as saturated zone Groundwater Protectiveness Demonstrations (GWPD) to demonstrate that UICs are protective of water wells in accordance with Condition 7(b) of Schedule A of the City's UIC Water Pollution Control Facilities (WPCF) permit (the permit).

1 Introduction

WMAs were calculated by simulating pollutant fate and transport from a wet foot UIC with a transient three-dimensional finite difference numerical model for groundwater flow and pollutant fate and transport. Two models were developed: (1) a model for horizontal UICs and (2) a model for vertical UICs. The UIC was simulated as an injection well that infiltrates stormwater into the aquifer over a 35 year period. Pollutant infiltration was simulated only during years 3 to 35 (33 years total) so that the hydraulics associated with the transient injection simulations stabilized before pollutant injection began. Pollutant concentrations were estimated directly down-gradient of the UIC in the direction of groundwater flow. The transport scenarios were conducted for pentachlorophenol (PCP), benzo(a)pyrene, lead, and di-2-ethylhexyl phthalate (DEHP). These pollutants are among the most mobile, toxic, and environmentally persistent in their respective chemical classes (GSI, 2008), and are the most likely pollutants in their respective chemical classes to exceed regulatory standards for stormwater at UICs (Kennedy/Jenks, 2009).

The pollutant fate and transport modeling conservatively estimates pollutant fate and transport so that it can be applied to all UICs with less than the protective vertical separation distance established by the unsaturated zone GWPD (i.e., see Attachment B, 1.8 feet for vertical UICs and 2.5 feet for horizontal UICs). The conservative modeling assumptions for the saturated zone GWPD included the following:

- The UIC was assumed to discharge directly to groundwater.
- Pollutant concentrations down-gradient of the UIC were measured directly down-gradient of the direction of groundwater flow, which is where the highest concentrations occur.

- Groundwater flow direction was constant and did not exhibit seasonal changes, which underestimates dilution of the pollutants (i.e., because seasonal changes in groundwater flow direction increase the volume of the mixing zone between UIC discharges and groundwater).

- The input concentration for PCP (the pollutant that determines the waste management area) was equal to the action level in the City's UIC WPCF permit, which is greater than any observed PCP concentration observed from stormwater sampling at UICs in the City of Gresham (over 70 samples) or City of Portland (over 1,400 samples).

- Pollutant transport and aquifer parameters were selected as averages based on field studies.

- Stormwater infiltration was assumed to occur when the rainfall intensity was equal to or exceeded 0.04 inches per hour, which is half of the intensity threshold of 0.08 inches per hour cited in the City of Portland UIC WPCF Permit Evaluation report (DEQ, 2005b).

2 Saturated Zone Groundwater Protectiveness Demonstration Modeling

The following model runs were conducted as a part of the saturated zone GWPD:

- **Base Model.** A single model run (i.e., "base model") was conducted using input parameters based on average conditions to represent the central tendency or expected mean value of the input parameter. The base model was used to calculate the WMA that determines the horizontal protective separation distance.

- **Sensitivity Analysis Model.** Uncertainty exists about the hydraulic conductivity the subsurface. Additional model runs were conducted to calculate protective horizontal separation distances based on a range of hydraulic conductivities. The sensitivity analysis model was used to assess the sensitivity of model results to model input parameters.

2.1 Model Software

Model software included a groundwater flow model and a pollutant fate and transport model. Groundwater flow was simulated using the 3D finite difference United States Geological Survey (USGS) block centered numerical groundwater flow model MODFLOW-2000. MODFLOW divides an aquifer into discrete cubes (known as cells) and solves the groundwater flow equation for groundwater elevation in each cell by minimizing mass balance errors in between the cells. The groundwater model output includes groundwater velocity at each cell. The velocities output by MODFLOW are used by the three dimensional pollutant fate and transport code MT3D to simulate reactive pollutant transport.

The groundwater flow equation was solved by MODFLOW using the Pre Conditioned Conjugant Gradient 2 package (PCG2). Particle advection was simulated in MT3D using the total variation diminishing (TVD) solution scheme. Groundwater Vistas version 6.51 (build 6) was used as a pre and post processor for model input and output, respectively.

2.2 Model Boundaries

Numerical groundwater models simulate groundwater and pollutant movement over a user-specified area. The edges of the area are called boundaries. Different types of model boundaries are used to create flow conditions that mimic real-world groundwater flow. The upgradient and downgradient model boundaries were assigned constant head boundaries (i.e., groundwater elevation is constant over time). Lateral boundaries were no flow boundaries oriented parallel to the direction of groundwater flow (i.e., groundwater flows parallel to and does not cross the boundary).

2.3 Spatial and Temporal Discretization

The model is divided into cells (i.e., spatially discretized) and time units (i.e., temporally discretized). Spatial and temporal model discretization is summarized in Table C-1.

The models for vertical and horizontal UICs have different aerial extents. The aerial extents of the vertical UIC model domain (1,960 feet by 360 feet) and horizontal UIC model domain (1,724 feet by 377 feet) were selected to maximize computational efficiency. Trial simulations with a larger model domain (approximately 10,000 feet by 10,000 feet) were conducted to confirm that the aerial extent of a smaller model domain did not affect simulation results. Cell sizes in the area of pollutant transport were chosen based on maintaining a Peclet number of less than 2 in order to prevent artificial oscillation (Huyakorn and Pinder, 1983). For simulation of pollutant transport, the MT3D time step was chosen to be ten percent of the MODFLOW time step in order to achieve a Courant number of 1, which is in the range of 0 to 2 necessary to prevent numerical dispersion (Van Ganutchen, 1994). Numerical dispersion is spreading of a pollutant plume caused by interpolation errors in between time steps. Numerical dispersion is undesirable because it is an artifact of the numerical solution scheme (as opposed to dispersion caused by physical properties of the aquifer).

2.4 Model Input Parameters

Model input parameters include aquifer properties and pollutant properties, and are summarized in Table C-2, Table C-3 and Table C-4.

2.4.1 Aquifer Properties

Aquifer properties are hydraulic characteristics of the aquifer that govern groundwater flow, and are summarized in Table C-2. Based on a geologic map from the Oregon Department of Geology and Mineral Industries (DOGAMI), the City's UICs are located in the floodplain deposits of the Willamette River (Qalc) and the catastrophic flood deposits (Qff). The aquifer properties used in the saturated zone GWPD are selected to simulate hydrogeologic conditions in the Qalc (see main document text for rationale).

Hydraulic Gradient

Hydraulic gradient is the slope of the water table. Direct measurement of the hydraulic gradient in the Floodplain deposits of the Willamette River (Qalc), which the saturated zone model simulates, is not possible because most water wells in the City are completed in the underlying Troutdale Formation. Therefore, the hydraulic gradient in the Qalc was estimated based on the hydraulic gradient in the Troutdale Formation (0.001 feet/foot was calculated using groundwater elevations measured at City wells). The hydraulic gradient was increased by a factor of five to account for the fact that the hydraulic gradient is likely larger in the Qalc[1]. Therefore, a hydraulic gradient of 0.005 feet/foot was used in the base and sensitivity analysis models. Because increasing hydraulic gradient results in faster pollutant migration, using a hydraulic gradient of 0.005 feet/foot instead of 0.001 feet/foot is conservative.

Hydraulic Conductivity

Hydraulic conductivity describes the ease with which groundwater moves through subsurface soils. Hydraulic conductivity of the Qalc was measured using infiltration tests (see Section 4 of Attachment B for details on infiltration testing procedures and selecting/testing UICs). The test results are summarized in Table B-6. The horizontal hydraulic conductivities in the Qalc ranged from 2.4 to 95 ft/day. These hydraulic conductivities are slightly higher than the published range for hydraulic conductivities of a silt [which range from less than 1 ft/day to 10 ft/day in Anderson and Woessner (Table 3.3, pg. 40, 1992)], which may indicate that the Qalc contains interbedded, higher permeability lenses (i.e., sands) in the areas where infiltration tests were conducted.

As is shown in Table C-2, the median hydraulic conductivity of 13 ft/day was used in the base model. For the sensitivity analysis model runs, the hydraulic conductivity was increased and decreased by an order of magnitude (i.e., values of 1.3 ft/day and 130 ft/day were used).

Saturated Thickness

Saturated thickness is the portion of a hydrogeologic unit that is saturated with groundwater. The saturated thickness was assumed to be the total thickness of the Qalc, which was estimated based on driller's logs downloaded from the OWRD online well log database (OWRD, 2013). Based on analysis of 27 driller's logs, the thickness of the Qalc ranged from 8 feet to 30 feet, and averaged 18 feet. The average saturated thickness across the model domain for the base and sensitivity analysis models was 20 feet.

Porosity, Effective Porosity, and Specific Yield

Porosity is a weight-based percentage of void space in a soil. Porosity (0.375) was the midrange for a sand from Freeze and Cherry (1979) to represent the Qalc. The effective porosity and specific yield (0.20) were taken from Conlon et al. (2005) for the Upper Sedimentary Unit, which includes the Qalc geologic unit. This porosity, effective porosity and specific yield were used in the base and sensitivity analysis models.

Dispersivity

Dispersivity (α) is related to the spreading of a solute plume as pollutants are transported by groundwater. Solutes spread during transport because some solute particles move faster than the average groundwater flow velocity and other solute particles move slower than the average groundwater flow velocity. The spreading of a solute occurs in three dimensions, and is called dispersion.

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[1] According to Darcy's Law, hydraulic conductivity and hydraulic gradient are inversely correlated. Therefore, hydrogeologic units with lower hydraulic conductivity have higher hydraulic gradients.

Dispersivity is scale-dependent, and increases with increasing pollutant transport distance. The Environmental Protection Agency (EPA) recommends using the equation of Xu and Eckstein (1995) to calculate a longitudinal dispersivity (i.e., dispersivity parallel to the direction of groundwater flow) (EPA, 1996). Following recommendations in EPA (1996), transverse dispersivity (the horizontal dispersivity perpendicular to longitudinal dispersivity) was set as 33 percent of longitudinal dispersivity, and vertical dispersivity was set as 10 percent of longitudinal dispersivity.

Stormwater Infiltration Volume

Calculations for stormwater infiltration volumes are shown on Table C-3. Stormwater infiltration volume was estimated from the following equation (e.g., Snyder, 1994):

$$I = (A)(p)(1-e) \tag{C.1}$$

Where:

I = Annual stormwater infiltration volume (cubic feet per year)

A = Impervious area within a UIC drainage basin (square feet)

p = Precipitation that runs off into the UIC (feet per day)

e = Evaporative loss factor

<u>Impervious Area (*A*)</u>

The City has delineated impervious areas for all of its UIC catchment areas. Based on the City's July 2012 UIC inventory (which included 95 UICs), the impervious area ranges from 300 ft^2 to 1,300,000 ft^2. The median impervious area, which was used for A in Equation C.1, is 17,109 ft^2.

<u>Precipitation That Runs Off Into a UIC (*p*)</u>

Based on the City of Portland's WPCF permit evaluation report, runoff into a UIC occurs when the rainfall intensity exceeds 0.08 inches per hour (DEQ, 2005b). For the purpose of infiltration calculations, it was conservatively assumed that all precipitation that falls during a storm intensity of greater than or equal to 0.04 inches per hour runs off into UICs. As shown on Table C-3, approximately 2.03 feet of precipitation is produced annually by storm intensities greater than or equal to 0.04 inches per hour.

<u>Infiltration Volume (*I*)</u>

As shown in Table C-3, the annual infiltration volume in an average UIC drainage basin is estimated to be approximately 26,500 ft^3. This value was used in the base and sensitivity analysis models.

Stormwater Infiltration Time

Stormwater infiltration time is shown on Table C-3. On average, precipitation intensity is equal to or exceeds 0.04 inches per hour for about 309 hours per year. In the model, the UIC is estimated to discharge the entire year's volume of stormwater runoff over eight months, with an alternating series of one day long rain events followed by two day long dry periods. This method of inputting runoff into the model resulted in an efficient model and produced a reasonable hydraulic head in the UIC during discharge. A simplifying assumption in the modeling was that stormwater discharges were not assumed to occur from June through September.

Fraction Organic Carbon

Fraction organic carbon (f_{oc}) is a dimensionless measure of organic carbon content in a material (i.e., g_{carbon} / g_{soil}). Pollutants primarily sorb to organic carbon; therefore, pollutant retardation is directly proportional to fraction organic carbon.

Carbon in saturated soil beneath a UIC is derived from two sources:

- Organic carbon incorporated into the soil when the soil is deposited (i.e., "background f_{oc}), and
- Particulate matter (e.g., degraded leaves, pine needles, pollen, etc.) that is filtered out of stormwater and accumulates in soil adjacent to UICs as stormwater discharges from the UIC.

The model includes f_{oc} from both sources.

The background f_{oc} was estimated to be 0.001826 g_{carbon}/g_{soil} based on the average total organic carbon (TOC) in three soil samples that were collected from temporary borings in the Unconsolidated Sedimentary Aquifer (USA) near Gresham, Oregon, in the City of Gresham's UIC area (GSI, 2013).

An estimate of f_{oc} based on accumulation of TOC from stormwater around a UIC by filtration and sorption was determined by calculating the grams of organic carbon added to the saturated zone around the UIC during a 10-year period. The approach was also used to calculate grams of organic carbon added to the unsaturated zone as a part of the City's unsaturated zone GWPD (see Appendix B). The following equations were used in the analysis:

$$I = (A)(p)(1-e) \tag{C.2}$$

$$CL = (t)\left[\sum_{i=1}^{n} I_i C\right]\frac{1\text{ liter}}{1{,}000\text{ cm3}}\,\frac{1\text{ gram}}{1{,}000{,}000\text{ milligrams}} \tag{C.3}$$

$$\rho_{oc} = \frac{CL}{SV} \tag{C.4}$$

$$f_{oc} = \frac{\rho_{oc}}{\rho_b + \rho_{oc}} \tag{C.5}$$

Where the variables in Equation (C.2) were identified previously, and:

CL = Organic carbon loaded into the saturated zone beneath a UIC during a 10-year period (grams)

C = TOC concentration in stormwater (milligrams per liter)

t = Time of carbon loading (years)

ρ_{oc} = Organic carbon weight per unit saturated zone material volume (grams per cubic centimeter)

SV = Material volume into which the organic carbon would accumulate because of filtration and adsorption (assumed to be the volume of the grid cell(s) where the UIC is located) (cubic centimeters)

f_{oc} = Fraction organic carbon (g_{carbon}/g_{soil})

ρ_b = Bulk density (grams per cubic centimeter)

The value of SV is different for horizontal and vertical UICs:

- For vertical UICs, SV is assumed to be the size of a single grid cell (a cube that is 5 feet by 5 feet by 5 feet, or 125 ft^3).
- For horizontal UICs, SV is assumed to be the size of 21, 5 foot long grid cells to represent the 102 feet length of the horizontal UIC (the equivalent of 21 cubes that are each 5 feet by 5 feet by 5 feet, or 2,625 ft^3).

Based on Equation (C.4), ρ_{oc} (and f_{oc}) is inversely proportional to SV. Therefore, because SV at horizontal UICs is larger than SV at vertical UICs, the ρ_{oc} (and f_{oc}) at horizontal UICs is lower than the ρ_{oc} (and f_{oc}) at vertical UICs.

Calculation of f_{oc}, based on the filtering of TOC as suspended solids is shown in Table C-4 for the different UIC configurations. First, the volume of stormwater that infiltrates into a UIC each month was calculated by Equation (C.2). Next, Equation (C.3) was used to calculate the grams of carbon added to the saturated zone surrounding the UIC during a 10-year period. Equation (C.4) was used to calculate the mass of organic carbon per unit volume of material surrounding the UIC (ρ_{oc}), and Equation (C.5) was used to convert ρ_{oc} to f_{oc}.

2.4.2 Pollutant Properties

Pollutant properties used in the base model are summarized in Table C-5. With the exception of half-life, the data sources for calculating pollutant properties for saturated transport are the same as is used for unsaturated transport (see Appendix B). The saturated transport simulations used half-lives that were the midrange of field studies for pollutant degradation in aerobic groundwater from Howard et al. (1991).

3 Saturated Zone GWPD Results

Results of the base model are summarized in Table C-6. PCP migrates farther than the other pollutants that were modeled because it is more mobile and persistent in the environment. Therefore, the protective horizontal separation distance at City UICs is conservatively based on PCP. If PCP is not present in a UIC drainage basin, then the protective separation distance should be based on DEHP.

Results of the sensitivity analysis model are summarized in Table C-6. Sensitivity analysis simulations were performed the fate and transport of PCP from vertical UICs because this pollutant and UIC orientation produce the largest (i.e., worst-case) WMAs based on the results of the base model. The sensitivity analysis involved increasing and decreasing hydraulic conductivity:

- **Effect of decreasing Hydraulic Conductivity.** Hydraulic conductivity was lowered from the median value of 13 ft/day by an order of magnitude to 1.3 ft/day, which had the effect of reducing the WMA from 117 to 74 feet (a 43 foot reduction).
- **Effect of increasing Hydraulic conductivity.** Hydraulic conductivity was increased from the median value of 13 ft/day by an order of magnitude to 130 ft/day, which had the effect of increasing the WMA from 117 to 265 ft/day (a 148 foot increase).

It should be noted that this sensitivity analysis was conducted by changing the hydraulic conductivity without changing the hydraulic gradient. Hydraulic gradient is inversely correlated to hydraulic conductivity. Changing the hydraulic gradient would reduce the magnitude of the effect of changing the hydraulic conductivity. Therefore, the results of the sensitivity analysis tend to overstate the sensitivity of the WMA to hydraulic conductivity.

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Table C-1

Model Discretization

City of Keizer

Variable	**Value**	
	Vertical UIC	*Horizontal UIC*
Spatial Discretization		
Horizontal *x*-extent	1,960 feet	1,724 feet
Horizontal *y*-extent	360 feet	377 feet
Vertical Extent	30 feet	30 feet
Number of Rows	23	40
Number of Columns	103	100
Number of Layers	5	5
Total Number of Cells	11,845	20,000
Cell Size	5 feet to 20 feet	
Temporal Discretization		
Simulation Length	35 years (33 years of pollutant loading)	
Number of Time Steps	12,775	
MODFLOW Time Step Length	1 day	
MT3D Time Step Length	0.1 day	

Table C-2

Aquifer Properties

City of Keizer

Variable	Symbol	Units	Value	Reference
Hydraulic Gradient	h	feet/foot	0.005	Based on water levels measured in City wells in the Troutdale gravels, and multiplied by a factor of 5 to conservatively account for the fact that the hydraulic gradient is likely higher in the lower permeability Qalc.
Hydraulic Conductivity	K_h	feet/day	13	Median hydraulic conductivity in the Qalc (USHU) calculated from infiltration tests at UICs. See Table B-2 in Appendix B.
Anisotropy	$K_h:K_v$	dimensionless	100:1	Freeze and Cherry (1979)
Average Hydrogeologic Unit Thickness	b_{HGU}	feet	20 ft	Average thickness of the Qalc.
Porosity	η	dimensionless	0.375	Midrange of porosity for sand in Freeze and Cherry (Table 2.4, pg. 37, 1979)
Effective Porosity	η_e	dimensionless	0.20	Conlon et al. (pg. 9, 2005) for the Upper Sedimentary Unit
Specific Yield	S_y	dimensionless	0.20	Conlon et al. (pg. 9, 2005) for the Upper Sedimentary Unit
Longitudinal Dispersivity	α_L	feet	17.93	Calculated using Xu and Eckstein (1995). $a_L = (3.28)(0.83)[\log(L_p/3.28)]^{2.414.}$ A transport distance (L_p) of 500 feet was used in the calculation)
Transverse Dispersivity (y-direction)	α_T	feet	5.92	Calculated using EPA (1986). $a_T = 0.33(a_L)$
Vertical Dispersivity (z-direction)	α_V	feet	1.79	Calculated using EPA (1986). $a_v = 0.10(a_L)$
Fraction Organic Carbon	f_{oc}	dimensionless	0.0062	f_{oc} near a vertical UIC due to carbon loading from stormwater. See text for calculations and Table C-5
			0.00030	f_{oc} near a horizontal UIC due to carbon loading from stormwater. See text for calculations and Table C-5
			0.0018	f_{oc} in native sediments, based on TOC measurements of unconsolidated sediments of the USA in Gresham, Oregon (GSI, 2012), which includes the Qfc

Note:

bgs = below ground surface

USGS = United States Geological Survey

DTW = depth to groundwater

OWRD = Oregon Water Resources Department

EPA = Environmental Protection Agency

Qfc = Coarse grained catastrophic flood deposits

UIC = Underground Injection Control

USA = Unconsolidated Sedimentary Aquifer

TOC = Total Organic Carbon

Table C-3

Infiltration Volume and Rate

City of Keizer

Impervious Area in UIC Drainage Catchment (ft^2)	**Infiltration Time** (Annual Number of Hours with Precipitation ≥ 0.04 inches/hour [1]) (hours)	**Infiltration Time** (Annual Number of Days with Precipitation ≥ 0.04 inches/hour [1]) (days)	**Annual Precipitation ≥ 0.04 inches/hour [1]** (ft)	**Annual Infiltration Volume [2]** (ft^3)
17,109	309	12.86	2.03	26,439

Notes

(1) Data is from "SALEM_RG4" (2003) located at River Road Park and "SALEM_RG16" (2006 - 2009, 2011) located at Clearlake RD NE and Wheatland Road N. Precipitation data for years where over 6 days were missing. The amount of missing data ranged from 1 month (2004) to 8 months (2010).

(2) Assumes an evaporative loss factor of 24%.

Table C-4
Saturated Zone GWPD Carbon Loading Calculations
City of Keizer

Impervious Area (ft^2)	UIC Type	Annual Infiltration Volume (cm^3/yr)	TOC Concentration (mg/L)	Time (years)	Conversion Factor	Grams Carbon Added Over 10 Years (g)	Cell Width (cm)	Cell Length (cm)	Cell Depth (cm)	Number of Horizontal UIC Cells [1]	Aquifer Volume (cm^3)	g TOC per cm^3/soil (g/cm^3)	Bulk Density (g/cm^3)	f_{oc} (-)
17,109	Vertical UIC	758,490,908	4.86	10	1,000,000	36,863	152	152	152		3,539,260	0.010	1.66	0.0062
17,109	Horizontal UIC	758,490,908	4.86	10	1,000,000	36,863	152	152	152	21	74,324,468	0.000	1.66	0.00030

Notes
[1] Based on a cell size of 152.4 cm and a median horizontal UIC length of 3126 cm (102.58 feet)
mg/L = milligrams per liter
cm^3/yr = cubic centimeters per year
g = grams
cm = centimeters
g/cm^3 = grams per cubic centimeter

Table C-5

Pollutant Properties

City of Keizer

Variable	Symbol	Units	Pollutant	Value	Reference
Organic Carbon Partitioning Coefficient	K_{oc}	L/kg	B(a)P	282,185	Calculated by Roy and Griffin (1985), which relates Koc to solubility in water
			PCP	536.5	The K_{oc} for PCP is pH-dependent. pH has been measured at 6 shallow water wells (30 - 78 feet below ground surface) that are completed in the sand and gravels, Lane County, Oregon (Craner, Table 9, 2006). The average pH at monitoring wells was 6.8. When pH = 6.8, the K_{oc} for PCP is 592 L/kg.
			DEHP	12,200	Calculated by Roy and Griffin (1985), which relates Koc to solubility in water
Distribution Coefficient	K_d	L/kg	Lead	1,203,704	Calculated by the equation of Bricker (1988), which calculates Kd based on concentrations of total metals, dissolved metals, and TSS. See Appendix B.
			B(a)P	515 (Native Sediments) 1,750 (Near vertical UIC, reflects loading from stormwater) 84.7 (Near horizontal UIC, reflects loading from stormwater)	Calculated from the relationship: $K_d = (f_{oc})(K_{oc})$ (Watts, 1998)
			PCP	Native Sediments: 0.97 3.3 (Near vertical UIC, reflects loading from stormwater) 0.16 (Near horizontal UIC, reflects loading from stormwater)	Calculated from the relationship: $K_d = (f_{oc})(K_{oc})$ (Watts, 1998)
			DEHP	22.3 (Native Sediments) 75.6 (Near vertical UIC, reflects loading from stormwater) 3.66 (Near horizontal UIC, reflects loading from stormwater)	Calculated from the relationship: $K_d = (f_{oc})(K_{oc})$ (Watts, 1998)
Retardation Factor	R	dimensionless	Lead	5,328,397	Calculated from the relationship: $R = 1 + (\rho_b)(K_d)/(\eta)$. Based on a bulk density (ρ_b) of 1.66 g/cm^3, calculated from porosity using equation 8.26 of Freeze and Cherry (1979).
			B(a)P	2,280 (Native Sediments) 7,746 (Near vertical UIC, reflects loading from stormwater) 376 (Near horizontal UIC, reflects loading from stormwater)	Calculated from the relationship: $R = 1 + (\rho_b)(K_d)/(\eta)$. Based on a bulk density (ρ_b) of 1.66 g/cm^3, calculated from porosity using equation 8.26 of Freeze and Cherry (1979).
			PCP	Native Sediments: 5.3 15.7 (Near vertical UIC, reflects loading from stormwater) 1.7 (Near horizontal UIC, reflects loading from stormwater)	Calculated from the relationship: $R = 1 + (\rho_b)(K_d)/(\eta)$. Based on a bulk density (ρ_b) of 1.66 g/cm^3, calculated from porosity using equation 8.26 of Freeze and Cherry (1979).
			DEHP	100 (Native Sediments) 336 (Near vertical UIC, reflects loading from stormwater) 17.2 (Near horizontal UIC, reflects loading from stormwater)	Calculated from the relationship: $R = 1 + (\rho_b)(K_d)/(\eta)$. Based on a bulk density (ρ_b) of 1.66 g/cm^3, calculated from porosity using equation 8.26 of Freeze and Cherry (1979).
Half Life	h	days	B(a)P	587	Based on midrange observed biodegradation rate for B(a)p in aerobic groundwater (Howard et al., 1991)
			PCP	46	Based on observed biodegradation rate for PCP in aerobic groundwater (Howard et al., 1991)
			DEHP	10	Based on observed biodegradation rate for DEHP in aerobic groundwater (Howard et al., 1991)
Input Concentration	C_{AL}	ug/L	Lead	500	
			B(a)P	2	
			PCP	10	
			DEHP	300	

Table C-6

Model Simulation Results

City of Keizer

	Horizontal Distance for Pollutants to Attenuate to Below MRL (WMA is Based on the MRL)			
	PCP	DEHP	B(a)P	Lead
	MRL (0.04 ug/L)	MRL (0.962 ug/L)	MRL (0.01 ug/L)	MRL (0.1 ug/L)
Base Model (Used to Delineate WMA)				
Vertical UIC Hydraulic Conductivity = 13 ft/day	117	59	28	3
Horizontal UIC Hydraulic Conductivity = 13 ft/day	101	41	17	< 1
Sensitivity analysis				
Vertical UIC High hydraulic conductivity (K=130 ft/day)	265			
Vertical UIC Low hydraulic conductivity (K= 1.3 ft/day)	74			

Notes:

MRL= Method Reporting Limit

B(a)P = benzo(a)pyrene

DEHP = di(2-ethylhexyl)phthalate

PCP = pentachlorophenol

SIMULATION NOT RUN

GSI Water Solutions, Inc.

Attachment D – Conservative Assumptions for GWPD Models

The unsaturated zone and saturated zone groundwater protectiveness demonstration (GWPD) models are based on several conservative assumptions. The conservative modeling assumptions for the saturated zone GWPD model included the following:

- The Underground Injection Control (UIC) device was assumed to discharge directly to groundwater.
- Pollutant concentrations down-gradient of the UIC were measured directly down-gradient of the direction of groundwater flow, which is where the highest concentrations occur.
- Groundwater flow direction was constant and did not exhibit seasonal changes, which underestimates dilution of the pollutants (i.e., because seasonal changes in groundwater flow direction increase the volume of the mixing zone between UIC discharges and groundwater).
- The input concentration for pentachlorophenol (PCP, the pollutant that determines the waste management area) was equal to the action level in the City's UIC Water Pollution Control Facilities (WPCF) permit, which is greater than any observed PCP concentration observed from stormwater sampling at UICs in the City of Gresham (over 70 samples) or City of Portland (over 1,400 samples).
- Pollutant transport and aquifer parameters were selected as averages based on field studies.
- Stormwater infiltration was assumed to occur when the rainfall intensity was equal to or exceeded 0.04 inches per hour, which is half of the intensity threshold of 0.08 inches per hour cited in the City of Portland UIC WPCF Permit Evaluation report (DEQ, 2005b).

The conservative modeling assumptions for the unsaturated zone GWPD model included the following:

- Transport is one-dimensional vertically downward from the bottom of the UIC to the water table (Note: water at some City exfiltrates from holes in the side of the UIC, as well as from the bottom).
- The stormwater infiltration rate into the UIC is constant and maintains a constant head within the UIC to drive the water into the unsaturated soil. (Note: stormwater flows are highly variable, short duration, and result in varying water levels within the UIC dependent on the infiltration capacity of the formation.)

- Pollutant concentrations in water discharging into the UIC are uniform and constant throughout the period of infiltration (Note: concentrations are variable seasonally and throughout storm events).
- The pollutant undergoes equilibrium sorption (instantaneous and reversible) following a linear sorption isotherm.
- The pollutant is assumed to undergo a first-order transformation reaction involving biotic degradation.
- The pollutant does not undergo transformation reactions in the sorbed phase (i.e., no abiotic or biotic degradation).
- There is no portioning of the pollutant to the gas phase in the unsaturated zone.
- The soil is initially devoid of the pollutant.