Report

Groundwater Protectiveness Demonstrations

Prepared for

Lane County, Oregon

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Executive Summary

This report presents model-based Groundwater Protectiveness Demonstrations (GWPD) which will be used by Lane County, Oregon (County) to identify and prioritize Underground Injection Control (UIC) device retrofits or decommissioning. The GWPD was conducted in accordance with the October 18, 2012, scope of work prepared by GSI Water Solutions, Inc. (GSI), and was authorized by contract no. 2013-00213 between GSI and the City of Eugene (City) and through an Intergovernmental Agreement (IGA) between the City and Lane County.

The County currently uses 94 UIC devices to manage stormwater from public rights-of way and adjacent properties in residential areas. Lane County applied for a UIC Water Pollution Control Facilities (WPCF) permit for its UICs on March 24, 2009, and anticipates receiving its permit in late 2013. Under the July 2012 draft UIC WPCF permit template, the permittee must address UICs that are located within permit-specified setbacks to water wells (500 feet of a public or private drinking water or irrigation supply well, or inside the 2-year time of travel of a public water supply well). Approximately 69 of the County's UICs are located within permit-specified setbacks. The County has chosen unsaturated zone and saturated zone GWPD models to address the UICs within permit-specified setbacks.

The GWPDs documented in this report are based on pollutant fate and transport models that simulate pollutant attenuation in the subsurface using conservative assumptions. The Unsaturated Zone GWPD calculates a vertical protective separation distance by simulating vertical transport of pollutants in unsaturated soils between the bottom of the UIC and the seasonal high groundwater table. A UIC is protective of the groundwater resource if the vertical separation distance is greater than about 2.3 feet (vertical UICs) or 4.8 feet (horizontal UICs). The Saturated Zone GWPD calculates a horizontal protective separation distance by simulating horizontal transport of pollutants in saturated soils downgradient of a UIC. The horizontal separation distances vary based on the impervious area within a UIC drainage basin, and are summarized on Table 9.

The model-based GWPDs documented in this report address most of the UICs within permit-specified setbacks. 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 EWEB service), evaluation of whether PCP is likely present within a UIC's drainage basin (i.e., whether utility poles—the source of PCP—are present), or documentation that a UIC is located outside of the capture zone of a water well. A capture zone consists of the upgradient and downgradient areas that will drain into a pumping well (Fetter, 1994).

1. Introduction

An Underground Injection Control (UIC) device is designed for the subsurface infiltration of fluids and is commonly referred to as a drywell. Lane County (the County) currently uses 94 UIC devices to manage stormwater from public rights-of-way (ROW) and adjacent properties in residential areas. The City of Eugene also owns 163 UICs, many of which are in the vicinity of Lane County's. The locations of the County's UICs, including five decommissioned UICs, are shown in Figure 1. While the County's UICs provide protection of sensitive aquatic receptors by providing an alternative to direct discharge to surface water, there are some concerns that contamination from UICs could affect underground sources of drinking water. Therefore, the County would like to further evaluate the environmental risk posed by UICs. UICs are regulated by the Oregon Department of Environmental Quality (DEQ). Because the County's UICs infiltrate only nonhazardous stormwater runoff from residential, commercial and roadway areas, DEQ considers them to be Class V injection systems under Oregon Administrative Rules (OAR) 340-044-0011(5)(d). Lane County applied for a UIC Water Pollution Control Facility (WPCF) permit (the permit) for its UICs on March 24, 2009. The County anticipates receiving its permit in late 2013.

UIC WPCF permits are customized for each applicant based on the July 2012 draft UIC WPCF permit template. To date, only the City of Gresham and City of Eugene have received their permits based on the July 2012 permit template. This technical memorandum assumes that the conditions of the County's permit will likely be similar to the conditions of the City of Eugene's UIC WPCF permit, which was recently issued on January 25, 2013.

The permit is designed to protect groundwater to its highest beneficial use. Based on the City's permit, the County anticipates that Condition 7 of Schedule A will stipulate that the County 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[1] within one year of discovery, retrofit the UIC, or decommission the UIC. The County has chosen to develop a GWPD to identify which UICs are protective of groundwater, and to prioritize future UIC decommissioning and retrofitting. This report summarizes a model-based GWPD that was prepared to satisfy the permit and inform future decisions about UIC retrofit and decommissioning.

Pollutants in stormwater are attenuated in both the unsaturated zone and saturated zone after infiltration from a UIC. To evaluate whether beneficial use of groundwater is adversely impacted by stormwater pollutants as a result of infiltration, pollutant fate and

[1] A GWPD is a science-based evaluation of a UIC or group of UICs that shows whether the UIC or group of UICs is protective of a receptor (e.g., water well). GWPDs may include pollutant fate and transport modeling, documentation that a water well is not being used for potable supply (e.g., well property connected to EWEB service), evaluation of whether PCP is likely present within a UIC's drainage basin (i.e., whether utility poles—the source of PCP—are present), or documentation that a water well is located upgradient and outside of the capture zone of a UIC. A capture zone consists of the upgradient and downgradient areas that will drain into a pumping well (Fetter, 1994).

transport modeling can be conducted in each of these zones. Modeling simulates attenuation of stormwater pollutants in the subsurface (i.e., after infiltration from a UIC):

- **Unsaturated Zone GWPD**. Unsaturated zone GWPDs are based on modeling pollutant fate and transport *vertically* through the *unsaturated* soils beneath a UIC. Groundwater protectiveness is demonstrated by showing that the pollutants attenuate to below background levels (i.e., which is considered to be the method reporting limit, MRL, for non-metals or background concentrations for metals) before reaching the seasonal high groundwater table, and, therefore, that the pollutants do not impair groundwater quality. If pollutants reach groundwater, then the saturated zone GWPD model can be used.

- **Saturated Zone GWPD.** A saturated zone GWPD consists of modeling *horizontal* pollutant fate and transport through *saturated* soils. The model is used to delineate a Waste Management Area (WMA) which is used to demonstrate that that the UIC does not adversely impact groundwater users. 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.

GWPDs have been conducted by several municipalities in Oregon, including Gresham, Portland, Bend, Redmond, Clackamas County Water Environment Services (WES), and Milwaukie. The County chose to develop both unsaturated zone and saturated zone GWPDs, although construction details of County UICs are not yet available. 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 the County's other relevant to groundwater protectiveness factors, permit requirements, and the County's goals and policies to develop a strategy for addressing Lane County's UICs.

1.1 Objectives

The objectives of this technical memorandum are:

- To calculate a minimum vertical separation distance in the unsaturated zone that is protective of groundwater.
- To delineate a WMA in the saturated zone by calculating the horizontal distance required for pollutant concentrations to decline to zero as represented by the MRL (synthetic organic compounds) or background levels (metals).
- Present technical documentation for the unsaturated zone and saturated zone GWPD models, and provide the County with methods for applying the model results (i.e., a protectiveness look-up table).

- Identify the number of UICs that are within the default setbacks to water wells that are specified within the July 2012 draft UIC WPCF permit template (500 feet of a water well or the 2 year time of travel) based on known well locations,
- Summarize development of Alternate Action Levels to support stormwater discharge monitoring under the permit using the unsaturated zone GWPD. Alternate Action Levels are developed because the unsaturated zone model results demonstrate that unsaturated zone soils will attenuate pollutant concentrations to zero (the MRL) even if the pollutant concentrations in stormwater are higher than the default Action Levels. The County will determine whether to request Alternate Action Levels based on stormwater sampling that is required by the permit.

The main text of the technical memorandum provides an overview of the UIC system and GWPD models. Additional technical details are provided in Appendix A (UIC database), Appendix B (technical documentation for the unsaturated zone GWPD model), Appendix C (technical documentation for the saturated zone GWPD model), and Appendix D (conservative assumptions used for modeling).

1.2 Technical Memorandum Organization

This technical memorandum is organized as follows:

- **Section 1: Introduction**. Discusses the County's UIC system and outlines the technical memorandum's objectives.
- **Section 2: UIC Conceptual Model.** Provides information about County UIC facilities and conceptual model for County UIC facilities.
- **Section 3: UICs Within Default Water Well Setbacks and Permit Requirements.** Identifies UICs within water well setbacks, and discusses actions required at these UICs by the permit.
- **Section 4: Groundwater Protectiveness Demonstrations.** Provides background related to the different types of GWPDs and summarizes how they are used to demonstrate groundwater protectiveness. Documents results of the unsaturated zone GWPD model (Section 4.1) and saturated zone GWPD (Section 4.2).
- **Section 5: Conclusions and Recommendations**. Summarizes GWPD results, and outlines the process for applying the results.
- **References.**

2. UIC Conceptual Model

This section summarizes the conceptual model for stormwater infiltration at UICs, fate and transport of pollutants through subsurface soils after stormwater discharges from UICs, and subsurface geology in the Lane County vicinity (which affects the fate and transport).

2.1 Stormwater Infiltration at UICs

A typical County UIC facility is comprised of a catch basin that collects stormwater runoff from the public ROW; piping that conveys the stormwater from the catch basin to the UIC; and the UIC itself that infiltrates stormwater to the subsurface. Occasionally, a sedimentation manhole (i.e., a solid concrete cylinder) is installed between the catch basin and UIC to allow for separation of sediment and floatables (e.g., trash and debris, oil and grease). The County uses two types of UIC configurations—horizontal UICs and vertical UICs.

Measured depths at vertical UICs in the County are generally less than 9 feet-deep, and County UICs are 12 to 48 inch diameter cylindrical structures constructed of concrete[2]. Rectangular openings (perforations) in the concrete walls of a UIC allow stormwater to infiltrate from the sides of the UIC. The County only has about seven horizontal UICs, and does not have much information about their construction. Based on information from other jurisdictions in Oregon, a typical horizontal UIC is comprised of perforated PVC pipe installed in a trench with gravel backfill. The pipe diameter is typically 10 to 12 inches, and horizontal UIC pipe lengths reach up to 500 feet, with a median of 50 feet.

The conceptual site model for stormwater infiltration from a UIC and pollutant fate and transport after the water infiltrates from the UIC is shown schematically in Figure 2. Stormwater discharges into the UIC, and infiltrates through the unsaturated zone from the sides and bottom of the UIC. In Figure 2, infiltration is only shown from the bottom of the UIC, which is the scenario that is conservatively modeled in the GWPD. These simplifying assumptions are necessary to simulate a complex system using a model. After infiltration, the stormwater migrates downward and recharges groundwater. Infiltration through the unsaturated zone likely occurs under near-saturated conditions because of the near-constant infiltration of water during the rainy season. Low levels of pollutants are present in stormwater due to processes such as pentachlorophenol (PCP) leaching from utility poles, poly-aromatic hydrocarbons (PAHs) formed by incomplete combustion of gasoline from cars, and metals deposited onto streets from brake pad deterioration. Before entering the unsaturated zone, large-size particulate matter (which pollutants may be sorbed to) falls out of suspension into the bottom of the UIC. During transport through the unsaturated zone, pollutant concentrations attenuate because of degradation, dispersion, volatilization, filtration of particulates, and retardation. Therefore, pollutant concentrations in unsaturated zone pore water beneath the UIC decrease as the water migrates downward through the unsaturated zone to the water table.

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[2] Lane County UICs have not been cleaned recently, and contain solids that settle out of stormwater during infiltration. Therefore, exact UIC depth is uncertain.

Organic carbon is also present in stormwater (i.e., from pollen, leaves, organic material), and accumulates in soils around UICs due to filtration by the soil matrix during stormwater infiltration. Organic carbon concentrations in stormwater vary during the year, reaching the highest levels in the fall during leaf drop and the lowest levels during the winter. The soil organic content is likely higher at vertical UICs and lower at horizontal UICs because horizontal UICs are larger devices; therefore, the carbon accumulates over a relatively larger volume of soil at horizontal UICs (i.e., is more diluted by the surrounding soil volume). The total organic carbon (TOC) in the soil is an important component of pollutant fate and transport evaluations because most pollutants readily sorb to organic carbon. The City of Eugene collected samples of backfill and native soils beneath the backfill at a horizontal UIC on Shirley Street that was being decommissioned, and submitted the samples to an analytical laboratory to quantify the TOC. The TOC results are summarized in Table 1, with footnotes that provide additional details about field and lab methods used during sampling. The TOC in backfill below the UIC's PVC pipe ranged from 1,220 to 2,330 milligrams per kilogram (mg/kg). The TOC in native soil samples collected below the backfill was the same order of magnitude, ranging from 1,590 to 3,520 mg/kg. Therefore, the TOC concentrations in backfill and native soil are similar. This similarity is important for the unsaturated zone GWPD because the model assumes that TOC concentrations are vertically homogeneous (i.e., do not change spatially).

2.2 Subsurface Geology and Hydrogeology

The nature of fate and transport of pollutants in subsurface soil is based on surficial geology in the areas north of Eugene and Springfield where the County's UICs are located. The County's UICs are located in a valley between the foothills of the Coast Range to the west and Cascade Range to the east. The foothills are comprised of marine sandstone, siltstone, shale and mudstone, as well as volcanic rocks of dacitic and andesitic composition. The valley is filled with unconsolidated Pleistocene and Holocene alluvial deposits that form the principal aquifer in the area. The alluvium ranges in thickness from a few feet near the valley margins to over 300 feet in the central portion of the valley, and is comprised of coarse volcanic sand and gravel interbedded with fine-grained sand and silt (Frank, 1973).

A surficial geology map of the area was obtained from the Oregon Department of Geology and Mineral Industries (DOGAMI), Oregon Geologic Data Compilation (DOGAMI, 2012), and is provided in Figure 3. As is shown on Figure 3, the County's UICs are located in the braided/delta fan deposits (unit Qfd). Input parameters for the GWPD models are based on soil properties in the Qfd, which is the most permeable of the unconsolidated Pleistocene and Holocene alluvial deposits (i.e., the Qfd is characterized by the most rapid movement of pore water as compared to the Qal) based on specific capacity tests at water wells (see Appendix C) and United States Geological Survey studies (i.e., Frank, 1973). Because the Qfd is the most permeable unit, there is less pollutant attenuation than in other units of alluvial deposits.

Shallow geology and hydrogeology in the unconsolidated Pleistocene and Holocene alluvial deposits were evaluated based on infiltration test studies that were conducted by professional engineers as a part of UIC device design. The following engineering reports were used to support the GWPDs:

- Professional Service Industries, Inc., 1991. *Report of Subsurface Exploration for the Residential Subdivision in Santa Clara*. Prepared for: Coldwell Banker Curtis Irving Realty. February 27.
- GEO Environmental Engineering, 1997. *Evaluation of Soil Permeability, Dahlia Meadows Subdivision, Eugene, Oregon*. Prepared for: Weber Engineering Company. March 11.
- Poage Engineering, undated, *Cherry Tree Estates.*
- Poage Engineering, 1997. *Andersen Meadows First Addition.* July 17.

Shallow soils are comprised primarily of fine grained, low permeability silts and sands, with interbedded "bar run" gravels that are relatively permeable. As documented in Appendix B, vertical hydraulic conductivity of the shallow bar run gravels ranged from 2.0 to 64 feet per day (ft/d), with a median of 8.4 ft/d. Vertical hydraulic conductivity of the shallow silts and sands ranged from 0.003 ft/d to 0.0125 ft/d, with a median of 0.0025 ft/d. As documented in Appendix C, the deeper unconsolidated Pleistocene and Holocene alluvial deposits (where water wells are completed) have a median horizontal hydraulic conductivity of 15 ft/d (Qfd) or 5 ft/d (Qal).

3. UICs Within Default Water Well Setbacks and Permit Requirements

This section presents a screening-level analysis of the number of County UICs that are within the default setbacks to water wells specified within the July 2012 draft UIC permit template. The results of the analysis are used to inform the GWPD modeling approach.

The analysis of UICs within water well setbacks is based on two data sources for water well locations:

- The City of Eugene researched water well locations in the River Road/Santa Clara and Willakenzie areas surrounding City and County maintained UICs, and the County researched and located water wells surrounding County owned UICs in the urban growth boundary of the City of Springfield. Water well logs were downloaded from the Oregon Water Resources Department (OWRD) on-line well log database. The City located 966 water wells accurately to the property boundary (i.e., exact location of the well on the property is uncertain) based on information on the well logs that included tax lots, addresses, and maps. The City estimates that the water wells that were located in the City of Eugene urban growth boundary are accurate to $^+/_-$ 50 feet (personal communication, J. Wilson, 2012).
- The County conducted a similar analysis for the Springfield area based on location information from the OWRD database. The County identified a total of 523 water wells that could be located accurately to a property using information on the well logs that included tax lots, addresses, and maps. Based on the size of the properties, the County estimates that 449 of the wells were located with an accuracy of 50 to 150 feet (accuracy code = 1), 34 of the wells were located with an accuracy of 151 to 250 feet (accuracy code = 2), 29 of the wells were located with an accuracy of 251 to 500 feet (accuracy code = 3), and 11 wells were located with an accuracy of 501 to 930 feet (accuracy code = 4) (personal communication, S. Bajracharya, 2013).

GSI imported the 966 water wells that were located by the City and 512 of the water wells that were located by the County (accuracy codes 1, 2 and 3) into Geographical Information System (GIS) software. Duplicate water wells (i.e., wells with the same OWRD well number) in the City and County databases were removed from the analysis. The distance between each County UIC and the nearest water well was calculated. A histogram showing the frequency distribution of horizontal distance between County UICs and accurately-located water wells is shown in Figure 4. The histogram indicates that the County has approximately 69 UICs within the default horizontal setbacks to water wells.

Under the July 2012 draft UIC WPCF permit template, it is not a permit violation for existing injection systems to be within the default horizontal setbacks from water wells. If protectiveness cannot be demonstrated, then the County must take the following actions as soon as practicable under the 10 year term of the permit (based on the City of Eugene's permit):

- Retrofit or implement a passive, structural, and/or technological control to reduce or eliminate pollutants to the UIC (Condition 7(b)(i) of Schedule A of the City of Eugene's permit).
- Close the UIC (Condition 7(b)(ii) of Schedule A of the City of Eugene's permit).

Because approximately 69 of the County's UICs are located within default horizontal setbacks, the County conducted GWPDs.

4. Groundwater Protectiveness Demonstrations

This section provides an overview of the unsaturated zone (Section 4.1) and saturated zone (Section 4.2) GWPDs. Detailed technical documentation for input parameters, the governing equations, and conservative assumptions for the GWPD are provided in Appendix B (unsaturated zone GWPD) and Appendix C (saturated zone GWPD).

The saturated zone and unsaturated zone GWPDs are significantly different models. However, the models share the following similarities:

- Both models output pollutant concentrations over time and distance based on user-provided input parameters (soil properties, pollutant properties, and organic carbon content of the subsurface).
- 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). Pollutant fate and transport were also simulated for copper because the Action Level for this pollutant in Table 1 of the City of Eugene's permit has not been adjusted upwards based on other jurisdiction's GWPDs. Action Levels for other Table 1 pollutants in the City of Eugene's permit, including lead, benzo(a)pyrene, zinc, and PCP, have already have been adjusted upward based on other municipalities' unsaturated zone GWPDs. The County does not plan to request an Alternate Action Level for copper at this time, but would like the flexibility to do so in the future.

Pollutant attenuation in subsurface soils depends on the following variables: (1) soil properties, (2) organic carbon content of the subsurface, and (3) pollutant properties. These variables are input parameters for the GWPD models, and are based on local geologic conditions and stormwater chemistry in the County.

4.1 Unsaturated Zone GWPD

This section summarizes the input parameters for and results of an unsaturated zone GWPD. The conceptual model for the unsaturated zone GWPD is shown in Figure 2, and consists of a UIC constructed in unsaturated zone soils. The unsaturated zone GWPD model simulates pollutant fate and transport in soils below the bottom of the UIC and above the seasonal high groundwater table. The unsaturated zone GWPD model is based on a conservative analytical pollutant fate and transport equation that simulates one-dimensional pollutant attenuation by dispersion, degradation, and retardation. The objectives of the unsaturated zone GWPD are to calculate a minimum vertical separation distance that is protective of groundwater and develop Alternate Action Levels for the permit:

- **Protective Vertical Separation Distance.** The protective vertical separation distance is calculated by determining the distance beneath the UIC that pollutant concentrations are attenuated to zero as represented by the MRL (synthetic organic compounds) or background levels (metals) before reaching the water table.

- **Alternate Action Level for Copper.** The July 2012 draft UIC WPCF permit template establishes Action Levels for pollutants in stormwater. Exceedance of an Action Level is not a permit violation. However, if a pollutant concentration exceeds an Action Level, then additional action is required in accordance with Conditions 3, 4 and 5 of Schedule A of the permit. The Action Levels in the draft permit may be replaced with Alternate Action Levels based on an unsaturated zone GWPD model (Condition 2, Schedule A of the City of Eugene's UIC WPCF permit). The County will determine whether to request Alternate Action Levels based on stormwater sampling that is required by the permit.

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 or expected mean value of the input parameter, and (2) the reasonable maximum scenario, which is an upper bound on what could occur but is considered unlikely to occur due to compounding conservatism.

The following sections provide an overview of unsaturated zone GWPD model input parameters (Section 4.1.1) and results (Section 4.1.2).

4.1.1 Input Parameters

The following sections summarize the input parameters used in the unsaturated zone GWPD model for the average and reasonable maximum scenarios.

Soil Properties

Soil properties used for the average and reasonable maximum scenarios of the unsaturated zone GWPD model are summarized in Table 2. Total porosity, effective porosity, bulk density, and the dispersivity were taken from literature references based on the properties of the Qfd geologic unit. Average linear pore water velocity was estimated from 17 infiltration tests conducted by professional engineers as a part of UIC design (including test pit tests and laboratory tests). Technical documentation for using infiltration tests to calculate average linear pore water velocity is provided in Appendix B.

Organic Carbon Content of the Subsurface

The organic carbon content of the subsurface that is input into the unsaturated zone GWPD model (i.e., f_{oc}, a dimensionless measure of organic carbon content in a soil [grams of carbon per grams of soil]) is based on carbon loading of soil during stormwater infiltration. Technical documentation for calculating f_{oc} based on carbon loading is provided in Section 2.2 of Appendix B. The TOC concentration in stormwater was calculated from 5 stormwater samples collected from public ROWs by the City of Eugene. For the average scenario, the unsaturated zone GWPD model uses an f_{oc} of 0.0210 g_{carbon}/g_{soil} (vertical UICs) and 0.0025 g_{carbon}/g_{soil} (horizontal UICs) based on average TOC concentration in stormwater. For the reasonable maximum scenario, the unsaturated zone GWPD uses an f_{oc} of 0.0152 g_{carbon}/g_{soil} (vertical UICs) and 0.0018 g_{carbon}/g_{soil} (horizontal UICs) based on minimum TOC concentrations observed in stormwater. These calculated f_{oc}s at horizontal UICs are in the range of measured f_{oc} in backfill and native soil at the Shirley Street horizontal UIC (see Table 1).

Pollutant Properties

Pollutant property values and data sources used for the average and reasonable maximum scenarios of the unsaturated zone GWPD model are summarized in Table 3. Note that half-lives (i.e., the time required for the pollutant concentration to decline to half of the initial concentration) were not assigned to metals because they do not degrade in the subsurface. Technical documentation for the pollutant properties is presented in Appendix B.

4.1.2 Model Results

This section presents the results of the unsaturated zone GWPD model, including the protective vertical separation distance and Alternate Action Level for copper.

Protective Vertical Separation Distance

Table 4 presents the minimum protective vertical separation distances under the average and reasonable maximum scenarios of the unsaturated zone GWPD model. The model calculations for these scenarios are presented in Appendix B.

The average scenario represents most reasonably likely conditions, and is used for regulatory compliance. Protective separation distances are based on PCP, which migrates further than the other pollutants that were modeled. Under the average scenario, the minimum protective vertical separation distances are 0.39 feet for vertical UICs and 2.95 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 1.85 feet to the model-calculated vertical separation distances. The 1.85 feet accounts for uncertainties in the seasonal high groundwater elevation contour map (0.25 feet)[3] and natural variation of seasonal groundwater high elevations over time (1.6 feet)[4]. Therefore, we recommend using

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[3] The seasonal high groundwater elevation contour map was developed using depth to groundwater measurements from water well logs located with an accuracy of +/- 50 feet. Assuming a horizontal hydraulic gradient of 0.005 feet/feet (see Table C-2), the depth to water could be off by 0.25 feet because of the uncertainty in water well location (0.005 * 50 feet = 0.25 feet).

[4] The protective vertical separation distance is a separation from the seasonal high groundwater elevation. However, the seasonal high groundwater elevation fluctuates annually. The factor 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 wells LANE 51613 (located in T17S R2W Section 32BCC) and LANE 8029 (located in T16S R4W Section 16CAC) were downloaded from the OWRD on-line groundwater elevation database. The period of record for LANE 51613 is 1994 to 2012, and the period of record for LANE 8029 is 1967 to 2012. Both wells are 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 the months of April or May were included, which is when the seasonal groundwater high typically occurs. The prediction intervals for LANE 51613 and LANE 8029 were 1.4 feet and 1.6 feet greater than their median seasonal high groundwater elevations, respectively. Therefore, annual variation in seasonal high groundwater elevations is expected to be within 1.4 feet (LANE 51613) to 1.6 feet (LANE 8029) of the median seasonal high groundwater elevation 90% of the time. The factor of safety was conservatively chosen to be 1.6 feet.

a protective separation distance of 2.3 feet for the minimum separation distance at vertical UICs (instead of the exact value of 0.39 feet) and 4.8 feet for the minimum separation distance at horizontal UICs (instead of the exact value of 2.95 feet).

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 4, the protective separation distances under the worst-case "reasonable maximum scenario" are an order of magnitude greater than the protective separation distances under the most likely "average scenario."

Alternate Action Level for Copper

An Alternate Action Level for copper is shown in Table 5, and a calculation for the Alternate Action Level is provided in Appendix B. Under the average and reasonable maximum scenarios copper attenuates to below the MRL before reaching the water table when initial concentrations in influent stormwater are equal to the Alternate Action Level. The Alternate Action Level was developed using the following assumptions:

- The Alternate Action Level applies to horizontal and vertical UICs.
- Alternate Action Level is limited to maximum concentrations of 10 times the existing Action Level.

4.2 Saturated Zone GWPD

This section summarizes the results of a saturated zone GWPD. The conceptual model for the saturated zone GWPD assumes that the UIC intersects the seasonal high groundwater table such that the UIC extends five feet below the water table. The saturated zone GWPD model is based on a conservative, numerical groundwater model (MODFLOW) that is coupled with a pollutant fate and transport model (MT3D) to simulate three-dimensional pollutant attenuation by dilution, dispersion, biodegradation, and retardation. MODFLOW and MT3D are numerical models that simulate groundwater flow and pollutant fate and transport by subdividing the aquifer into discrete cubes known as cells, and minimizing mass balance errors between cells. The objective of the saturated zone GWPD is to delineate a WMA by calculating the horizontal distance required for pollutant concentrations to decline to zero as represented by the MRL (synthetic organic compounds) or background levels (metals). The horizontal distance is defined as the distance directly downgradient from the UIC. 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 objective of the base model run was to determine the drivers for the calculated horizontal separation distance, specifically—pollutants (i.e., PCP, DEHP, lead, or benzo(a)pyrene) and UIC configurations (horizontal or vertical).

- **UIC Drainage Basin Sensitivity Runs ("DB Sensitivity Runs").** Variability exists in the amount of impervious area within each of the County's UIC drainage basins. Because the horizontal separation distance is sensitive to the impervious area within the UIC drainage basin, additional model runs were conducted to calculate protective horizontal separation distances based on a range of impervious areas within UIC drainage basins.

The following section provides an overview of unsaturated zone GWPD model input parameters (Section 4.2.1) and results (Section 4.2.2).

4.2.1 Input Parameters

The following sections summarize the input parameters used in the base model and DB sensitivity runs.

Soil Properties

Soil properties used for the base model and DB sensitivity runs are summarized in Table 6. Total porosity, effective porosity, bulk density, and the dispersivity were taken from literature references based on the properties of the Qfd geologic unit. Hydraulic conductivity was estimated from 26 specific capacity tests in the Qfd conducted by drillers as a part of water well installation. Data from the specific capacity tests were obtained from well logs from the OWRD on-line well log database. Technical documentation for using specific capacity tests to calculate average linear pore water velocity is provided in Appendix C.

Organic Carbon Content of the Subsurface

The organic carbon content of the subsurface that is input into the unsaturated zone GWPD model is based on carbon loading of soil during stormwater infiltration and organic carbon in native soils. Particulate organic carbon in stormwater is filtered out of solution by the aquifer matrix and accumulates within several feet of the UIC. Beyond these several feet, the organic carbon content of the subsurface is related to organic material that is incorporated in soil at the time of deposition. Therefore, near the UIC, the organic carbon content of the subsurface is based on carbon loading by stormwater, and distal from the UIC, organic carbon content is based on soil samples collected from gravel soils in the Willamette Valley (specifically, from the catastrophic Missoula flood deposits in Gresham, Oregon, as documented in GSI [2013]).

Technical documentation for calculating f_{oc} based on carbon loading is provided in Section 2.4.1 of Appendix C. For the base model, the GWPD model uses an f_{oc} of 0.02781 g_{carbon}/g_{soil} (vertical UICs) and 0.00285 g_{carbon}/g_{soil} (horizontal UICs) based on average TOC concentration in stormwater. The f_{oc} used in the DB Sensitivity models varies based on drainage basin size, and is summarized in Table C-5.

Pollutant Properties

Pollutant property values and data sources for the saturated zone GWPD are provided in Appendix C. Table 7 presents a subset of pollutant property values and data sources used in the base model. Note that half-lives (i.e., the time required for the pollutant concentration to decline to half of the initial concentration because of degradation) were not assigned to metals because they do not degrade in the subsurface. Technical documentation for the pollutant properties is presented in Appendix C.

4.2.2 Model Results

This section presents the results of the saturated zone GWPD model, including the base model and DB sensitivity models. The saturated zone GWPD does not include a safety factor because the horizontal separation distances simulated by the model are an order of magnitude higher than the sources of error. For example, the horizontal separation distances simulated by the model are several hundred feet, and the uncertainty in water well location is +/- 50 feet.

Base Model

Minimum protective horizontal separation distances for the base model are presented in Table 8. Protective horizontal separation distances are slightly larger for vertical UIC configuration as compared to horizontal UIC configuration. In addition, protective horizontal separation distances are significantly larger for PCP, which is more mobile and persistent than the other common stormwater pollutants that were modeled (DEHP, benzo(a)pyrene, and lead). These results establish that the most conservative (i.e., largest) horizontal separation distance occurs at vertical UICs for PCP. Therefore, the DB sensitivity analyses were based on the worst-case conditions of PCP transport from vertical UICs.

Drainage Basin Sensitivity Analyses

Minimum protective horizontal separation distances based on the impervious area within a UIC drainage basin are presented in Table 9. Protective horizontal separation distance is positively correlated with impervious area within a UIC drainage basin. Note that the simulations are conservatively based on fate and transport of PCP from vertical UICs.

5. Conclusions and Recommendations

The GWPDs in this technical memorandum will fulfill permit conditions that require the permittee to conduct a GWPD within one year of discovering a UIC within a default setback of water wells (assuming the County's permit contains the same requirements as the City of Eugene's permit). According to these model-based GWPDs, the County's UICs are protective if any one of the following are true:

- The UIC is located outside a default water well setback,
- The vertical separation distance to seasonal high groundwater is more than 2.3 feet (vertical UIC) or 4.8 feet (horizontal UIC),
- The horizontal separation distance between a UIC and water well is more than the distances in Table 9. Note that the distances in Table 9 are based on the impervious area within the UIC drainage basin.

UICs that are not protective according to the model-based GWPDs need to be retrofit or decommissioned, or groundwater protectiveness can be documented using another method. As was discussed with DEQ during a meeting on February 12, 2013, 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 EWEB service), evaluation of whether PCP is likely present within a UIC's drainage basin (i.e., whether utility poles—the source of PCP—are present), or documentation that a water well is located upgradient and outside of the capture zone of a UIC.

The GWPDs were developed under conservative assumptions that are summarized in Appendix D. The process for applying the results of the unsaturated zone and saturated zone GWPDs involves the following steps:

1. Determine whether the UIC is within the default setback to a water well, as specified in the July 2012 draft UIC WPCF permit (500 feet from a water well or the two year time of travel of a municipal 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 4.8 feet (horizontal UICs) or 2.3 feet (vertical UICs). <u>The UIC is protective of groundwater if the vertical separation distance at the UIC is greater than this protective separation distance.</u>
3. If the vertical separation distance at the UIC is less than the protective separation distance of 4.8 feet (horizontal UICs) or 2.3 feet (vertical UICs), compare the horizontal separation distance between the UIC and nearest water well to the protective horizontal separation distances in Table 9, which are based on the impervious area within the UIC drainage basin. <u>The UIC is protective of</u>

groundwater is the horizontal separation distance between the UIC and water well is greater than the separation distances in Table 9.

4. 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.

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Tables

Table 1

TOC and F_{oc} at the Shirley Street Horizontal UIC

Lane County

Site	Material Type	Sample ID	Sample Location	TOC (mg/kg)	f_{oc} (dimensionless)
Shirley Street Horizontal UIC	Backfill	124481-1	Trench Midpoint	2,330	0.0023
	Backfill	124487-1	South End of Trench	1,220	0.0012
	Native Soil	124481-2	Trench Midpoint	1,590	0.0016
	Native Soil	124487-2	South End of Trench	3,520	0.0035

Notes

TOC = total organic carbon

mg/kg = milligrams per kilogram

f_{oc} = fraction organic carbon (gram of carbon per gram of soil)

<u>Sample Collection Information:</u>

Samples were collected at the UIC system located on Shirley Street at the intersection of Shirley Street and Brett Loop. The UIC system is comprised of two vertical UICs that overflow into an approximately 270 foot long horizontal UIC. Samples of gravel backfill and native soils were collected by compositing two discrete soil grab samples from immediately beneath the perforated pipe. Twigs and other organic debris were removed from the sample prior to submitting the sample to the laboratory. Samples were analyzed at Specialty Analytical (Clackamas, Oregon) for total organic carbon by method SW-9060.

Table 2

Unsaturated Zone GWPD Model Input Parameters – Soil Properties

Lane County

Input Parameter	Units	Average Scenario	Reasonable Maximum Scenario	Data Source and Location of Technical Documentation
Total Porosity (η)	-	0.325	0.325	Midrange porosity for a gravel, Freeze and Cherry (1979) Table 2.4. Appendix B, Section 2.1.1.
Effective Porosity (η_e)	-	0.30	0.30	Effective porosity of the Upper Sedimentary Hydrogeologic Unit (Craner, pg. 133, 2006). Appendix B, Sections 2.1.1.
Bulk Density (ρ_b)	g/cm^3	1.79	1.79	Calculated by equation 8.26 in Freeze and Cherry (1979). Appendix B, Section 2.1.2.
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	0.25	1.25	Based on 17 permeability measurements collected as a part of UIC design studies. Average scenario uses the median of permeability measurements, reasonable maximum scenario uses the 95% UCL on the mean of permeability measurements. Appendix B, Section 2.1.4 and Section 4.0.

Notes

g/cm^3 = grams per cubic centimeter

m/d = meters per day

95% UCL = 95% Upper Confidence Limit on the mean

(-) = input parameter units are dimensionless

Table 3

Unsaturated Zone GWPD Model Input Parameters – Pollutant Properties

Lane County

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 Eugene UIC WPCF Permit
		DEHP	60	60	Action Level in City of Gresham UIC WPCF Permit
		B(a)P	2	2	Action Level in City of Eugene UIC WPCF Permit
		Lead	500	500	Action Level in City of Eugene UIC WPCF Permit
Organic Carbon Partitioning Coefficient (K_{oc})	L/Kg	PCP	592	592	EPA (1996), assuming a pH of 6.8 from Table 9 of on page 82 of Craner (2006). 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	12.4 (V), 1.5 (H)	9.0 (V), 1.1 (H)	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		DEHP	256 (V), 30.3 (H)	185 (V), 21.7 (H)	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		B(a)P	5,915 (V), 700 (H)	4,281 (V), 502 (H)	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		Copper	159,000	25,000	Calculated from City of Milwaukie stormwater discharge monitoring data. Appendix B, Section 2.3.2.
		Lead	1,200,000	535,000	
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	69.3 (V), 9.1 (H)	50.4 (V), 6.8 (H)	Calculated based on Equation (9.14) in Freeze and Cherry (1979). Appendix B, Section 2.3.4.
		DEHP	1,408 (V), 168 (H)	1,020 (V), 121 (H)	
		B(a)P	32,554 (V), 3,853 (H)	23,562 (V), 2,766 (H)	
		Copper	877,000	137,000	
		Lead	6,600,000	2,900,000	

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

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Table 4

Unsaturated Zone GWPD - Protective Vertical Separation Distances

Lane County

Pollutant	MRL (µg/L)	Minimum Protective Vertical Separation Distance (feet)		
		Average Scenario	Reasonable Maximum Scenario	Recommended Value [3]
Vertical UICs				
Lead [1]	0.1	0.0052	0.059	2.3
Benzo(a)pyrene	0.01	0.00081	0.00563	
PCP	0.04	0.39	2.69	
DEHP	1	0.016	0.11	
Horizontal UICs				
Lead [1]	0.1	0.0052	0.059	4.8
Benzo(a)pyrene	0.01	0.00683	0.048	
PCP	0.04	2.95	19.9	
DEHP	1	0.138	0.97	

Notes:

MRL = method reporting limit

µg/L = micrograms per liter

PCP = pentachlorophenol

DEHP = di(2-ethylhexyl)phthalate

[1] Metals transport simulations are longer than 13.93 days because metals do not biodegrade over time. Metals transport simulations assume 1000 years of transport at 13.93 days per year = 13,930 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 (0.39 for vertical UICs and 2.95 feet for horizontal UICs) to a safety measure of 1.85 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, as discussed on Page 4-3 of the document text.

Table 5

Unsaturated Zone GWPD - Alternate Action Levels (UICs $\geq$ 3 Feet Vertical Separation Distance)

Lane County

Pollutant	MRL (μg/L) [1]	Existing Action Level (μg/L) [2]	Alternate Action Level (μg/L) [3]	Output Concentration (μg/L) [4]	
				Average Scenario	Reasonable Maximum Scenario
Copper	0.1	1,300	13,000	0	0

Notes:

μg/L = micrograms per liter

MRL = method reporting limit

[1] Method Reporting Limit (MRL) based on typically achievable MRLs during the Gresham winter 2009 - 2010 stormwater monitoring event.

[2] Existing Action Levels from Table 1 of the City of Eugene's UIC WPCF permit

[3] Alternate Action Levels are based on the "average transport scenario" of the GWPD model and the assumption that groundwater is protected when pollutant concentrations just above the water table are below the MRL. The Alternate Action Level is the input concentration of the pollutant entering the UIC in the unsaturated zone GWPD model.

[4] Output concentration is the concentration below the UIC after 3 feet of transport.

Table 6

Saturated Zone GWPD Model Input Parameters – Soil Properties

Lane County

Input Parameter	Units	Base Model and DB Sensitivity Runs	Data Source and Location of Technical Documentation
Total Porosity (η)	-	0.325	Midrange porosity for a gravel, Freeze and Cherry (1979) Table 2.4. Appendix C, Section 2.4.1.
Effective Porosity (η_e)	-	0.30	Effective porosity of the Upper Sedimentary Hydrogeologic Unit (Craner, pg. 133, 2006). Appendix C, Sections 2.4.1.
Hydraulic Conductivity (K)	ft/d	15	Median hydraulic conductivity calculated from well tests available on OWRD well logs in the Braided/Delta Fan Deposits (Qfd). Appendix C, Section 2.4.1.
Hydraulic Gradient (h)	ft/ft	0.005	Based on Willakenzie Area Seasonal High Groundwater Estimates Map produced by Eugene PWE GIS Info Team, July 2012. Appendix C, Section 2.4.1.
Bulk Density (ρ_b)	g/cm^3	1.79	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 7

Saturated Zone GWPD Model Input Parameters – Pollutant Properties

Lane County

Input Parameter	Units	Pollutant	Base Model - Near Vertical UIC	Base Model - Distal From Vertical UIC	Data Source and Location of Technical Documentation
Initial Concentration	µg/L	PCP	10	10	Action Level in City of Eugene UIC WPCF Permit
		DEHP	60	60	Action Level in City of Gresham UIC WPCF Permit
		B(a)P	2	2	Action Level in City of Eugene UIC WPCF Permit
		Lead	500	500	Action Level in City of Eugene UIC WPCF Permit
Organic Carbon Partitioning Coefficient (K_{oc})	L/Kg	PCP	592	592	EPA (1996), assuming a pH of 6.8 from Table 9 of on page 82 of Craner (2006). 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	16.5	1.08	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		DEHP	339	22.3	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		B(a)P	7,850	515	Calculated based on Equation 5.12 in Watts (1998). Appendix B, Section 2.3.2.
		Lead	1,000,000	1,000,000	
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	91.7	6.95	Calculated based on Equation (9.14) in Freeze and Cherry (1979). Appendix B, Section 2.3.4.
		DEHP	1,870	124	
		B(a)P	43,200	2,800	
		Lead	5,500,000	5,500,000	

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

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Table 8

Saturated Zone GWPD - Base Model Results

Lane County

Pollutant	Minimum Protective Horizontal Separation Distance (feet) Impervious Area = 60,000 ft^2
Vertical UICs	
Lead	10
Benzo(a)pyrene	43
PCP	187
DEHP	70
Horizontal UICs	
Lead	7
Benzo(a)pyrene	28
PCP	177
DEHP	60

Notes:

DEHP = di(2-ethylhexyl)phthalate

PCP = pentachlorophenol

ft^2 = square feet

Table 9

Saturated Zone GWPD - Protective Horizontal Separation Distances

Lane County

Impervious Area in UIC Drainage Basin [1] (square feet)	**Minimum Protective Horizontal Separation Distance** [2] (feet)
0 - 20,000	142
20,000 - 40,000	167
40,000 - 60,000	187
60,000 - 80,000	201
80,000 - 100,000	211
100,000 - 120,000	225
120,000 - 140,000	235
140,000 - 160,000	245
160,000 - 180,000	252
180,000 - 200,000	262

Notes:

[1] Simulations are conservatively based on the largest impervious area within the range class. For example, the protective horizontal separation distance in the 20,000 to 40,000 ft^2 range is based on a model run with a 40,000 ft^2 impervious area drainage basin.

[2] Conservatively based on fate and transport of PCP from a vertical UIC

Figures

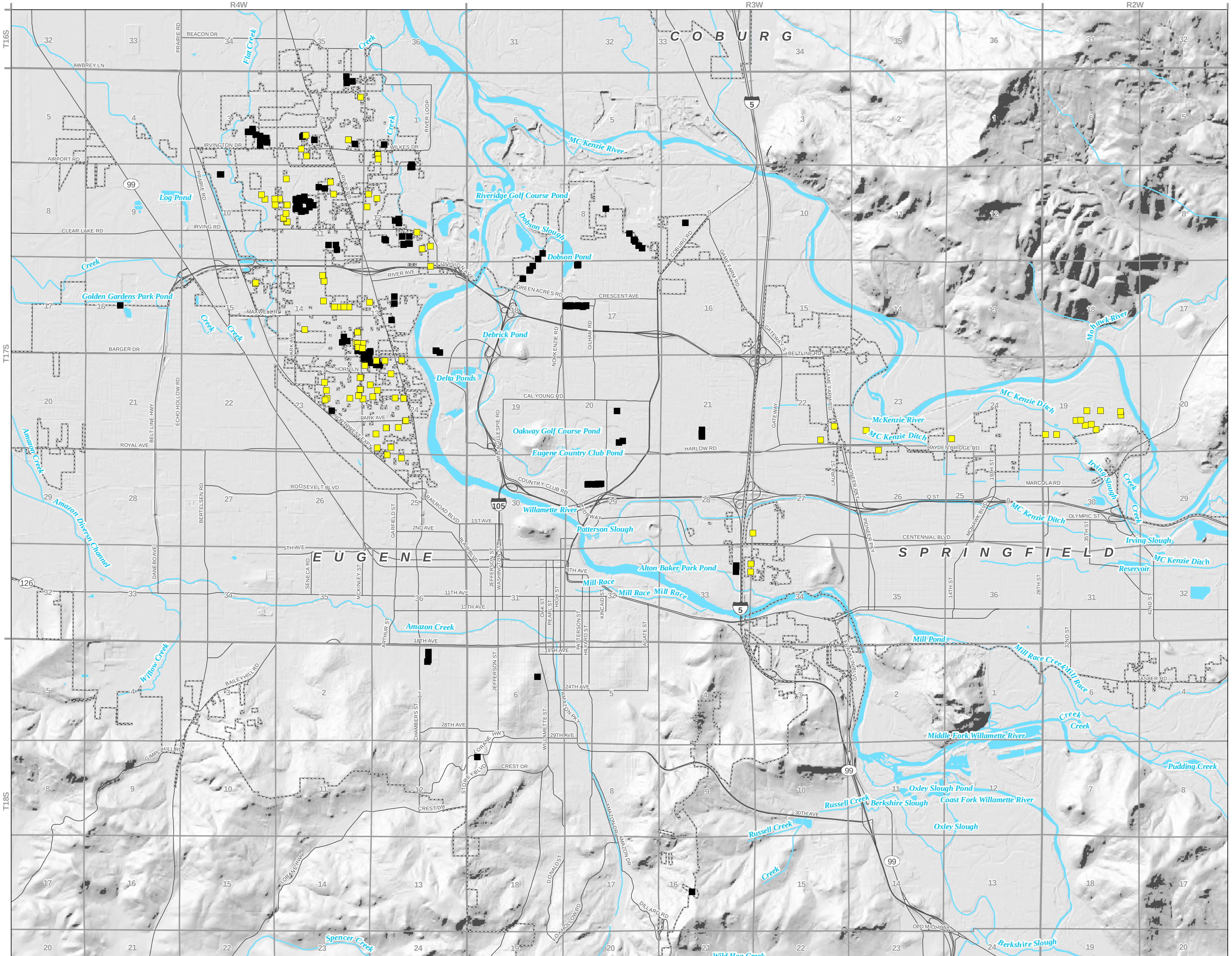

FIGURE 1

Lane County UIC Locations

Groundwater Protectiveness Demonstration

LEGEND

- Lane County UICs (99 Total)
- City of Eugene UICs (163 Total)

All Other Features

- Cities
- Major Roads
- Watercourses
- Waterbodies

NOTES:

1) Three City of Eugene UICs are not shown.
2) Five of the Lane County UICs that are shown have been decommissioned.

N

0 0.5 1 1.5

Miles

MAP NOTES:

Date: March 18, 2013

Data Sources: Lane County, USGS, ESRI

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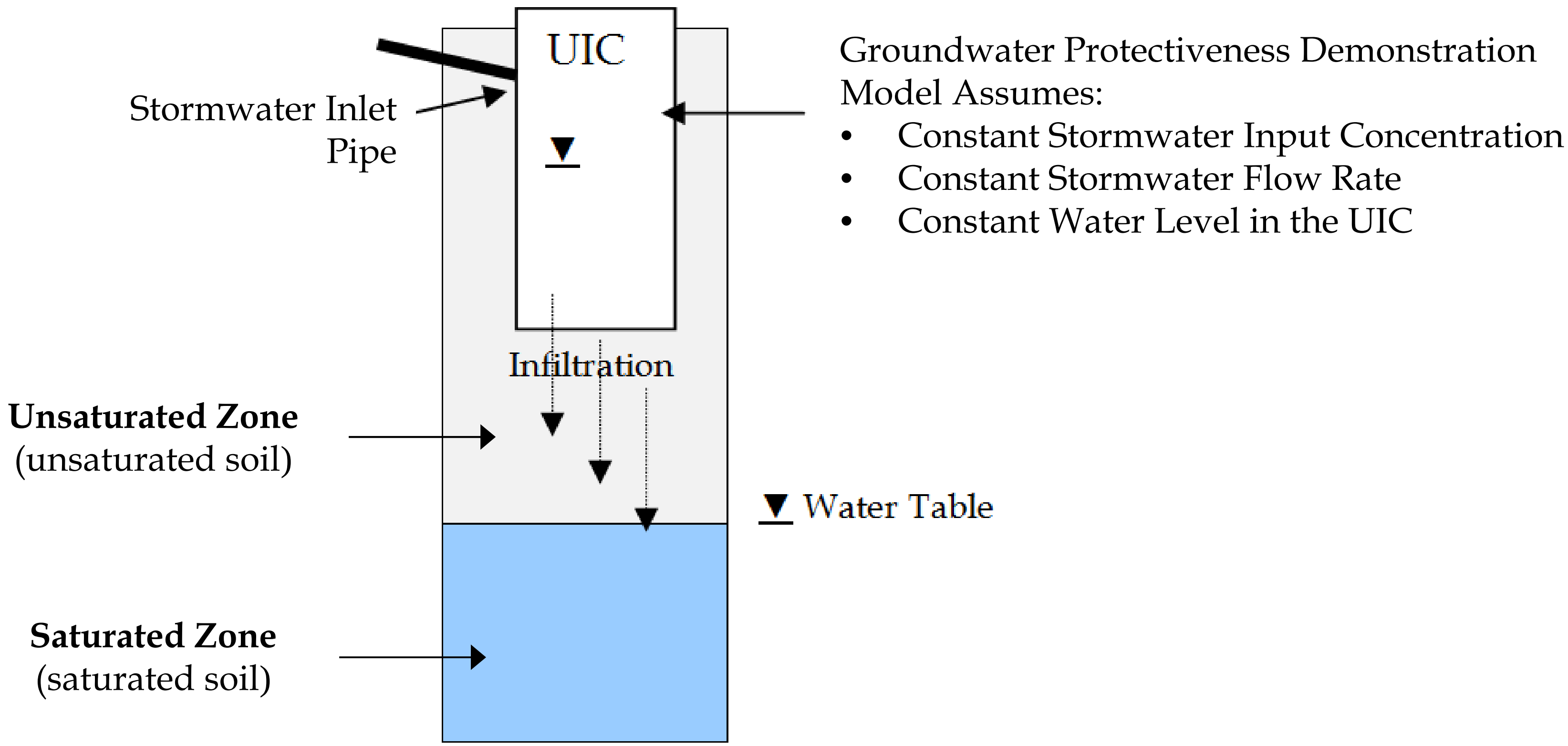

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FIGURE 2
UIC Conceptual Model
Lane County

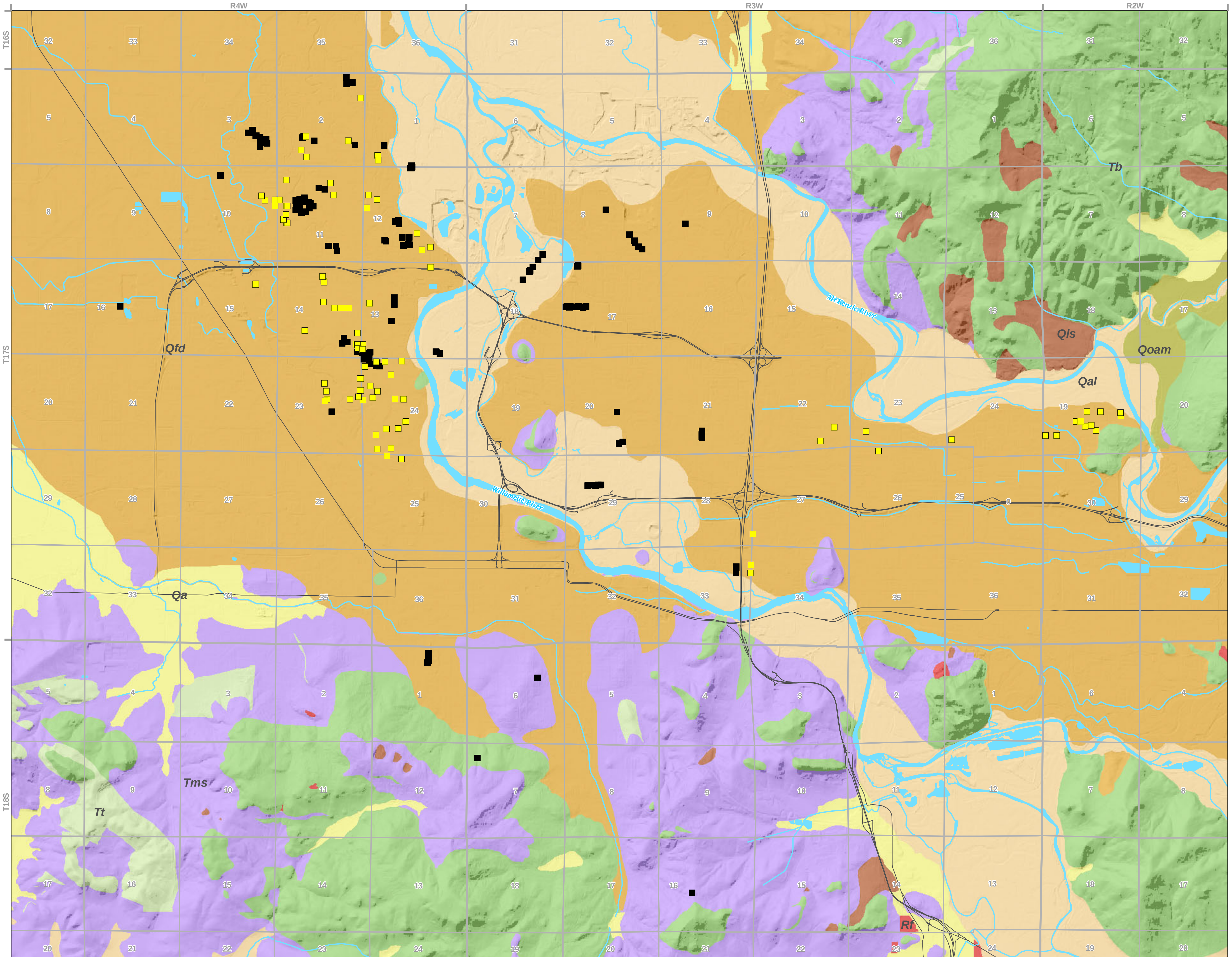

FIGURE 3

Lane County UIC Locations and Surficial Geology

Groundwater Protectiveness Demonstration

LEGEND

- Lane County UICs (99 Total)
- City of Eugene UICs (163 Total)

Surficial Geology

Quaternary Unconsolidated Sedimentary Units

- Qa - Recent Alluvial Deposits
- Qal - Meander/Floodplain Deposits
- Qfd - Braided/Delta Fan Deposits, Fine Grained Alluvium and Post Missoula Flood Sands & Gravel
- Qls - Landslide Deposits
- Qoam - Older Alluvium
- Rf - Artificial Fill

Quaternary Volcanic Units

- Tb - Basalt & Other Volcaniclastic Rocks
- Tt - Tuff

Quaternary Sedimentary Rock Units

- Tms - Marine Sedimentary Rock Units

All Other Features

- Major Roads
- Watercourses
- Waterbodies

NOTES:

1) Three City of Eugene UICs are not shown.
2) Five of the Lane County UICs that are shown have been decommissioned.

N

0 0.5 1 1.5

Miles

MAP NOTES:

Date: March 18, 2013

Data Sources: DOGAMI, City of Eugene, Lane County, USGS, ESRI

GSI Water Solutions, Inc.

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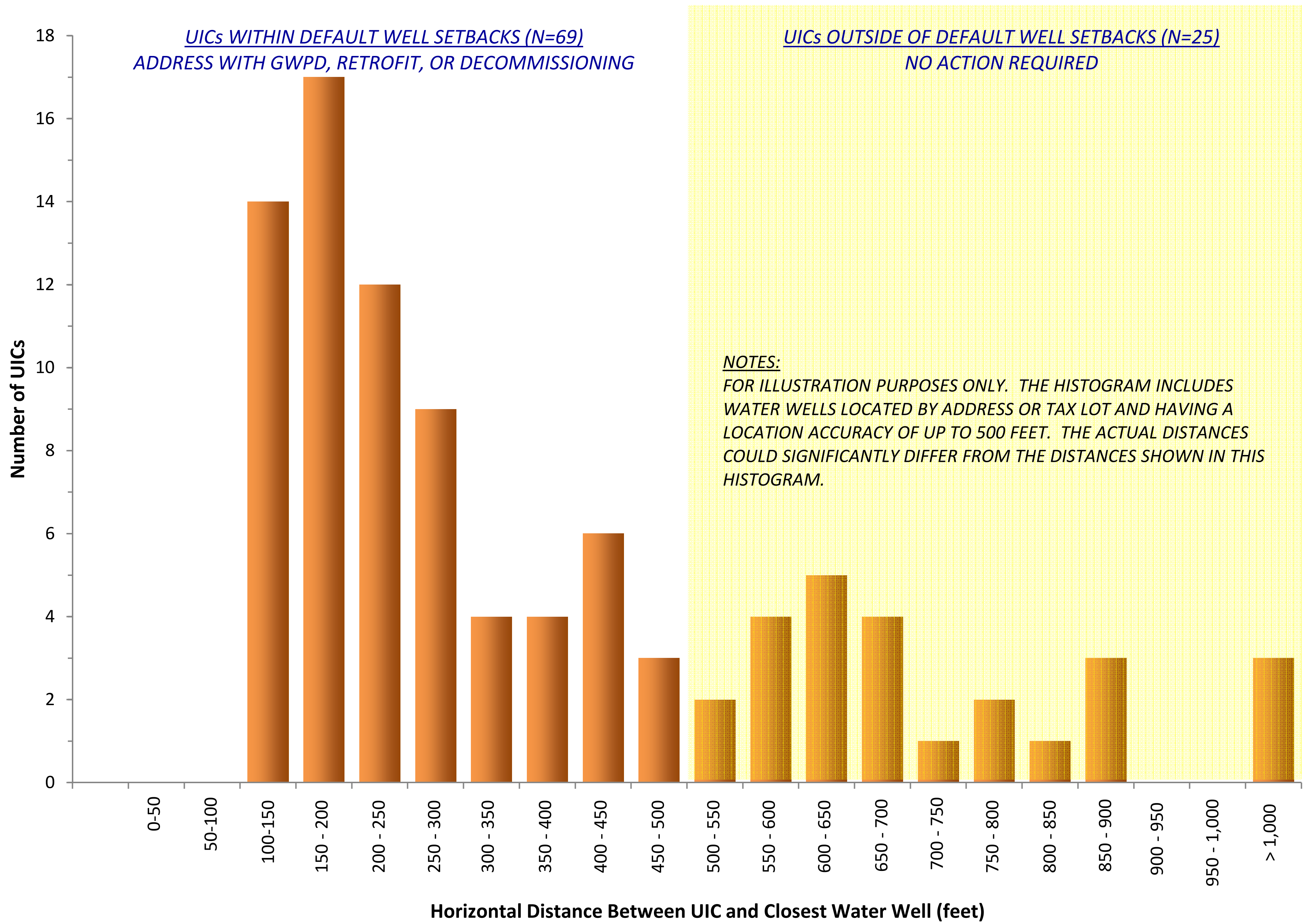

FIGURE 4

Histogram of Horizontal Separation Between UICs and Water Wells

Groundwater Protectiveness Demonstration

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APPENDIX A
UIC Database

APPENDIX A

Lane County UIC Database

Lane County, Oregon

Lane County UIC #	Date Inputed	Facilitly Name (DEQ Facility # 11037)	Address	Along Local Access Road	Land Use	Northing	Easting	Operation Status	EPA Type Code	Waste Type	Design Type	Well Depth and Diameter	Plug - Yes or No	ADT	Contributing Area
1	6/21/2001	Lane County Public Works	126 Greenleaf Ave	No	RA	891656.456	4232451.39	Active	5D2	Stormwater	Vertical	6.33'/3.0'	No	140	66677.00
2	6/21/2001	Lane County Public Works	128 Hansen Lane	No	RA	886235.299	4232272.82	Active	5D2	Stormwater	Vertical	3.0'/3.0'	No	950	321455.00
3	6/21/2001	Lane County Public Works	537 Hansen Lane	No	RA	886852.015	4230947.38	Active	5D2	Stormwater	Vertical	3.0'/3.0'	No	850	44621.00
4	6/21/2001	Lane County Public Works	107 Mayfair Lane	No	RA	886447.823	4231481.83	Active	5D2	Stormwater	Vertical	5.33'/3.0'	No	330	85167.00
5	6/21/2001	Lane County Public Works	265 Bauer Court	No	RA	886853.385	4231704.76	Active	5D2	Stormwater	Horizontal	3.0'/3.0'	No	80	102934.00
6	6/21/2001	Lane County Public Works	398 Meriau Lane	No	RA	887626.565	4230908.09	Active	5D2	Stormwater	Vertical	6.17'/3.0'	No	140	186756.00
7	6/21/2001	Lane County Public Works	310 Hardy Ave	No	RA	887930.667	4231489.14	Active	5D2	Stormwater	Vertical	6.67'/3.0'	No	190	628512.00
8	6/21/2001	Lane County Public Works	310 Hardy Ave	No	RA	887936.354	4231483.61	Active	5D2	Stormwater	Vertical	6.67'/3.0'	No	190	628512.00
9	6/21/2001	Lane County Public Works	175 Hardy Ave	No	RA	887936.492	4232140.83	Active	5D2	Stormwater	Vertical	4.0'/3.0'	No	190	217287.00
~~10~~	6/21/2001	Lane County Public Works	Intersection Park & Dorris	Yes	RA	888301.981	4232536.6	Decommissioned in 2010	5D2	Stormwater		6.33'/3.0'			
~~11~~	6/21/2001	Lane County Public Works	Intersection Park & Dorris	Yes	RA	888303.842	4232583.01	Decommissioned in 2010	5D2	Stormwater		4.42'/3.0'			
12	6/21/2001	Lane County Public Works	32 Marion Lane	No	C1	889540.905	4232485.74	Active	5D2	Stormwater	Unknown	3.0'/3.0'		420	30065.00
13	6/21/2001	Lane County Public Works	76 Marion Lane	No	RA	889577.145	4232014.05	Active	5D2	Stormwater	Vertical	4.0'/3.0'	No	420	67249.00
14	6/21/2001	Lane County Public Works	381 Marion Lane	No	RA	889577.795	4230231.86	Active	5D2	Stormwater	Vertical	6.67'/3.0'	No	420	269106.00
15	6/21/2001	Lane County Public Works	1026 Custer Court	No	RA	889685.316	4230790.33	Active	5D2	Stormwater	Vertical	6.83'/3.0'	No	90	356074.00
16	6/21/2001	Lane County Public Works	955 Fairway Drive	No	RA	889764.882	4229994.63	Active	5D2	Stormwater	Vertical	6.33'/3.0'	No	250	116832.00
17	6/21/2001	Lane County Public Works	1260 Beebe Lane	No	RA	889625.769	4229525.2	Active	5D2	Stormwater	Unknown	3.0'/3.0'		170	84558.00
18	6/21/2001	Lane County Public Works	1592 Beebe Lane	No	C1	889671.739	4228258.11	Active	5D2	Stormwater	Vertical	5.83'/3.0'	No	190	301856.00
19	6/21/2001	Lane County Public Works	925 Park Ave	No	C1	889595.029	4228140.42	Active	5D2	Stormwater	Vertical	3.0'/3.0'	No	750	249622.00
20	6/21/2001	Lane County Public Works	158 W. Hilliard Lane	No	RA	890031.11	4231068.68	Active	5D2	Stormwater	Vertical	4.50'/3.0'	No	1300	366114.00

21	6/21/2001	Lane County Public Works	1025 W. Hilliard Lane	No	RA	890120.906	4228229.37	Active	5D2	Stormwater	Vertical	5.92'/3.0'	No	800	164371.00
22	6/21/2001	Lane County Public Works	Apple Drive @ end of street	No	RA	890341.328	4230675.22	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	40	180653.00
23	6/21/2001	Lane County Public Works	1160 Maple Drive	No	RA	890757.967	4230151.85	Active	5D2	Stormwater	Vertical	3.0'/3.0'	No	240	210667.00
24	6/21/2001	Lane County Public Works	1160 Maple Drive	No	RA	890758.128	4230121.62	Active	5D2	Stormwater		3.0'/3.0'		240	50603.00
25	6/21/2001	Lane County Public Works	Intersection Maple Dr & Hilliard Lane	No	RA	890114.855	4230131.25	Active	5D2	Stormwater	Vertical	3.0'3.0'	No	850	171951.00
26	6/21/2001	Lane County Public Works	Intersection Maple Dr & Hilliard Lane	No	RA	890112.359	4230101.4	Active	5D2	Stormwater	Unknown	3.0'/3.0'		850	27398.00
27	6/21/2001	Lane County Public Works	108 Horn Lane	No	RA	890922.415	4231825.94	Active	5D2	Stormwater	Vertical	6.42'3.0'	No	1850	185898.00
28	6/21/2001	Lane County Public Works	1625 Horn Lane	No	RA	890549.03	4228136.39	Active	5D2	Stormwater	Vertical	6.67'/3.0'	No	1150	153882.00
29	6/21/2001	Lane County Public Works	1304 Anderson Lane	Yes	RA	891417.991	4230394.28	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	200	132222.00
30	6/21/2001	Lane County Public Works	197 Rosetta Street	No	RA	891660.012	4231047.29	Active	5D2	Stormwater	Vertical	5.34'/3.0'	No	340	205484.00
31	6/21/2001	Lane County Public Works	133 Rosetta Street	No	RA	891651.952	4231509.54	Active	5D2	Stormwater	Vertical	6.34'/3.0'	No	340	106887.00
32	6/21/2001	Lane County Public Works	340 Hatton Ave.	No	RA	892639.55	4230328.58	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	140	289465.00
33	6/21/2001	Lane County Public Works	Hatton Ave- West end	No	RA	892683.348	4229942.28	Active	5D2	Stormwater	Vertical	5.58/'3.0'	No	40	60843.00
34	6/21/2001	Lane County Public Works	1410 Parnell Street	No	RA	892648.576	4230022.05	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	800	119666.00
35	6/21/2001	Lane County Public Works	295 Harvey Ave.	No	RA	892437.602	4230066.32	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	150	60639.00
36	6/21/2001	Lane County Public Works	242 Harvey Ave.	No	RA	892374.668	4230309.73	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	150	115980.00
37	6/21/2001	Lane County Public Works	320 Parnell Street	No	RA	893287.253	4230046.73	Active	5D2	Stormwater	Vertical	5.17'/3.0'	No	800	187794.00
38	6/21/2001	Lane County Public Works	1509 Brentwoood Street	No	R1	893517.334	4227136.15	Inactive	5D2	Stormwater	Vertical	3.0'/3.0'	No	190	94208.00
39	6/21/2001	Lane County Public Works	409 Hamilton	No	RA	894685.79	4229618.91	Active	5D2	Stormwater	Vertical	6.0'3.0'	No	80	149717.00
40	6/21/2001	Lane County Public Works	457 Hamilton	No	RA	894696.565	4229325.56	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	80	109911.00
41	6/21/2001	Lane County Public Works	485 Hamilton	No	RA	894708.305	4229004.68	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	80	86201.00
42	6/21/2001	Lane County Public Works	525 Hamilton	Possibly: Need to research road status	RA	894715.691	4228808.48	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	80	113139.00
43	6/21/2001	Lane County Public Works	94 Kourt Drive	No	RA	894919.815	4230766.57	Active	5D2	Stormwater	Unknown	3.0'/3.0'		850	141631.00
44	6/21/2001	Lane County Public Works	1825 Grove	No	RA	895055.156	4228217.07	Active	5D2	Stormwater	Horizontal	3.0'/3.0'		2500	227710.00

~~45~~	6/21/2001	Lane County Public Works	Intersection Grove & Silver Lea	No	R1	896201.31	4228264.83	Decommissioned in 2008	5D2	Stormwater		4.34'/3.0'			83818.00
~~46~~	6/21/2001	Lane County Public Works	Intersection Grove & Silver Lea	No	R1	896161.124	4228283.14	Decommissioned in 2008	5D2	Stormwater		4.5'/3.0'			144622.00
~~47~~	6/21/2001	Lane County Public Works	2148 Grove	No	R1	896469.599	4228198.26	Decommissioned in 2008	5D2	Stormwater		6.0'/3.0'			64326.00
48	6/21/2001	Lane County Public Works	660 Bushnell Lane	No	RA	896142.01	4224488.2	Active	5D2	Stormwater	Vertical	5.34'/3.0'	No	400	85066.00
49	6/21/2001	Lane County Public Works	661 Bushnell Lane	No	RA	896176.29	4224495.04	Active	5D2	Stormwater	Vertical	5.34'/3.0'	No	400	67702.00
~~50~~	6/21/2001	Lane County Public Works	372 Lodenquai Lane	No	R1	903504.175	4227237.6	Decommissioned in 2003Reconstruct of Irvington Drive	5D2	Stormwater		7.0'/3.0'			126907
51	6/21/2001	Lane County Public Works	3500 Byron	No	RA	903113.404	4227519.85	Active	5D2	Stormwater	Vertical	4.34'/3.0'	No	90	148259.00
52	6/21/2001	Lane County Public Works	Intersection Ferndale & Quiet Lane	No	RA	900961.711	4228958.6	Active	5D2	Stormwater	Vertical	7.0'/3.0'	No	1275	97544.00
53	6/21/2001	Lane County Public Works	3188 Cindy @ end of street	No	RA	901629.135	4228801.55	Active	5D2	Stormwater	Vertical	5.0'/3.0'	No	220	189089.00
54	6/21/2001	Lane County Public Works	2756 Alyndale	No	R1	899481.576	4226304.34	Active	5D2	Stormwater	Vertical	3.17'/3.0'	No	110	53574.00
55	6/21/2001	Lane County Public Works	2771 Alyndale	No	R1	899512.757	4226338.11	Active	5D2	Stormwater	Vertical	3.17'/3.0'	No	110	52676.00
56	6/21/2001	Lane County Public Works	2790 Alyndale	No	R1	899695.243	4226139.15	Active	5D2	Stormwater	Vertical	3.17'/3.0'	No	110	108613.00
57	6/21/2001	Lane County Public Works	2790 Alyndale	No	R1	899727.153	4226139.56	Active	5D2	Stormwater	Vertical	3.17'/3.0'	No	110	57657.00
58	6/21/2001	Lane County Public Works	2865 Stark	No	R1	899957.903	4226293.14	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	60	59116.00
59	6/21/2001	Lane County Public Works	2960 Alyndale	No	R1	900431.484	4226323.16	Active	5D2	Stormwater	Vertical	5.0'/3.0'	No	110	43616.00
60	6/21/2001	Lane County Public Works	2965 Alyndale	No	R1	900440.677	4226367.46	Active	5D2	Stormwater	Vertical	5.0'/3.0'	No	110	96659.00
61	6/21/2001	Lane County Public Works	3193,3187 Alyndale	No	R1	901875.708	4226352.71	Inactive	5D2	Stormwater	Unknown	5.0'/3.0'	Yes	110	137559.00
62	6/21/2001	Lane County Public Works	830 Bobolink	No	RA	900782.168	4225960.8	Active	5D2	Stormwater	Vertical	4.0'/3.0'	No	320	54215.00
63	6/21/2001	Lane County Public Works	Intersection Bobolink & Maesner	No	RA	900790.219	4225696.24	Active	5D2	Stormwater	Vertical	4.0'/3.0'	No	320	49605.00
64	6/21/2001	Lane County Public Works	1029 Boblink	No	RA	900786.284	4225152.22	Active	5D2	Stormwater	Vertical	4.0'/3.0'	No	320	136724.00
65	6/21/2001	Lane County Public Works	2948 Maesner	No	RA	900448.973	4225708.64	Inactive	5D2	Stormwater	Vertical	5.0'/3.0'	Yes	220	53862.00

66	6/21/2001	Lane County Public Works	3019 Hyacinth	No	RA	901047.888	4224958.59	Inactive	5D2	Stormwater	Vertical	5.0'/3.0'	Yes	1850	53862.00
67	6/21/2001	Lane County Public Works	326 Argon	No	AG	904260.511	4227523.19	Active	5D2	Stormwater	Vertical	6.67'/3.0'	No	40	192084.00
68	6/21/2001	Lane County Public Works	501 Warrington	No	AG	906285.102	4230610.99	Active	5D2	Stormwater	Vertical	5.17'/3.0'	No	480	167815.00
69	6/21/2001	Lane County Public Works	3687 Suburban	No	R1	903952.453	4229879.17	Active	5D2	Stormwater	Vertical/Horizontal	3.0'/3.0'	No	90	60715.00
70	6/21/2001	Lane County Public Works	3605 Suburban	No	R1	903953.917	4229852.88	Active	5D2	Stormwater	Vertical/Horizontal	3.0'/3.0'	No	90	14985.00
71	6/21/2001	Lane County Public Works	3554 Poplar Street	No	R1	903086.52	4231449.87	Active	5D2	Stormwater	Vertical	3.0'/3.0'	No	100	18757.00
72	6/21/2001	Lane County Public Works	3553 Poplar Street	No	R1	903064.431	4231475.26	Active	5D2	Stormwater	Vertical	3.0'/3.0'	No	100	43650.00
73	6/21/2001	Lane County Public Works	Intersection Poplar St. & Anchor Ave.	No	R1	902819.42	4231476.17	Active	5D2	Stormwater	Vertical	3.0'/3.0'	No	120	20555.00
74	6/21/2001	Lane County Public Works	3089 DaleWood	No	AG	900908.351	4230886.06	Active	5D2	Stormwater	Vertical	6.34'/3.0'	No	350	197391.00
75	6/21/2001	Lane County Public Works	441 Silver Meadows	No	AG	900639.587	4231345.22	Active	5D2	Stormwater	Vertical	4.0'/3.0'	No	180	310141.00
76	6/21/2001	Lane County Public Works	272 Banton	No	AG	900205.496	4230787.17	Active	5D2	Stormwater	Vertical	6.17'/3.0'	No	500	333872.00
77	6/21/2001	Lane County Public Works	2682 Klamath St	No	RA	898718.015	4233514.4	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	130	246741.00
78	6/21/2001	Lane County Public Works	585 Lone Oak	No	RA	897916.139	4234218.77	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	2500	227541.00
79	6/21/2001	Lane County Public Works	549 Lone Oak	No	RA	897778.696	4233754.51	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	2500	182074.00
80	6/21/2001	Lane County Public Works	2323 Moore Street	No	NO CODE	896806.598	4234204.13	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	2050	51325.00
81	6/21/2001	Lane County Public Works	2400 Laralee	No	LD	885900.036	4258683.59	Inactive	5D2	Stormwater	Vertical	6.17'/3.0'	Yes	70	140936.00
82	6/21/2001	Lane County Public Works	2755 Nova	No	LD	887285.544	4256268.67	Active	5D2	Stormwater	Vertical	5.17'/3.0'	No	220	39603.00
83	6/21/2001	Lane County Public Works	Pheasant @ Crossland Economy Studios	No	CC	886557.657	4255502.53	Active	5D2	Stormwater	Unknown	3.0'/3.0'		1000	67712.00
84	6/21/2001	Lane County Public Works	Intersection Castle & Estate	No	LD	886999.257	4258020.75	Active	5D2	Stormwater	Horizontal	3.0'/3.0'		300	128470.00
85	6/21/2001	Lane County Public Works	2575 Harvest Lane	No	LD	886397.099	4262757.16	Active	5D2	Stormwater	Vertical	5.17'/3.0'	No	900	111859.00
86	6/21/2001	Lane County Public Works	Intersection Winslow & Hayden Bridge Rd.	No	LD	887430.769	4272151.52	Active	5D2	Stormwater	Vertical	5.0'/3.0'	No	130	1597140.00
87	6/21/2001	Lane County Public Works	3859 Hayden Bridge Rd	No	LD	887628.196	4272136.24	Active	5D2	Stormwater	Vertical	6.0'/3.0'		1050	101038.00

88	6/21/2001	Lane County Public Works	3393 Hayden Bridge Rd.	No	LD	887738.613	4270284.57	Active	5D2	Stormwater	Vertical	6.0'/3.0'	No	1300	131966.00
89	6/21/2001	Lane County Public Works	Hayden Bridge Rd between 34 & 35	No	LD	887707.001	4271027.29	Active	5D2	Stormwater	Horizontal	3.0'/3.0'	No	1300	218171.00
90	6/21/2001	Lane County Public Works	2450 N. 34th Middle of street	No	LD	886918.771	4270155.79	Active	5D2	Stormwater	Vertical	3.34'/3.0'	No	300	666813.00
91	6/21/2001	Lane County Public Works	2665 Montebello	No	LD	887203.065	4269652.95	Active	5D2	Stormwater	Vertical	6.34'/3.0'	No	50	92858.00
92	6/21/2001	Lane County Public Works	Yolanda @ 35th	No	LD	886669.743	4270752.56	Active	5D2	Stormwater	Vertical	8.83'/3.0'	No	225	609867.00
93	6/21/2001	Lane County Public Works	3440 Sue Ann Court	No	LD	886967.103	4270498.02	Active	5D2	Stormwater	Vertical	4.25'/3.0'	No	70	380402.00
94	6/21/2001	Lane County Public Works	3044 Yolanda	No	LD	886452.268	4268558.95	Active	5D2	Stormwater	Vertical	4.67'/3.0'	No	1450	224795.00
95	6/21/2001	Lane County Public Works	2933 Yolanda	No	LD	886486.043	4267949.75	Active	5D2	Stormwater	Vertical	4.67'/3.0'	No	1500	296000.00
96	6/21/2001	Lane County Public Works	2685 N. 33rd Backyard drywell	No	LD	887203.828	4269928.54	Active	5D2	Stormwater	HORIZONTAL	6.0'	No	225	259624.00
97	6/21/2001	Lane County Public Works	Cottonwood Between 1754 & 1957	No	LD	881500.12	4251593.1	Active	5D2	Stormwater	Vertical	6.83'/3.0'	No	380	431643.00
98	6/21/2001	Lane County Public Works	768 S. Anderson	No	MD	879798.39	4251434.12	Active	5D2	Stormwater	Vertical	7.50'/3.0'	No	100	344155.00
99	6/21/2001	Lane County Public Works	700 S. Anderson	No	MD	879362.559	4251414.82	Active	5D2	Stormwater	Vertical	7.0'/3.0'	No	100	260465.00

APPENDIX B

Technical Documentation for 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 gravel was used based on the gravel lenses in the Qfd geologic unit. Effective porosity is the percent of pore space through which flow occurs, as was estimated as 0.30 for the Upper Sedimentary Hydrogeologic Unit as indicated on page 133 of Craner (2006).

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:

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

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:

$$D = \alpha\ v \tag{B.2}$$

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):

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

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):

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

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), estimated from infiltration tests and laboratory tests on Shelby tube samples,

$\left(\frac{\partial \psi}{\partial y}\right)$ 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 Lane County UICs), $\left(\frac{\partial \psi}{\partial y}\right)$ = 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 0.30, the effective porosity of the Upper Sedimentary Hydrogeologic Unit as indicated on page 133 of Craner (2006).

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 11.2%. An evaporative loss factor has not been published for the Eugene vicinity, so this value was chosen so that the runoff volumes calculated by Equation (B.7) would be consistent with existing runoff volumes calculated for a subset of City of Eugene catchment areas using the EPA simple method.

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).
- 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 50 feet, SV is about 46,000,000 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).

The TOC concentration in stormwater was calculated from stormwater samples collected from public ROWs in the City of Eugene (TOC data from stormwater in parking lots was excluded from the calculations because the TOC likely contains contribution from oils and hydrocarbons). Five TOC concentrations were used in the analysis from different times of the year, and did not show significant seasonal variation: 5.7 mg/L (February), 5.7 mg/L (November), 5.9 mg/L (October), 5.7 mg/L (April), 3.9 mg/L (March). The February, October and November samples were from the Copping Street UIC, the April sample was from the Storm Comp M1 6700 site, and the March sample was from the Willow Creek and 18th site.

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).

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 the range of groundwater pH of shallow groundwater presented in Table 9 of Craner (2006).

- **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):

$$K_d = f_{oc}K_{oc} \tag{B.11}$$

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:

$$K_d = \frac{C_s}{C_w} \tag{B.12}$$

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:

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

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 and these are summarized for each of the compounds of interest. 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-4. Summary statistics provided in Table B-4 include number of measurements, minimum, maximum, mean, 25th, and 50th 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 25th 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 1999 to 2010 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 typically 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.

The unsaturated zone GWPD provides a conservative simulation of pollutant fate and transport for the following reasons:

- In the model, pollutant concentrations are higher than what is typically observed in stormwater. For example, the concentration of PCP (the most mobile and persistent of the common stormwater pollutants) in the model is higher than any of the PCP concentrations observed during the City of Portland's seven years of Stormwater Discharge Monitoring (over 1,400 stormwater samples). The PCP concentration is also 10 times higher than the EPA Maximum Contaminant Level (MCL).

- The model does not include pre-treatment upstream of the UIC (e.g., attenuation caused by processes in the sedimentation manhole, vegetated facilities, etc.)

- The model does not take into account pollutant attenuation that occurs while in the UIC (i.e. through adsorption to sediment or organic matter that falls out of solution, or volatilization as water cascades into the UIC from the end-of-pipe) before entering the surrounding soil. The model also does not take into account filtering of pollutants that are sorbed to particulates during transport through the unsaturated zone.

- The model uses very conservative parameters for estimating pollutant attenuation. For example, the first-order rate constant for PCP (which governs pollutant attenuation by microbial activity) is 10% of the average of literature values.

- Pollutant attenuation is a directional process that occurs in three dimensions. However, the unsaturated zone model simulates pollutant attenuation in only one dimension, which underestimates pollutant attenuation.

- At a typical vertical UIC, most stormwater infiltrates horizontally through the weep holes in the sides of the UIC several feet above the UIC bottom, and then migrates vertically downward. The models assume that stormwater only flows vertically downward from the bottom of the UIC, thereby underestimating the travel distance of stormwater through the unsaturated zone.

- In reality, stormwater flows are highly variable and short in duration resulting in varying water levels within the UIC depending on the infiltration capacity of the formation. Thus, the UIC periodically will fill with water and then drain during the wet season. The model assumes pollutant fate and transport occurs constantly for the time period during the wet season that the UIC likely contains water. This approach is conservative because it minimizes attenuation by microbial activity, and maximizes the infiltration that would be expected to reach the water table.

- Pollutant concentrations are assumed to be constant, while in reality they are variable throughout storm events. This likely over-predicts the concentration throughout the duration of a storm event.

4 Infiltration Tests for Calculating Average Linear Pore Water Velocity

Infiltration tests are conducted to estimate hydraulic conductivity (a proportionality constant that, under unsaturated conditions, is equivalent to specific discharge [see Equation B.5]). Hydraulic conductivity in the unsaturated zone GWPD was calculated based on infiltration tests conducted by professional engineers as a part of UIC design evaluations in the City of Eugene. The infiltration tests are documented in the following reports

- Professional Service Industries, Inc., 1991. *Report of Subsurface Exploration for the Residential Subdivision in Santa Clara*. Prepared for: Coldwell Banker Curtis Irving Realty. February 27.
- GEO Environmental Engineering, 1997. *Evaluation of Soil Permeability, Dahlia Meadows Subdivision, Eugene, Oregon*. Prepared for: Weber Engineering Company. March 11.
- Poage Engineering, undated, *Cherry Tree Estates.*
- Poage Engineering, 1997. *Andersen Meadows First Addition.* July 17.

Hydraulic conductivity values were used in the unsaturated zone GWPD only if the report provided documentation about the methods that were used to calculate hydraulic conductivity and the data that was collected in the field. A total of 9 values of hydraulic conductivity were used in the unsaturated zone GWPD, as summarized in Table B-5. Hydraulic conductivity calculations were based on a variety of methods, including falling head tests at test pits, constant head tests at test pits, and lab-based permeameter testing of Shelby tube samples. Hydraulic conductivities were calculated for both fine-grained sediments (i.e., silt and sand) and coarse-grained "bar run" gravels. The following assumptions were used to develop unsaturated zone GWPD model input parameters:

- Hydraulic conductivity measured at test pits represents horizontal hydraulic conductivity, and was converted to vertical hydraulic conductivity by assuming a horizontal to vertical anisotropy of 10:1 (Freeze and Cherry, 1979).
- Hydraulic conductivity measured from lab tests (i.e., a small-scale test), is likely not representative of field-scale hydraulic conductivity. Therefore, hydraulic conductivity from lab tests was multiplied by a factor of 50 to upscale the value.
- For the average scenario of the unsaturated zone GWPD, median hydraulic conductivities were used for the "bar run" gravels, and for the fine grained sediments.

For the reasonable maximum scenario of the unsaturated zone GWPD, 95%Upper Confidence Limit (UCL) on the mean hydraulic conductivities were used for the "bar run" gravels and for the fine-grained sediments. The harmonic mean was used to calculate an effective hydraulic conductivity for unconsolidated sediments beneath UICs based on the median (average scenario) or 95% UCL on the mean (reasonable maximum scenario) hydraulic conductivities, which is recommended when flow direction is perpendicular to geologic layering (Freeze and Cherry, 1979).

The vertical hydraulic conductivities were used to calculate vertical pore water velocity by substituting hydraulic conductivity into Equation (B.6) and dividing by an effective porosity of 0.30 (Craner, 2006).

5 Unsaturated Zone GWPD Results

The unsaturated zone GWPD model input, calculations and results are provided in Table B-6 (protective vertical separation distance at vertical UICs), Table B-7 (protective vertical separation distance at horizontal UICs), and Table B-8 (Alternate Action Level for copper).

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Table B-1

Precipitation, 1999 - 2010

Lane County

Year	**Precipitation** (inches)	**Precipitation ≥ 0.04 inches/hour intensity** (feet)	**Hours With ≥ 0.04 inches/hr intensity** (hours)	**Days with ≥ 0.04 inches/hr intensity** (days)
1999	42.1	29.4	391	16.3
2000	34.0	23.5	306	12.8
2001	27.8	16.2	222	9.3
2002	36.9	28.3	346	14.4
2003	41.2	30.7	392	16.3
2004	30.8	21.6	268	11.2
2005	34.6	25.8	315	13.1
2006	49.7	40.3	460	19.2
2007	34.2	25.5	320	13.3
2008	29.2	19.6	270	11.3
2009	31.8	24.1	290	12.1
2010	45.6	33.9	456	19.0
Maximum	*49.65*	*40.31*	*460*	*19.17*
Minimum	*27.77*	*16.22*	*222*	*9.25*
Average	*36.60*	*26.89*	*335*	*13.96*
Median	*35.58*	*26.35*	*328*	*13.65*
Geomean	*36.54*	*26.69*	*334*	*13.93*

Notes

Data from Eugene Airport rain gauge

GSI Water Solutions, Inc.

Table B-2

Unsaturated Zone GWPD Stormwater Infiltration Volume

Lane County

	Impervious Area, *A* (ft^2)	**Annual Precipitation, *P*** (Geometric Mean, 1999 - 2010) (ft/yr)	**Evaporative Loss Factor, *e*** (-)	**Infiltration Volume, *I*** (ft^3/year)	**Infiltration Volume, *I*** (cm^3/yr)
Lane County	62,533 (1)	2.22	0.112	123,511 (2)	3.50E+09 (2)

Notes

(1) Average impervious area based on drainage area delineations for Lane County UICs in the City of Eugene, Oregon.

(2) Calculated by the following equation: $I = (A)(P)(1-e)$

ft = feet

cm = centimeters

GSI Water Solutions, Inc.

Table B-3
Unsaturated Zone GWPD Fraction Organic Carbon
Lane County

	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	3.50E+09	5.42	10	1,000,000	189,562	60.96	91.44	1,333,723	4001170.42		5,334,894	0.035532418	1.66	0.020956
Reasonable Maximum Scenario	3.50E+09	3.90	10	1,000,000	136,400	60.96	91.44	1,333,723	4001170.42		5,334,894	0.025567607	1.66	0.015169
Horizontal UIC														
Average Scenario	3.50E+09	5.42	10	1,000,000	189,562	14.05	44.52			16,405	45,977,090	0.00412296	1.66	0.002478
Reasonable Maximum Scenario	3.50E+09	3.90	10	1,000,000	136,400	14.05	44.52			16,405	45,977,090	0.002966705	1.66	0.001784

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 (assumed to be the soil from three feet above the UIC bottom to five feet below the base of the UIC, extending 1 foot from the radius of the UIC (equation not shown)
f_{oc} = fraction organic carbon
ρ_b = bulk density

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Table B-4

Unsaturated Zone GWPD Biodegradation Rates

Lane County

Compound	First-Order Biodegradation Rate (day^{-1})					
	N	*Median*	*Mean*	*Maximum*	*25th 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-5

Hydraulic Conductivity From Infiltration Tests

Lane County

Source	K_H (ft/d)	K_V (ft/d)		Hydraulic Conductivity Used in GWPD	Notes	Notes
Professional Service Industries (1991)	NA	0.001616		0.081	Silty sand	Lab test on Shelby Tube
Professional Service Industries (1991)	NA	0.001956		0.098	Silty Sand	Lab test on Shelby Tube
Professional Service Industries (1991)	NA	0.001134		0.057	Clayey silt	Lab test on Shelby Tube
Professional Service Industries (1991)	NA	0.007937		0.397	Saturated Zone, silty sand	Lab test on Shelby Tube
Geo Environmental Engineering (1997)	0.03	0.003	[1]	0.150	Clayey silt	Falling head, test pit
Geo Environmental Engineering (1997)	0.125	0.0125	[1]	0.625	Silt	Falling head, test pit
Geo Environmental Engineering (1997)	65	6.5	[1]	6.5	Gravels	Falling head, test pit
Poage Engineering (undated)	639	64	[1]	64	Gravels	Constant Head Test
Poage Engineering (1997)	NA	329		329	Gravels	Falling head, test pit

Median K_{FINES}	0.124	Harmonic Mean (ft/d)	0.25
Median K_{GRAVEL}	64		
95% UCL K_{FINES} [2]	0.625	Harmonic Mean (ft/d)	1.25
95% UCL K_{GRAVEL} [2]	329		

Notes

1 Calculated assuming an anisotropy of 10:1

2 Max is used for the 95% UCL (see text)

Table B-6. Pollutant Fate and Transport

Groundwater Protectiveness Demonstration, Lane County, 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	0.00158	0.0180	0.00025	0.0017	0.12	0.82	0.0050	0.0348
		y	ft	0.00520	0.059	0.00081	0.00563	0.39	2.69	0.016	0.11
	Concentration	C_0	mg/L	0.50 [1]	0.50 [1]	0.002 [1]	0.002 [1]	0.01 [1]	0.01 [1]	0.06 [1]	0.06 [1]
	Infiltration Time	t	d	13,930 [2]	13,930 [2]	13.93 [3]	13.93 [3]	13.93 [3]	13.93 [3]	13.93 [3]	13.93 [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	-	0.325 [9]	0.325 [9]	0.325 [9]	0.325 [9]	0.325 [9]	0.325 [9]	0.325 [9]	0.325 [9]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [10]	1.79 [10]	1.79 [10]	1.79 [10]	1.79 [10]	1.79 [10]	1.79 [10]	1.79 [10]
	Fraction Organic Carbon	f_{oc}	-			0.0210 [11]	0.0152 [11]	0.0210 [11]	0.0152 [11]	0.0210 [11]	0.0152 [11]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg			282,185 [12]	282,185 [12, 13]	592 [14]	592 [14]	12,200 [12]	12,200 [12, 13]
	Distribution Coefficient	K_d	L/kg	1,203,704 [15]	535,040 [16]	5,915 [17]	4,281 [17]	12.4 [17]	9.0 [17]	255.7 [17]	185.1 [17]
	Pore Water Velocity	v	m/d	0.25 [18]	1.27 [19]	0.25 [18]	1.27 [19]	0.25 [18]	1.27 [19]	0.25 [18]	1.27 [19]
Calculations	Retardation Factor	R	-	6,625,003	2,944,779	32,554	23,562	69.3	50.4	1,408	1,020
	Dispersion Coefficient	D	m^2/d	1.99E-05	1.14E-03	3.09E-06	1.09E-04	1.49E-03	5.20E-02	6.28E-05	2.21E-03
	Normalized Dispersion	D'	m^2/d	3.00E-12	3.87E-10	9.50E-11	4.62E-09	2.14E-05	1.03E-03	4.46E-08	2.17E-06
	Normalized Velocity	v'	m/d	3.79E-08	4.31E-07	7.72E-06	5.38E-05	3.63E-03	2.51E-02	1.78E-04	1.24E-03
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	3.99E-08	1.10E-08	3.19E-04	2.76E-04	1.07E-05	9.81E-06
	A_1	-	-	0.00E+00	0.00E+00	-1.27E-06	-3.52E-07	-1.04E-02	-8.98E-03	-2.98E-04	-2.75E-04
	A_2	-	-	2.58E+00	2.58E+00	1.91E+00	1.91E+00	1.96E+00	1.96E+00	1.59E+00	1.59E+00
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.90E-01	9.91E-01	1.00E+00	1.00E+00
	erfc(A_2)	-	-	2.64E-04	2.64E-04	7.04E-03	7.01E-03	5.63E-03	5.62E-03	2.42E-02	2.43E-02
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01
	B_2	-	-	5.16E+00	5.16E+00	4.86E+00	4.86E+00	4.88E+00	4.88E+00	4.75E+00	4.75E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.90E+08	4.90E+08	4.85E+08	4.85E+08
	erfc(B_2)	-	-	2.84E-13	2.85E-13	6.21E-12	6.19E-12	4.95E-12	4.96E-12	1.89E-11	1.90E-11
	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]			

NOTES *(SEE APPENDIX B FOR CITATIONS)*

[1] Equal to the action level in Table 1 of the City of Eugene UIC WPCF permit (lead, pentachlorophenol, benzo(a)pyrene) or the City of Gresham UIC WPCF permit (DEHP).

[2] Infiltration time for lead is 1,000 years (1,000 years at 13.93 days per year = 13,930 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. Precipitation data source is the Eugene Airport rain gage. Annual precipitation from 1999 to 2010 were used in the analysis, and were averaged using the geometric mean.

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

[5] 25th percentile biodegradation rate from a review of scientific literature (seeTable B-4 for references).

[6] 10 percent of the average biodegradation rate of PCP under aerobic conditions (see Table B-4 for references).

[7] 10 percent of the minimum biodegradation rate of PCP under aerobic conditions (see Table B-4 for references).

[8] Calculated from the following formula: $C_t = C_0 e^{-kt}$, 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 gravel 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 Appendix B text 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 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 Koc for PCP is 592 L/kg.

[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] Based on N=17 hydraulic conductivity values from infiltration tests and lab analysis of Shelby tubes conducted within Eugene city limits and an effective porosity of 0.30 after Craner (2006).

[19] The 95% UCL on the mean of infiltration tests and Shelby tubes conducted within Eugene city limits and an effective porosity of 0.30 after Craner (2006)

[20] Action Levels from Table 1 of the City of Eugene UIC WPCF permit.

Table B-7. Pollutant Fate and Transport

Groundwater Protectiveness Demonstration, Lane County, 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	0.00158	0.0180	0.00208	0.0146	0.90	6.07	0.0420	0.2946
		y	ft	0.00520	0.059	0.00683	0.04800	2.95	19.90	0.138	0.97
	Concentration	C_0	mg/L	0.50 [1]	0.50 [1]	0.002 [1]	0.002 [1]	0.01 [1]	0.01 [1]	0.06 [1]	0.06 [1]
	Infiltration Time	t	d	13,930 [2]	13,930 [2]	13.93 [3]	13.93 [3]	13.93 [3]	13.93 [3]	13.93 [3]	13.93 [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	-	0.325 [9]	0.325 [9]	0.325 [9]	0.325 [9]	0.325 [9]	0.325 [9]	0.325 [9]	0.325 [9]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [10]	1.79 [10]	1.79 [10]	1.79 [10]	1.79 [10]	1.79 [10]	1.79 [10]	1.79 [10]
	Fraction Organic Carbon	f_{oc}	-			0.0025 [11]	0.0018 [11]	0.0025 [11]	0.0018 [11]	0.0025 [11]	0.0018 [11]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg			282,185 [12]	282,185 [12, 13]	592 [14]	592 [14]	12,200 [12]	12,200 [12, 13]
	Distribution Coefficient	K_d	L/kg	1,203,704 [15]	535,040 [16]	700 [17]	502 [17]	1.5 [17]	1.1 [17]	30.3 [17]	21.7 [17]
	Pore Water Velocity	v	m/d	0.25 [18]	1.27 [19]	0.25 [18]	1.27 [19]	0.25 [18]	1.27 [19]	0.25 [18]	1.27 [19]
Calculations	Retardation Factor	R	-	6,625,003	2,944,779	3,853	2,766	9.1	6.8	168	121
	Dispersion Coefficient	D	m^2/d	1.99E-05	1.14E-03	2.61E-05	9.28E-04	1.13E-02	3.85E-01	5.28E-04	1.87E-02
	Normalized Dispersion	D'	m^2/d	3.00E-12	3.87E-10	6.79E-09	3.35E-07	1.25E-03	5.66E-02	3.15E-06	1.55E-04
	Normalized Velocity	v'	m/d	3.79E-08	4.31E-07	6.52E-05	4.59E-04	2.77E-02	1.86E-01	1.50E-03	1.05E-02
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	3.37E-07	9.40E-08	2.43E-03	2.04E-03	8.95E-05	8.30E-05
	A_1	-	-	0.00E+00	0.00E+00	-1.08E-05	-3.00E-06	-7.88E-02	-6.63E-02	-2.51E-03	-2.32E-03
	A_2	-	-	2.58E+00	2.58E+00	1.91E+00	1.91E+00	1.94E+00	1.94E+00	1.59E+00	1.59E+00
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.24E-01	9.36E-01	9.97E-01	9.98E-01
	$erfc(A_2)$	-	-	2.64E-04	2.64E-04	7.01E-03	7.00E-03	6.04E-03	5.97E-03	2.43E-02	2.43E-02
	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	4.75E+00	4.75E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08	5.25E+08	5.18E+08	4.86E+08	4.86E+08
	$erfc(B_2)$	-	-	2.84E-13	2.85E-13	6.19E-12	6.18E-12	4.59E-12	4.66E-12	1.89E-11	1.89E-11
	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]			

NOTES *(SEE APPENDIX B FOR CITATIONS)*

[1] Equal to the action level in Table 1 of the City of Eugene UIC WPCF permit (lead, pentachlorophenol, benzo(a)pyrene) or the City of Gresham UIC WPCF permit (DEHP).

[2] Infiltration time for lead is 1,000 years (1,000 years at 13.93 days per year = 13,930 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. Precipitation data source is the Eugene Airport rain gage. Annual precipitation from 1999 to 2010 were used in the analysis, and were averaged using the geometric mean.

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

[5] 25th percentile biodegradation rate from a review of scientific literature (seeTable B-4 for references).

[6] 10 percent of the average biodegradation rate of PCP under aerobic conditions (see Table B-4 for references).

[7] 10 percent of the minimum biodegradation rate of PCP under aerobic conditions (see Table B-4 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 gravel 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 Appendix B text 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 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 Koc for PCP is 592 L/kg.

[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] Based on N=17 hydraulic conductivity values from infiltration tests and lab analysis of Shelby tubes conducted within Eugene city limits and an effective porosity of 0.30 after Craner (2006).

[19] The 95% UCL on the mean of infiltration tests and Shelby tubes conducted within Eugene city limits and an effective porosity of 0.30 after Craner (2006)

[20] Action Levels from Table 1 of the City of Eugene UIC WPCF permit.

Table B-8. Pollutant Fate and Transport
Alternate Action Levels, Lane County, Horizontal UIC

	Parameter	Symbol	Units	Metals: Copper, Average Scenario	Metals: Copper, Reasonable Maximum Scenario
UIC Properties	Transport Distance	y	m	0.91	0.91
		y	ft	3.00	3.00
	Concentration	C_0	mg/L	13.0 [1]	13.0 [1]
	Infiltration Time	t	d	13,930 [2]	13,930 [2]
Pollutant Properties	First-Order Rate Constant	k	d^{-1}		
	Half-Life	h	d		
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [3]	0.325 [3]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [4]	1.79 [4]
	Fraction Organic Carbon	f_{oc}	-		
	Organic Carbon Partition Coefficient	K_{oc}	L/kg		
	Distribution Coefficient	K_d	L/kg	159,310 [5]	24,801 [6]
	Pore Water Velocity	v	m/d	0.25 [7]	1.25 [8]
Calculations	Retardation Factor	R	-	876,819	136,502
	Dispersion Coefficient	D	m^2/d	1.13E-02	5.71E-02
	Normalized Dispersion	D'	m^2/d	1.29E-08	4.18E-07
	Normalized Velocity	v'	m/d	2.83E-07	9.14E-06
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00
	A_1	-	-	0.00E+00	0.00E+00
	A_2	-	-	3.39E+01	5.16E+00
	e^{A1}	-	-	1.00E+00	1.00E+00
	$erfc(A_2)$	-	-	0.00E+00	3.03E-13
	B_1	-	-	2.00E+01	2.00E+01
	B_2	-	-	3.42E+01	6.83E+00
	e^{B1}	-	-	4.85E+08	4.85E+08
	$erfc(B_2)$	-	-	0.00E+00	4.76E-22
	Concentration Immediately Above Water Table	C	mg/L	0.00E+00	3.47E-12
MRL		C	mg/L	1.00E-04	1.00E-04
Action Level		C	mg/L	1.30E+00 [9]	

NOTES *(SEE APPENDIX B FOR CITATIONS)*

[1] Equal to the 10X the action level in Table 1 of the City of Eugene UIC WPCF permit

[2] Infiltration time for metals is for 1,000 years (1,000 years at 13.93 days per year = 13,930 days)

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

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

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

[6] 10th percentile K_d for copper, calculated using stormwater analytical data collected by the City of Milwaukie in spring of 2012 and an equation from Brickner (1998)

[7] Based on N=17 hydraulic conductivity values from infiltration tests conducted within Eugene city limits and an effective porosity of 0.30 after Craner (2006).

[8] The 95% UCL on the mean of infiltration tests conducted within Eugene city limits and an effective porosity of 0.30 after Craner (2006)

[9] Action Levels from Table 1 of the City of Eugene UIC WPCF permit template.

APPENDIX C

Technical Documentation for 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 Lane County, Oregon (County). 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] for non-metals). 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 County's UIC Water Pollution Control Facilities (WPCF) permit (the permit).

1 Introduction

Pollutant fate and transport from a typical wet foot UIC was simulated with a transient three-dimensional finite difference numerical model for groundwater flow and pollutant fate and transport. 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 (32 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 were chosen for the following reasons:

- These pollutants most frequently exceed the Maximum Allowable Discharge Limit[1] (MADL) based on the Kennedy Jenks (2009) statistical analysis of stormwater quality data in western Oregon (PCP exceeded MADLs in 11.7% of samples, DEHP exceeded MADLs in 4.7% of samples, and lead exceeded MADLs in 12.7% of samples), and/or

- Two of these contaminants (benzo(a)pyrene and PCP) have resulted in noncompliant conditions in the City of Portland's UIC WPCF permit by exceeding the MADL for two consecutive years of annual stormwater discharge monitoring.

In addition to periodically exceeding MADLs, these pollutants are among the most mobile, persistent, or toxic stormwater pollutants in their respective class (i.e., metals, semi-volatile organic compounds, and polynuclear aromatic hydrocarbons) (GSI, 2011a).

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, less than 1 foot for vertical UICs and less than 3 feet for horizontal UICs). The conservative modeling assumptions for the saturated zone GWPD included the following:

[1] DEQ has variously referred to numeric discharge triggers provided in the permit for UICs as Maximum Allowable Discharge Limits, Effluent Discharge Limits, and Action Levels. The July 2012 draft UIC WPCF permit template uses the term Action Levels.

- 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 driver for determining the waste management area) was equal to the action level in the City of Eugene'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). In addition, the 95% upper confidence limit (UCL) on the mean PCP concentration in Gresham stormwater is 1.19 micrograms per liter (ug/L), whereas the Action Level is 10 ug/L—nearly ten times greater.

- 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 objective of the base model run was to determine the drivers for the protective horizontal separation distance, specifically—the pollutants (i.e., PCP, DEHP, lead, or benzo(a)pyrene) and the UIC configurations (horizontal or vertical).

- **UIC Drainage Basin Sensitivity Runs ("DB sensitivity runs").** Uncertainty exists about the amount of impervious area within the County's UIC drainage basins. Because the horizontal separation distance is sensitive to the impervious area within the UIC drainage basin, additional model runs were conducted to calculate protective horizontal separation distances based on a range of impervious areas within UIC drainage basins. Before applying the saturated zone GWPD results to a given UIC, the County will delineate the approximate impervious area for the basin.

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 groundwater flow equation was solved using the Pre Conditioned Conjugant Gradient 2 package (PCG2). The velocities output by MODFLOW are used by the three dimensional pollutant fate and transport code MT3D to simulate reactive pollutant transport. Particle advection was simulated using the TVD solution scheme.

Groundwater Vistas version 6.27 (build 17) 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 aerial extent of the model domain (2,000 feet by 400 feet) was 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 the 2,000 feet by 400 feet 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 County's UICs are located in the braided/delta fan deposits (unit Qfd). The aquifer properties used in the saturated zone GWPD are representative of hydrogeologic conditions in the Qfd.

Hydraulic Gradient

Hydraulic gradient is the slope of the water table. Hydraulic gradient (0.005 feet/foot) was calculated based on a seasonal high groundwater elevation contour map of the Willakenzie Area prepared by City of Eugene GIS staff. Groundwater elevations were taken from well logs in the Oregon Water Resources Department (OWRD) on-line database (OWRD, 2012). Specifically, water levels were used from water supply wells drilled to relatively shallow depths during the wet months of the year.

Hydraulic Conductivity

Hydraulic conductivity describes the ease with which groundwater moves through subsurface soils. According to Frank (1973), the unconsolidated Pleistocene and Holocene alluvial deposits (which includes the Qfd and Qal geologic units) are highly permeable. Hydraulic conductivities in the Qfd and Qal were calculated from specific capacity test data on well logs using the following equations from Driscoll (page 1021, 1986):

$$T = 2000 * \left(\frac{Q}{s}\right) \tag{C.1}$$

$$K = \frac{T}{b} \tag{C.2}$$

Where:

T is transmissivity (gallons per day per foot)
Q is pumping rate (gallons per minute)
s drawdown (feet)
K is hydraulic conductivity (feet per day), and
b is aquifer thickness (feet)

In Equation (C.1), 2000 is a conversion factor. Hydraulic conductivities in the Qfd and Qal geologic units are summarized in Table C-3. The median hydraulic conductivity for the Qfd geologic unit (15 ft/day) is higher than the median hydraulic conductivity for the Qal geologic unit (5 ft/day).

Saturated Thickness

Saturated thickness is the portion of a hydrogeologic unit that is saturated with groundwater. The hydrogeologic unit thickness (which includes saturated and unsaturated portions of the hydrogeologic unit) of 50 feet was conservatively selected based on the minimum unconsolidated sediment thickness above bedrock from driller logs in the County's UIC area. The saturated thickness of 42.4 feet was calculated by subtracting the average depth to seasonal high groundwater (DTSHGW) (7.6 feet below ground surface as documented on the DTSHGW map of the River Road/Santa Clara area that was produced by the City of Eugene) from the hydrogeologic unit thickness of 50 feet.

Porosity, Effective Porosity, and Specific Yield

Porosity is a weight-based percentage of void space in a soil. Porosity (0.325) was the midrange for a gravel from Freeze and Cherry (1979) to represent the gravels of the Qfd. The effective porosity and specific yield (0.30) were taken from Craner (2006) as the representative value for the Upper Sedimentary Unit, which is the hydrogeologic unit that includes the Qfd and Qal geologic units.

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.

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 of 17.93 feet (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-4. Stormwater infiltration volume was estimated from the following equation (e.g., Snyder, 1994):

$$I = (A)(p)(1-e) \tag{C.3}$$

Where:

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

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

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

e = Evaporative loss factor

As shown in Table C-4, infiltration volumes were calculated for several different theoretical impervious areas, ranging from 20,000 ft^2 to 200,000 ft^2 in increments of 20,000 ft^2. These infiltration volumes were the basis for the DB sensitivity runs.

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

The County has delineated impervious areas for 96 of its 99 UIC catchment areas[2]. The average impervious area is 62,533 ft^2. An impervious area of 60,000 ft^2 was used for the base model runs. For the DB sensitivity runs, impervious area was varied from 20,000 ft^2 to 200,000 ft^2 in increments of 20,000 ft^2.

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[2] Delineated impervious areas include 4749 Escalante (Escalante, Santa Rosa), 4749 Escalante (Shirley MH), 4748 Shirley, and 4857 Taz.

Precipitation That Runs Off Into a UIC (*p*)
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-4, approximately 2.22 feet of precipitation is produced annually by storm intensities greater than or equal to 0.04 inches per hour. Precipitation data is from 1999 to 2010 at the Eugene Airport. Using the Eugene Airport rain gauge is conservative because rain gauge data within City limits indicates that rainfall recorded at the Eugene airport is about 20 percent higher than rainfall recorded within City limits.

Infiltration Volumes (*I*)
As shown in Table C-4, the annual infiltration volume in an average UIC drainage basin is estimated to be approximately 118,500 ft^3. The infiltration volumes assumed an evaporative loss factor, *e*, of 11.2%. An evaporative loss factor has not been published for the Eugene vicinity, so this value was chosen so that the runoff volumes calculated by Equation (C.3) would be consistent with existing runoff volumes calculated for a subset of City catchment areas using the EPA simple method.

Stormwater Infiltration Time
Stormwater infiltration time is shown on Table C-4. On average, precipitation intensity is equal to or exceeds 0.04 inches per hour for about 334 hours per year based on precipitation data from the Eugene Airport. 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 included 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 estimated 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:

$$I = (A)(p)(1-e) \tag{C.4}$$

$$CL = (t)\left[\sum_{i=1}^{n} I_i C\right] \frac{1\,\text{liter}}{1{,}000\,\text{cm3}} \frac{1\,\text{gram}}{1{,}000{,}000\,\text{milligrams}} \tag{C.5}$$

$$\rho_{oc} = \frac{CL}{SV} \tag{C.6}$$

$$f_{oc} = \frac{\rho_{oc}}{\rho_b + \rho_{oc}} \tag{C.7}$$

Where the variables in Equation (C.4) 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 10, 5 foot long grid cells to represent the 50 feet length of the horizontal UIC (the equivalent of ten cubes that are each 5 feet by 5 feet by 5 feet, or 1,250 ft^3).

Based on Equation (C.6), 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-5 for the different impervious areas within UIC drainage basins. First, the volume of stormwater that infiltrates into a UIC each month was calculated by Equation (C.4). Next, Equation (C.5) was used to calculate the grams of carbon added to the saturated zone surrounding the UIC during a 10-year period. Equation (C.6) was used to calculate the mass of organic carbon per unit volume of material surrounding the UIC (ρ_{oc}), and Equation (C.7) 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-6. Pollutant properties used in the DB sensitivity runs (which involved PCP transport from a vertical UIC) are summarized in Table C-7. 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 wet feet transport simulations used half-lives that were the midrange of field studies for pollutant degradation in aerobic groundwater from Howard et al. (1991).

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Table C-1

Model Discretization

Lane County

Variable	Reference
Spatial Discretization	
Horizontal *x* -extent	2000 feet
Horizontal *y* -extent	400 feet
Vertical Exent	50 feet
Number of Rows	58
Number of Columns	223
Number of Layers	5
Total Number of Cells	64,670
Cell Size	5 feet to 20 feet
Temporal Discretization	
Simulation Length	35 years (32 years of pollutant loading)
Number of Time Steps	13,140
MODFLOW Time Step Length	1 day
MT3D Time Step Length	0.1 day

Table C-2
Aquifer Properties
Lane County

Variable	Symbol	Units	Value	Reference
Hydraulic Gradient	h	feet/foot	0.005 (Unit 3)	Based on Willakenzie Area Seasonal High Groundwater Estimates Map produced by Eugene PWE GIS Info Team, July 2012
Hydraulic Conductivity	K_h	feet/day	15	Median hydraulic conductivity calculated from well tests available on OWRD well logs in the Braided/Delta Fan Deposits (Qfd)
Anisotropy	K_h:K_v	dimensionless	10:1	Freeze and Cherry (1979)
Average Hydrogeologic Unit Thickness	b_{HGU}	feet	50	Minimum saturated unconsolidated sediment thickness above bedrock, based on OWRD well logs where bedrock was reached.
Average Depth to Groundwater	DTW	feet bgs	7.6	Average depth to groundnwater calculated using River Road/Santa Clara seasonal High Groundwater Estimates - Produced by Lane County PW GIS March 29, 2007
Average Saturated Thickness	b	feet	42.4	Calculated from hydrogeologic unit thickness and depth to water
Porosity	η	dimensionless	0.325 (Qfd Deposits)	Midrange of porosity for gravel in Freeze and Cherry (Table 2.4, pg. 37, 1979)
Effective Porosity	η_e	dimensionless	0.30	Craner (2006) for the Upper Sedimentary Unit
Specific Yield	S_y	dimensionless	0.30	Craner (2006) 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	varies	f_{oc} near UIC due to carbon loading from stormwater. See text for calculations and Table C-5
			0.001826	f_{oc} in native sediments, based on TOC measurements of unconsolidated sediments of the USA in Gresham, Oregon (GSI, 2012)

Note:
bgs = below ground surface
HGU = hydrogeologic unit
DTW = depth to groundwater
OWRD = Oregon Water Resources Department
EPA = Environmental Protection Agency
Qfd = Quaternary Braided Delta Fan Deposits
PW GIS = Public Works Geographic Information System
UIC = Underground Injection Control
USA = Unconsolidated Sedimentary Aquifer
TOC = Total Organic Carbon

Table C-3

Hydraulic Conductivity Estimates from Driller Specific Capacity Tests

Lane County

OWRD Well Log ID	Well Depth (ft)	Aquifer Thickness, b (ft)	Pumping Rate, Q (gpm)	Test Duration, t (hrs)	Drawdown, s (ft)	Hydraulic Conductivity, K (ft/day)
Meander/Floodplain Deposits (Qal)						
LANE1036	26	16	50	1	18	46
LANE4183	79	64	30	1	60	2
LANE11589	55	39	12	2	38	2
LANE11596	88	55	30	2	30	5
LANE12327	50	29	300	3	24	115
LANE1047	59	56	25	1	47	3
LANE11943	57	53	40	1	18	11
LANE11945	81	63	30	1	45	3
LANE51269	60	57	60	1	42	7
Braided/Delta Fan Deposits (Qfd)						
LANE1038	40	30	50	1	10	45
LANE11633	47	28	20	1	4	48
LANE11641	42	20	50	2	10	67
LANE11631	45	31	50	1	29	15
LANE11663	27	5	390	1	12	1,738
LANE3158	80	57	200	1	66	14
LANE11853	58	52	20	1	30	3
LANE11870	60	55	30	1	20	7
LANE11873	50	42	45	2	15	19
LANE11820	55	49	20	1	30	4
LANE64260	78	68	40	78	66	2
LANE11983	51	46	40	1	8	31
LANE11995	53	39	60	4	28	15
LANE12034	60	53	75	1	10	38
LANE12046	142	113	450	1	7	152
LANE12049	52	46	25	1	12	12
LANE5332	74	65	300	1	63	20
LANE10265	58	22	40	1	6	81
LANE5474	78	75	42	1	72	2
LANE12122	52	48	3,000	1	15	1,114
LANE12148	50	33	50	2	30	14
LANE56427	78	72	200	1	68	11
LANE57486	85	20	15	1	69	3
LANE5319	57	49	20	1	39	3
LANE12317	61	53	75	2	12	32
LANE61301	60	39	20	1	38	4

Notes: ft = feet, ft/day = feet per day, gpm = gallons per minute, hrs = hours

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Table C-4

Infiltration Volume and Rate

Lane County

Impervious Area in UIC Drainage Catchment (ft^2)	**Infiltration Time** (Annual Number of Hours with Precipitation ≥ 0.04 inches/hour [1]) (days)	**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)
20,000	334.0	13.92	2.22	39,501
40,000	334.0	13.92	2.22	79,002
60,000	334.0	13.92	2.22	118,504
80,000	334.0	13.92	2.22	158,005
100,000	334.0	13.92	2.22	197,506
120,000	334.0	13.92	2.22	237,007
140,000	334.0	13.92	2.22	276,508
160,000	334.0	13.92	2.22	316,010
180,000	334.0	13.92	2.22	355,511
200,000	334.0	13.92	2.22	395,012

Notes

(1) Based on precipitation records from the Eugene Airport. Value is based on precipitation data from 1999 to 2010. Values calculated using the geometric mean.

(2) Assumes an evaporative loss factor of 11%.

BASE MODEL

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Table C-5

Saturated Zone GWPD Carbon Loading Calculations

Lane County

Impervious Area (ft^2)	**UIC Type**	**Annual Infiltration Volume** [1] (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)	**Aquifer Volume** (cm^3)	**g TOC per cm^3/soil** (g/cm^3)	**Bulk Density** (g/cm^3)	f_{oc} (-)
20,000	Vertical UIC	1,118,549,555	5.40	10	1,000,000	60,402	152.3926	152.4	152.393	3,539,260	0.0171	1.79	0.00944
	Horizontal UIC	1,118,549,555	5.40	10	1,000,000	60,402	152.3926	1523.93	152.393	35,390,877	0.0017	1.79	0.00095
40,000	Vertical UIC	2,237,099,110	5.40	10	1,000,000	120,803	152.3926	152.4	152.393	3,539,260	0.0341	1.79	0.01871
	Horizontal UIC	2,237,099,110	5.40	10	1,000,000	120,803	152.3926	1523.93	152.393	35,390,877	0.0034	1.79	0.00190
60,000	Vertical UIC	3,355,648,666	5.40	10	1,000,000	181,205	152.4	152.4	152.4	3,539,088	0.0512	1.79	0.02781
	Horizontal UIC	3,355,648,666	5.40	10	1,000,000	181,205	152.3926	1523.93	152.393	35,390,877	0.0051	1.79	0.00285
80,000	Vertical UIC	4,474,198,221	5.40	10	1,000,000	241,607	152.4	152.4	152.4	3,539,088	0.0683	1.79	0.03674
	Horizontal UIC	4,474,198,221	5.40	10	1,000,000	241,607	152.3926	1523.93	152.393	35,390,877	0.0068	1.79	0.00380
100,000	Vertical UIC	5,592,747,776	5.40	10	1,000,000	302,008	152.4	152.4	152.4	3,539,088	0.0853	1.79	0.04550
	Horizontal UIC	5,592,747,776	5.40	10	1,000,000	302,008	152.3926	1523.93	152.393	35,390,877	0.0085	1.79	0.00474
120,000	Vertical UIC	6,711,297,331	5.40	10	1,000,000	362,410	152.4	152.4	152.4	3,539,088	0.1024	1.79	0.05411
	Horizontal UIC	6,711,297,331	5.40	10	1,000,000	362,410	152.3926	1523.93	152.393	35,390,877	0.0102	1.79	0.00569
140,000	Vertical UIC	7,829,846,887	5.40	10	1,000,000	422,812	152.4	152.4	152.4	3,539,088	0.1195	1.79	0.06257
	Horizontal UIC	7,829,846,887	5.40	10	1,000,000	422,812	152.3926	1523.93	152.393	35,390,877	0.0119	1.79	0.00663
160,000	Vertical UIC	8,948,396,442	5.40	10	1,000,000	483,213	152.4	152.4	152.4	3,539,088	0.1365	1.79	0.07087
	Horizontal UIC	8,948,396,442	5.40	10	1,000,000	483,213	152.3926	1523.93	152.393	35,390,877	0.0137	1.79	0.00757
180,000	Vertical UIC	10,066,945,997	5.40	10	1,000,000	543,615	152.4	152.4	152.4	3,539,088	0.1536	1.79	0.07903
	Horizontal UIC	10,066,945,997	5.40	10	1,000,000	543,615	152.3926	1523.93	152.393	35,390,877	0.0154	1.79	0.00851
200,000	Vertical UIC	11,185,495,552	5.40	10	1,000,000	604,017	152.4	152.4	152.4	3,539,088	0.1707	1.79	0.08705
	Horizontal UIC	11,185,495,552	5.40	10	1,000,000	604,017	152.3926	1523.93	152.393	35,390,877	0.0171	1.79	0.00944

Notes

(1) Calculations from Table 4 (equivalent to 22,489 ft^3/yr for a small catchment and 52,927 ft^3/yr for a large catchment)

mg/L = milligrams per liter

cm^3/yr = cubic centimeters per year

g = grams

cm = centimeters

g/cm^3 = grams per cubic centimeter

BASE MODEL

Table C-6

Pollutant Properties

Lane County

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	592	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	1,000,000	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) 7,850 (Near vertical UIC, reflects loading from stormwater) 804 (Near horizontal UIC, reflects loading from stormwater)	Calculated from the relationship: $K_d = (f_{oc})(K_{oc})$ (Watts, 1998)
			PCP	Native Sediments: 1.081 16.5 (Near vertical UIC, reflects loading from stormwater) 1.7 (Near horizontal UIC, reflects loading from stormwater)	Calculated from the relationship: $K_d = (f_{oc})(K_{oc})$ (Watts, 1998)
			DEHP	22.3 (Native Sediments) 339 (Near UIC, reflects loading from stormwater) 34.8 (Near horizontal UIC, reflects loading from stormwater)	Calculated from the relationship: $K_d = (f_{oc})(K_{oc})$ (Watts, 1998)
Retardation Factor	R	dimensionless	Lead	5,507,693	Calculated from the relationship: $R = 1 + (\rho_b)(K_d)/(\eta)$. Based on a bulk density (ρ_b) of 1.79 g/cm^3, calculated from porosity using equation 8.26 of Freeze and Cherry (1979).
			B(a)P	2,839 (Native Sediments) 43,220 (Near vertical UIC, reflects loading from stormwater) 4,430 (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 1.79 g/cm^3, calculated from porosity using equation 8.26 of Freeze and Cherry (1979).
			PCP	Native Sediments: 6.95 91.7 (Near vertical UIC, reflects loading from stormwater) 10.3 (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 1.79 g/cm^3, calculated from porosity using equation 8.26 of Freeze and Cherry (1979).
			DEHP	124 (Native Sediments) 1,870 (Near vertical UIC, reflects loading from stormwater) 192.5 (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 1.79 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	60	

Table C-7
Kd and Retardation Factors Near UICs
Lane County

Impervious Area	UIC Type	f_{oc} (dimensionless)	K_{oc} (L/Kg)	ρ_b (g/cm^3)	η (dimensionless)	K_d (L/Kg)	R (dimensionless)
20,000	Vertical	0.00944	592	1.79	0.325	5.6	31.8
20,000	Horizontal	0.00095	592	1.79	0.325	0.6	4.1
40,000	Vertical	0.01871	592	1.79	0.325	11.1	62.0
40,000	Horizontal	0.0019	592	1.79	0.325	1.1	7.2
60,000	Vertical	0.02781	592	1.79	0.325	16.5	91.7
60,000	Horizontal	0.00285	592	1.79	0.325	1.7	10.3
80,000	Vertical	0.03674	592	1.79	0.325	21.8	120.8
80,000	Horizontal	0.0038	592	1.79	0.325	2.2	13.4
100,000	Vertical	0.0455	592	1.79	0.325	26.9	149.4
100,000	Horizontal	0.00474	592	1.79	0.325	2.8	16.5
120,000	Vertical	0.05411	592	1.79	0.325	32.0	177.4
120,000	Horizontal	0.00569	592	1.79	0.325	3.4	19.6
140,000	Vertical	0.06257	592	1.79	0.325	37.0	205.0
140,000	Horizontal	0.00663	592	1.79	0.325	3.9	22.6
160,000	Vertical	0.07087	592	1.79	0.325	42.0	232.1
160,000	Horizontal	0.00757	592	1.79	0.325	4.5	25.7
180,000	Vertical	0.07903	592	1.79	0.325	46.8	258.7
180,000	Horizontal	0.00851	592	1.79	0.325	5.0	28.7
200,000	Vertical	0.08705	592	1.79	0.325	51.5	284.8
200,000	Horizontal	0.00944	592	1.79	0.325	5.6	31.8

Note:
L/Kg = Liters per kilogram
g/cm^3 = grams per cubic centimeter
f_{oc} = fraction organic carbon
K_{oc} = organic carbon partitioning coefficient
UIC = Underground Injection Control

ρ_b = bulk density
η = total porosity
K_d = distribution coefficient
R = Retardation Factor
BASE MODEL

GSI Water Solutions, Inc.

APPENDIX D

Conservative Assumptions for GWPD Modeling

The following conservative assumptions were used for modeling:

- In the model, pollutant concentrations are higher than what is typically observed in stormwater. For example, the concentration of PCP (the most mobile and persistent of the common stormwater pollutants) in the model is higher than any of the PCP concentrations observed during the City of Portland's seven years of Stormwater Discharge Monitoring (over 1,400 stormwater samples). The PCP concentration is also 10 times higher than the EPA Maximum Contaminant Level (MCL).
- The model does not include pre-treatment upstream of the UIC (e.g., attenuation caused by processes in the sedimentation manhole, vegetated facilities, etc.)
- The model does not take into account pollutant attenuation that occurs while in the UIC (i.e. through adsorption to sediment or organic matter in the UIC, or volatilization as water cascades into the UIC from the end-of-pipe) before entering the surrounding soil.
- The model uses very conservative parameters for estimating pollutant attenuation. For example, the first-order rate constant for PCP (which governs pollutant attenuation by microbial activity) is 10% of average literature values.
- Pollutant attenuation is a directional process that occurs in three dimensions. However, the unsaturated zone model simulates pollutant attenuation in only one dimension, which underestimates pollutant attenuation.
- At a typical vertical UIC, most stormwater is discharged horizontally through the weep holes in the sides of the UIC at up to 20 feet above the UIC bottom, and then migrates vertically downward. The models assume that stormwater only flows vertically downward from the bottom of the UIC, thereby underestimating the travel distance of stormwater through the unsaturated zone.
- In reality, stormwater flows are highly variable and short in duration resulting in varying water levels within the UIC depending on the infiltration capacity of the formation. Thus, the UIC periodically will fill with water and then drain during the wet season. The model assumes pollutant fate and transport occurs constantly for the time period during the wet season that the UIC likely contains water. This approach is conservative because it minimizes attenuation by microbial activity, and maximizes the infiltration that would be expected to reach the water table.
- Pollutant concentrations are assumed to be constant, while in reality they are variable throughout storm events. This likely over-predicts the concentration throughout the duration of a storm event.