GSI Water Solutions, Inc.

Technical Memorandum

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Date: **September 21, 2012**

Re: **Proposed Alternate Action Levels for the City of Gresham UIC WPCF Permit – DEHP, Antimony, and Zinc**

In 2011, GSI Water Solutions, Inc. (GSI) performed fate and transport modeling to support the City of Gresham's (City's) application for an Underground Injection Control (UIC) Water Pollution Control Facilities (WPCF) Permit. Based on the modeling, the City requested alternate Effluent Discharge Limits (EDLs) that would replace the default EDLs in the draft UIC WPCF permit (dated June 2011). The proposed Effluent Discharge Limits (EDLs) were approved by DEQ in a letter dated February 13, 2012. In the most recent draft UIC WPCF permit template (dated July 20, 2012) EDLs have been changed to Action Levels.

Following the release of the July 2012 draft permit template, The City requested additional modeling to develop alternate Action Levels for antimony, zinc, and DEHP based on the frequency of detections and on the concentrations observed in stormwater. The results of the additional modeling are presented in this memorandum. Additional model simulations used to develop alternate Action Levels for antimony, zinc and DEHP are provided in Attachment A. Model input variables, equations, and assumptions are presented in Attachment B in the technical memorandum titled *Pollutant Fate and Transport Model Results in Support of the City of Gresham UIC WPCF Permit – Proposed EDLs*, dated June 10, 2011 (June 2011 TM). The February 13, 2012, letter from DEQ that approved the alternate EDLs is provided in Attachment C. The following sections summarize the alternate Action Levels for DEHP, antimony and zinc based on additional model simulations.

Proposed Action Level for DEHP

DEHP has been detected in 59% of the 902 stormwater samples collected statewide (Kennedy/Jenks, 2009), and has exceeded the Action Level listed in the July 2012 draft permit template in four samples. Attachment A-1 shows the simulated DEHP concentrations immediately above the water table, given a 5-foot separation distance between the bottom of the UIC and groundwater, for three different initial DEHP concentrations entering the UIC, using the Fate and Transport Tool. The three initial concentrations (C_0) are:

Case 1. The Action Level listed in the July 2012 draft permit template, 60 micrograms per liter (ug/L),
Case 2. The maximum statewide detection, 264 ug/L (Kennedy/Jenks, 2009), and
Case 3. Five times the Action Level listed in the July 2012 draft permit template, 300 ug/L.

Each of these modeled DEHP concentrations falls within the literature range for the solubility of DEHP in water at 25 degrees Celsius. Montgomery and Welkom (1990) give a range for DEHP solubility of 41 ug/L and 400 ug/L. Concentrations of DEHP in environmental water samples often exceed reported solubility limits and may be attributable to DEHP adsorption to suspended solids in the samples, rather than true dissolved concentrations (ATSDR, 2002).

In each of the three concentration cases listed above, an Average Scenario and a Reasonable Maximum Scenario were modeled. The two scenarios differ in the following model variables:

- First-order rate constant (k),
- Half-life (h),
- Fraction organic carbon (f_{oc}),
- Distribution coefficient (K_d), and
- Pore water velocity (v).

The average and reasonable maximum scenarios, and each of the model variables is described in detail in the June 2011 TM (Attachment B), and the input values are shown in Attachment A-1. The results of the modeling show that all three initial concentrations result in DEHP concentrations at the water table many orders of magnitude lower than the typical method reporting limit (MRL) of 1 ug/L. At an initial concentration of 300 ug/L (Case 3) and a separation distance of five feet, under the reasonable maximum scenario, the resulting concentration immediately above the water table would be 8×10^{-13} ug/L. The result shows that an Action Level for DEHP of 300 ug/L would be conservatively protective of groundwater. Note that the model assumes that the 300 ug/L DEHP is dissolved in water. However, in water, DEHP is predominantly sorbed to suspended particulates and sediments (ASTDR, 2002). The VIRULO filtration modeling (EPA, 2002) conducted for bacteria-sized particulate matter showing protectiveness from bacteria at 5 feet of separation is also supportive of protectiveness at 5 feet of separation distance (GSI, July 2010) for the DEHP that is sorbed to particulates and sediments. <u>The model results show that an Action Level for DEHP of 300 ug/L would be conservatively protective of groundwater.</u>

Proposed Action Levels for Antimony and Zinc

Three initial UIC concentrations of antimony and zinc were modeled using the Fate and Transport Tool:

Case 1. The Action Levels listed in the July 2012 draft permit template for antimony and zinc (6 ug/L and 5,000 ug/L, respectively),

Case 2. The maximum statewide detections (7.5 ug/L and 8,100 ug/L; Kennedy/Jenks, 2009), and

Case 3. Ten times the Action Levels listed in the June 2012 Draft Permit Template (60 ug/L and 50,000 ug/L).

In each case, an Average Scenario and a Reasonable Maximum Scenario were modeled, with a transport time of 1,000 years. The two scenarios differ in the following model variables:

- Distribution coefficient (K_d) and
- Pore water velocity (v).

The average and reasonable maximum scenarios, and each of the model variables is described in detail in the June 2011 TM (Attachment B), and the input values are shown in Attachment A-2. Modeling fate and transport of antimony and zinc required empirically determining appropriate distribution coefficients for the two metals. As discussed in the June 2011 TM, the City's preliminary stormwater monitoring did not include dissolved metals, which are required for calculating site-specific distribution coefficients. Therefore, City of Portland stormwater concentrations (2005-2011) were used as surrogates for City of Gresham stormwater concentrations. The distributions of calculated K_d for antimony and zinc are shown in Figure 1. For antimony and zinc proposed Action Levels, the median K_d was used in the Average Scenario, and the tenth percentile K_d was used in the Reasonable Maximum Scenario.

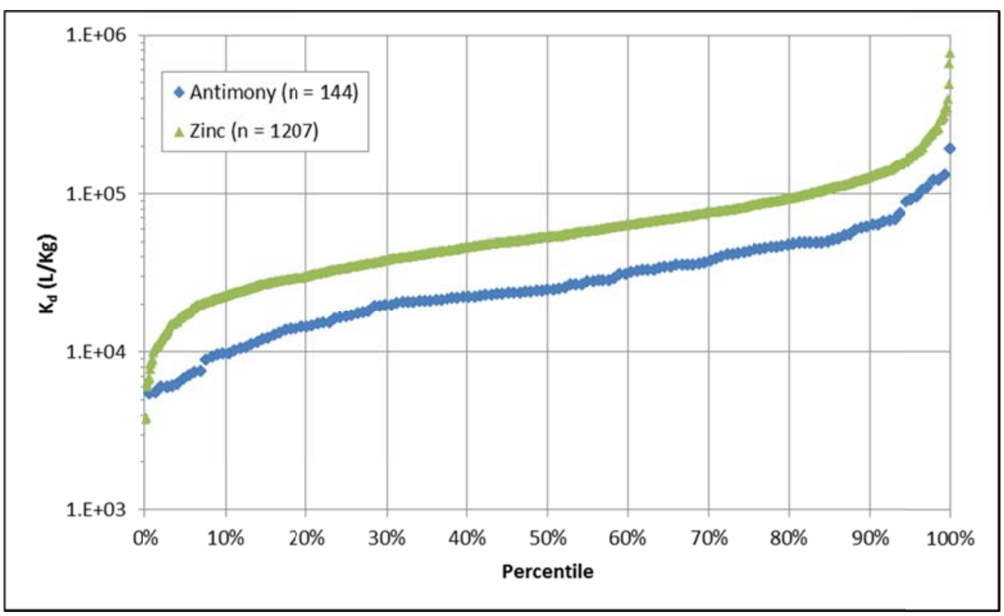

Figure 1. Calculated K_d distributions for antimony and zinc in Portland stormwater runoff.

The results of modeling fate and transport of antimony and zinc with three initial concentrations listed above demonstrate that all three initial concentrations result in metals concentrations at the water table that are several orders of magnitude lower than the typical detection limits.

As an additional comparison, the total time required for detection of antimony, zinc and lead at the water table was calculated. The antimony and zinc simulations assumed an initial concentration of ten times the Action Levels listed in the July 2012 draft permit template, and the lead simulation assumed an initial concentration equal to the Action Level listed in the July 2012 draft permit template (500 ug/L). The results of this comparison are shown in Table 1, and the model input values are shown in Attachment A-3. The shortest breakthrough time was 1,549 years for antimony, under the reasonable maximum scenario.

Table 1. Comparison of modeled breakthrough times for antimony, zinc and lead.

Pollutant	Separation Distance (feet)	Initial Concentration = Proposed Action Level (ug/L)	Typical MRL (ug/L)	Years to reach MRL immediately above the water table	
				Average Scenario	Reasonable Maximum Scenario
Antimony	5	60	0.1	**5,787**	**1,549**
Zinc	5	50,000	0.5	**7,911**	**2,309**
Lead	5	500	0.1	**196,440**	**46,062**

Antimony

Antimony has been detected in 63% of 534 stormwater samples collected statewide (Kennedy/Jenks, 2009), and has exceeded the Action Level in the July 2012 draft permit template in 21 samples. At an initial concentration of 60 ug/L (Case 3) and a separation distance of five feet, under the reasonable maximum scenario, the resulting modeled concentration immediately above the water table after 1,000 years of transport would be four orders of magnitude lower than the typical MRL. Under the same conditions, it would take 1,549 years for antimony to reach detectable concentrations immediately above the water table. The model results show that an Action Level for antimony of 60 ug/L would be conservatively protective of groundwater.

Zinc

Zinc has been detected in 98% of 1,923 stormwater samples collected statewide (Kennedy/Jenks, 2009), and has exceeded the Action Level in the July 2012 draft permit template in two samples. At an initial concentration of 50,000 ug/L (Case 3) and a separation distance of five feet, under the reasonable maximum scenario, the resulting modeled concentration immediately above the water table after 1,000 years of transport would be 12 orders of magnitude lower than the typical MRL. Under the same conditions, it would take 2,309 years for antimony to reach detectable concentrations immediately above the water table.

The model results show that an Action Level for zinc of 50,000 ug/L would be conservatively protective of groundwater.

Summary

An unsaturated zone Fate and Transport Tool was used to develop and propose alternate Action Levels for DEHP, antimony, and zinc. The results show that the proposed Action Levels listed below would be conservatively protective of groundwater:

- DEHP – 300 ug/L (five times the Action Level in the July 2012 draft permit template)[1]
- Antimony – 60 ug/L (ten times the Action Level in the July 2012 draft permit template)
- Zinc – 50,000 ug/L (ten times the Action Level in the July 2012 draft permit template)

The alternate Action Levels proposed in this memorandum are considered appropriate because (1) they are sufficiently high to capture the range of stormwater concentrations observed in Oregon, while being conservatively protective of groundwater, and (2) concentrations in excess of the alternate Action Levels may indicate potential sources of contamination, warranting further evaluation by the City.

[1] The alternate Action Level for DEHP was restricted to five times the July 2012 draft permit template Action Level to keep the Action Level within the published range of DEHP solubility in water.

References

ATSDR, 2002. *Toxicological profile for di(2-ethylhexyl)phthalate.* U.S. Department of Health and Human services, Public Health Service, Agency for toxic Substances and Disease Registry website: http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=65, retrieved July 25, 2012.

EPA, 2002. *Predicting Attenuation of Viruses during Percolation on Soils.* EPA/600/R-02/051b, August 2002.

GSI, 2011. *Pollutant Fate and Transport Model Results in Support of the City of Gresham UIC WPCF Permit – Proposed EDLs.* Technical Memorandum prepared by GSI Water Solutions, Inc. for City of Gresham. June 10, 2011.

GSI, 2010. *Fate and Transport Model Results for City of Gresham*. Prepared by GSI Water Solutions, Inc. for City of Gresham. July 13, 2010.

Kennedy/Jenks, 2009. *Compilation and Evaluation of Existing Stormwater Quality Data from Oregon.* Prepared by Kennedy/Jenks, Inc. for Oregon ACWA. December 16, 2009.

Montgomery, J.H. and L.M. Welkom, 1990. Groundwater Chemicals Desk Reference (second printing). Lewis Publishers, Inc., Chelsea, Michigan.

ATTACHMENT A

Risk Model Calculations

Attachment A-1. Concentrations of DEHP above the water table resulting from varying initial UIC concentrations.

City of Gresham, Oregon

	Parameter	Symbol	Units	di-(2-ethylhexyl)phthalate					
				July 2012 Draft Permit Template Action Level		**Maximum Detection**		**5 X July 2012 Draft Permit Template Action Level**	
				Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	1.524	1.524	1.524	1.524	1.524	1.524
		y	ft	5	5	5	5	5	5
	Concentration	C_0	mg/L	6.00E-02 [1]	6.00E-02 [1]	2.64E-01 [2]	2.64E-01 [2]	3.00E-01 [3]	3.00E-01 [3]
	Infiltration Time	t	d	14.24 [4]	14.24 [4]	14.24 [4]	14.24 [4]	14.24 [4]	14.24 [4]
Chemical Properties	First-Order Rate Constant	k	d^{-1}	1.50E-02 [5]	1.00E-02 [6]	1.50E-02 [5]	1.00E-02 [6]	1.50E-02 [5]	1.00E-02 [6]
	Half-Life	h	d	46.2 [7]	69.3 [7]	46.2 [7]	69.3 [7]	46.2 [7]	69.3 [7]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [8]	0.325 [8]	0.325 [8]	0.325 [8]	0.325 [8]	0.325 [8]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [9]	1.79 [9]	1.79 [9]	1.79 [9]	1.79 [9]	1.79 [9]
	Fraction Organic Carbon	f_{oc}	-	0.0072 [10]	0.0013 [10]	0.0072 [10]	0.0013 [10]	0.0072 [10]	0.0013 [10]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg	12,200 [11]	12,200 [11, 12]	12,200 [11]	12,200 [11, 12]	12,200 [11]	12,200 [11, 12]
	Distribution Coefficient	K_d	L/kg	87.8 [13]	16.4 [13]	87.8 [13]	16.4 [13]	87.8 [13]	16.4 [13]
	Pore Water Velocity	v	m/d	1.00 [14]	1.45 [15]	1.00 [14]	1.45 [15]	1.00 [14]	1.45 [15]
Calculations	Retardation Factor	R	-	484	91	484	91	484	91
	Dispersion Coefficient	D	m^2/d	7.62E-02	1.10E-01	7.62E-02	1.10E-01	7.62E-02	1.10E-01
	Normalized Dispersion	D'	m^2/d	1.57E-04	1.21E-03	1.57E-04	1.21E-03	1.57E-04	1.21E-03
	Normalized Velocity	v'	m/d	2.06E-03	1.59E-02	2.06E-03	1.59E-02	2.06E-03	1.59E-02
	Normalized Degradation	k'	d^{-1}	3.10E-05	1.10E-04	3.10E-05	1.10E-04	3.10E-05	1.10E-04
	A_1	-	-	-2.28E-02	-1.05E-02	-2.28E-02	-1.05E-02	-2.28E-02	-1.05E-02
	A_2	-	-	1.58E+01	4.94E+00	1.58E+01	4.94E+00	1.58E+01	4.94E+00
	e^{A1}	-	-	9.77E-01	9.90E-01	9.77E-01	9.90E-01	9.77E-01	9.90E-01
	$erfc(A_2)$	-	-	1.89E-110	2.96E-12	1.89E-110	2.96E-12	1.89E-110	2.96E-12
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01
	B_2	-	-	1.64E+01	6.66E+00	1.64E+01	6.66E+00	1.64E+01	6.66E+00
	e^{B1}	-	-	4.96E+08	4.90E+08	4.96E+08	4.90E+08	4.96E+08	4.90E+08
	$erfc(B_2)$	-	-	3.58E-119	4.46E-21	3.58E-119	4.46E-21	3.58E-119	4.46E-21
	Concentration Immediately Above Water Table	C	mg/L	1.E-111	2.E-13	5.E-111	7.E-13	5.E-111	8.E-13
MRL	Concentration	C	mg/L	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03

Attachment A-1. Concentrations of DEHP above the water table resulting from varying initial UIC concentrations.

City of Gresham, Oregon

NOTES

[1] Starting concentration equal to the July 2012 Draft Permit Template Action Level of 60 ug/L.

[2] Starting concentration equal to the maximum DEHP detected concentration (Kennedy/Jenks, 2009).

[3] Starting concentration equal to five times the July 2012 Draft Permit Template Action Level.

[4] Infiltration time is the number of days during the year that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate is equal to or exceeds 0.04 inches/hour. Precipitation data source is the Gresham Fire Department raingage located at 1333 NW Eastman Parkway in downtown Gresham, Oregon (HYDRA, 2010). Annual precipitation data from 1999 to 2009 were used in the analysis, and were averaged using the geometric mean.

[5] Median biodegradation rate from a review of scientific literature (see text for references).

[6] 25th percentile biodegradation rate from a review of scientific literature (see text for references).

[7] 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.

[8] Evarts and O'Conner (2008) identifies the Missoula Flood Deposits beneath Gresham as a "bouldery and cobbly gravel and sand." Therefore, typical porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.

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

[10] Estimate of f_{oc} based on loading of TOC in stormwater; see June 2011 TM for description.

[11] Calculated from the equation of Roy and Griffin (1985), which relates K_{oc} to water solubility and K_{ow}, as presented in Fetter (1994).

[12] 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 Koc calculated by Roy and Griffin (1985).

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

[14] The median hydraulic conductivity calculated using the pump-in method at 37 City of Gresham UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the June 2011 TM.

[15] The 95% UCL on the mean of hydraulic conductivity based on 37 pump-in tests at City of Gresham UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the June 2011 TM.

ABBREVIATIONS

d = days
DEHP = di-(2-ethylhexyl)phthalate
g/cm^3 = grams per cubic centimeter
m = meters
m/d = meters per day
m^2/d = square meters per day
mg/L = milligrams per liter
MRL = Method Reporting Limit
TOC = Total Organic Carbon
UCL = Upper Confidence Level
ug/L = micrograms per liter
UIC = Underground Injection Control

Attachment A-2. Concentrations of antimony and zinc above the water table resulting from varying initial UIC concentrations.
City of Gresham, Oregon

	Parameter	Symbol	Units	Antimony					
				July 2012 Draft Permit Template Action Level		Maximum Detection		10 X July 2012 Draft Permit Template Action Level	
				Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	1.524	1.524	1.524	1.524	1.524	1.524
		y	ft	5	5	5	5	5	5
	Concentration	C_0	mg/L	0.006 [1]	0.006 [1]	0.0075 [2]	0.0075 [2]	0.06 [3]	0.06 [3]
	Infiltration Time	t	d	14,240 [4]	14,240 [4]	14,240 [4]	14,240 [4]	14,240 [4]	14,240 [4]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [5]	0.325 [5]	0.325 [5]	0.325 [5]	0.325 [5]	0.325 [5]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [6]	1.79 [6]	1.79 [6]	1.79 [6]	1.79 [6]	1.79 [6]
	Distribution Coefficient	K_d	L/kg	24,927 [7]	9,675 [8]	24,927 [7]	9,675 [8]	24,927 [7]	9,675 [8]
	Pore Water Velocity	v	m/d	1.00 [9]	1.45 [10]	1.00 [9]	1.45 [10]	1.00 [9]	1.45 [10]
Calculations	Retardation Factor	R	-	137,195	53,251	137,195	53,251	137,195	53,251
	Dispersion Coefficient	D	m^2/d	7.62E-02	1.10E-01	7.62E-02	1.10E-01	7.62E-02	1.10E-01
	Normalized Dispersion	D'	m^2/d	5.55E-07	2.07E-06	5.55E-07	2.07E-06	5.55E-07	2.07E-06
	Normalized Velocity	v'	m/d	7.29E-06	2.72E-05	7.29E-06	2.72E-05	7.29E-06	2.72E-05
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	A_1	-	-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	A_2	-	-	7.98E+00	3.31E+00	7.98E+00	3.31E+00	7.98E+00	3.31E+00
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
	$erfc(A_2)$	-	-	1.44E-29	2.95E-06	1.44E-29	2.95E-06	1.44E-29	2.95E-06
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01
	B_2	-	-	9.15E+00	5.56E+00	9.15E+00	5.56E+00	9.15E+00	5.56E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.85E+08
	$erfc(B_2)$	-	-	2.59E-38	3.71E-15	2.59E-38	3.71E-15	2.59E-38	3.71E-15
	Concentration Immediately Above Water Table	C	mg/L	8.E-32	1.E-08	1.E-31	2.E-08	8.E-31	1.E-07
MRL	Concentration	C	mg/L	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04

Attachment A-2. Concentrations of antimony and zinc above the water table resulting from varying initial UIC concentrations.
City of Gresham, Oregon

	Parameter	Symbol	Units	Zinc					
				July 2012 Draft Permit Template Action Level		**Maximum Detection**		**10 X July 2012 Draft Permit Template Action Level**	
				Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	1.524	1.524	1.524	1.524	1.524	1.524
		y	ft	5	5	5	5	5	5
	Concentration	C_0	mg/L	5 [1]	5 [1]	8.1 [2]	8.1 [2]	50 [3]	50 [3]
	Infiltration Time	t	d	14,240 [4]	14,240 [4]	14,240 [4]	14,240 [4]	14,240 [4]	14,240 [4]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [5]	0.325 [5]	0.325 [5]	0.325 [5]	0.325 [5]	0.325 [5]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [6]	1.79 [6]	1.79 [6]	1.79 [6]	1.79 [6]	1.79 [6]
	Distribution Coefficient	K_d	L/kg	53,263 [7]	22,542 [8]	53,263 [7]	22,542 [8]	53,263 [7]	22,542 [8]
	Pore Water Velocity	v	m/d	1.00 [9]	1.45 [10]	1.00 [9]	1.45 [10]	1.00 [9]	1.45 [10]
Calculations	Retardation Factor	R	-	293,152	124,069	293,152	124,069	293,152	124,069
	Dispersion Coefficient	D	m^2/d	7.62E-02	1.10E-01	7.62E-02	1.10E-01	7.62E-02	1.10E-01
	Normalized Dispersion	D'	m^2/d	2.60E-07	8.91E-07	2.60E-07	8.91E-07	2.60E-07	8.91E-07
	Normalized Velocity	v'	m/d	3.41E-06	1.17E-05	3.41E-06	1.17E-05	3.41E-06	1.17E-05
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	A_1	-	-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	A_2	-	-	1.21E+01	6.03E+00	1.21E+01	6.03E+00	1.21E+01	6.03E+00
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
	$erfc(A_2)$	-	-	6.49E-66	1.54E-17	6.49E-66	1.54E-17	6.49E-66	1.54E-17
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01
	B_2	-	-	1.29E+01	7.51E+00	1.29E+01	7.51E+00	1.29E+01	7.51E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.85E+08
	$erfc(B_2)$	-	-	1.26E-74	2.55E-26	1.26E-74	2.55E-26	1.26E-74	2.55E-26
	Concentration Immediately Above Water Table	C	mg/L	3.E-65	7.E-17	5.E-65	1.E-16	3.E-64	7.E-16
MRL	Concentration	C	mg/L	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04

Attachment A-2. Concentrations of antimony and zinc above the water table resulting from varying initial UIC concentrations.

City of Gresham, Oregon

NOTES

[1] Starting concentration equal to the July 2012 Draft Permit Template Action Level.

[2] Starting concentration equal to the maximum detected concentration (Kennedy/Jenks, 2009).

[3] Starting concentration equal to ten times the July 2012 Draft Permit Template Action Level.

[4] Infiltration time is based on 1000 years of metals transport @ 14.24 days per year. (1000 years * 14.24 days per year = 14,240 days of transport).

[5] Evarts and O'Conner (2008) identifies the Missoula Flood Deposits beneath Gresham as a "bouldery and cobbly gravel and sand." Therefore, typical porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.

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

[7] Median K_d, calculated using City of Portland stormwater data.

[8] 10th percentile of K_d, calculated using City of Portland stormwater data.

[9] The median hydraulic conductivity calculated using the pump-in method at 37 City of Gresham UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the June 2011 TM.

[10] The 95% UCL on the mean of hydraulic conductivity based on 37 pump-in tests at City of Gresham UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the June 2011 TM.

ABBREVIATIONS

d = days
g/cm^3 = grams per cubic centimeter
m = meters
m/d = meters per day
m^2/d = square meters per day
mg/L = milligrams per liter
MRL = Method Reporting Limit
UCL = Upper Confidence Level
UIC = Underground Injection Control

Attachment A-3. Total travel time for detections at the water table, given initial UIC concentrations equal to proposed EDLs.

City of Gresham

	Parameter	Symbol	Units	Antimony		Zinc		Lead	
				10 X July 2012 Draft Permit Template Action Level		10 X July 2012 Draft Permit Template Action Level		July 2012 Draft Permit Template Action Level	
				Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	1.524	1.524	1.524	1.524	1.524	1.524
		y	ft	5	5	5	5	5	5
	Concentration	C_0	mg/L	0.06 [1]	0.06 [1]	50 [1]	50 [1]	0.5 [2]	0.5 [2]
	Infiltration Time	t	d	82,408 [3]	22,059 [3]	112,648 [3]	32,879 [3]	2,797,309 [3]	655,920 [3]
	Total Time		y	5,787 [4]	1,549 [4]	7,911 [4]	2,309 [4]	196,440 [4]	46,062 [4]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [5]	0.325 [5]	0.325 [5]	0.325 [5]	0.325 [5]	0.325 [5]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [6]	1.79 [6]	1.79 [6]	1.79 [6]	1.79 [6]	1.79 [6]
	Distribution Coefficient	K_d	L/kg	24,927 [7]	9,675 [8]	53,263 [7]	22,542 [8]	1,000,000 [7]	340,000 [8]
	Pore Water Velocity	v	m/d	1.00 [9]	1.45 [10]	1.00 [9]	1.45 [10]	1.00 [9]	1.45 [10]
Calculations	Retardation Factor	R	-	137,195	53,251	293,152	124,069	5,503,847	1,871,309
	Dispersion Coefficient	D	m^2/d	7.62E-02	1.10E-01	7.62E-02	1.10E-01	7.62E-02	1.10E-01
	Normalized Dispersion	D'	m^2/d	5.55E-07	2.07E-06	2.60E-07	8.91E-07	1.38E-08	5.90E-08
	Normalized Velocity	v'	m/d	7.29E-06	2.72E-05	3.41E-06	1.17E-05	1.82E-07	7.75E-07
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	A_1	-	-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	A_2	-	-	2.16E+00	2.16E+00	3.33E+00	3.33E+00	2.58E+00	2.58E+00
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
	$erfc(A_2)$	-	-	2.27E-03	2.27E-03	2.48E-06	2.48E-06	2.63E-04	2.63E-04
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01
	B_2	-	-	4.97E+00	4.97E+00	5.58E+00	5.58E+00	5.16E+00	5.16E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.85E+08
	$erfc(B_2)$	-	-	2.18E-12	2.18E-12	3.13E-15	3.13E-15	2.83E-13	2.83E-13
	Concentration Immediately Above Water Table	C	mg/L	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
MRL	Concentration	C	mg/L	1.00E-04	1.00E-04	5.00E-04	5.00E-04	1.00E-04	1.00E-04

Attachment A-3. Total travel time for detections at the water table, given initial UIC concentrations equal to proposed EDLs.

City of Gresham

NOTES

[1] Starting concentration equal to the July 2012 Draft Permit Template Action Level.

[2] Starting concentration equal to ten times the July 2012 Draft Permit Template Action Level.

[3] Infiltration time is the number of days during the year that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate is equal to or exceeds 0.04 inches/hour. Precipitation data source is the Gresham Fire Department raingage located at 1333 NW Eastman Parkway in downtown Gresham, Oregon (HYDRA, 2010). Annual precipitation data from 1999 to 2009 were used in the analysis, and were averaged using the geometric mean, yielding 14.24 infiltration days per year.

[4] Total time in years is based on infiltration time at 14.24 days per year. (Total Time = Infiltration Time / 14.24)

[5] Evarts and O'Conner (2008) identifies the Missoula Flood Deposits beneath Gresham as a "bouldery and cobbly gravel and sand." Therefore, typical porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.

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[7] Median K_d, calculated using City of Portland stormwater data.

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UCL = Upper Confidence Level
UIC = Underground Injection Control
y = years

ATTACHMENT B

***Pollutant Fate and Transport Model Results in Support of the City of Gresham UIC WPCF Permit—Proposed EDLs*, June 2011**

Water Solutions, Inc.

June 10, 2011

Ms. Lynne Kennedy
City of Gresham Department of Environmental Services
1333 NW Eastman Parkway
Gresham, Oregon 97030

Dear Ms. Kennedy,

Enclosed with this letter, please find a technical memorandum documenting pollutant fate and transport modeling that will be used to support the City of Gresham's application for an Underground Injection Control (UIC) Water Pollution Control Facility (WPCF) Permit from the Department of Environmental Quality (DEQ). The objectives of the modeling were to:

- Develop proposed Effluent Discharge Limits (EDLs) for vertical separation distances of 10 feet that are protective of groundwater quality in accordance with Oregon Administrative Rules (OAR) 340 – 040. We recommend that these proposed EDLs replace the EDLs currently in the DEQ UIC WPCF Municipal Permit template.

- Determine the distance that pollutants would be transported in groundwater if pollutant breakthrough above background were to occur using the Environmental Protection Agency (EPA) BIOSCREEN saturated fate and transport model.

The proposed EDLs are discussed in Section 3.0 of the technical memorandum, and are summarized in the table below. The proposed EDLs were developed using the average transport scenario, and are limited to a maximum of 10 times the current EDL in the permit template, or about 0.05% of the pollutant's solubility in groundwater (naphthalene only, which does not have an EDL in the UIC WPCF Permit Template). While the fate and transport model

Alternate EDLs (UICs ≥ 10 feet vertical separation distance)
City of Gresham, Oregon

Pollutant	MRL (µg/L)	DEQ Municipal UIC WPCF Permit Template EDL (µg/L)	Proposed EDL (µg/L)	Output Concentration (µg/L)
Naphthalene	0.0192	0.1400	10.0000	0.0000
PCP	0.040	1.000	10.000	0.000
DEHP	0.962	6.000	60.000	0.000
2,4-D	0.100	70.000	4.140	0.100
Toluene	0.50	1,000.0	9.6	0.50

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results indicate that naphthalene concentrations as high as 20,000 micrograms per liter (ug/L) will not reach the groundwater table, the proposed EDL for naphthalene is 10 micrograms per liter (µg/L). This represents about 0.05% of the solubility, which is well below the 1% solubility rule of thumb that suggests the presence of non-aqueous phase liquid.

Modeling using the EPA's BIOSCREEN groundwater fate and transport model is discussed in section 4.0 of the technical memorandum. BIOSCREEN modeling was performed for pentachlorophenol (PCP), naphthalene, 2,4-D, and toluene because these pollutants required over ten feet of transport to attenuate below background levels under certain overly-conservative transport scenarios (i.e., to attenuate to below the method reporting limit under the reasonable maximum/worst case transport scenario). The BIOSCREEN model results indicate that if pollutant breakthrough occurs at the water table, pollutants will travel only a few feet from the UIC.

If you have any questions, or need additional information, please do not hesitate to call me at (503) 239 – 8799 ext. 107.

Sincerely,

Heidi Blischke

Heidi Blischke, RG

Matthew Kohlbecker

Matthew Kohlbecker, RG

Attachments:

Technical Memorandum: "Pollutant Fate and Transport Model Results in Support of the City of Gresham WPCF Permit"

Technical Memorandum

To: Lynne Kennedy/City of Gresham
Torrey Lindbo /City of Gresham

From: Heidi Blischke, RG/GSI Water Solutions, Inc.
Matt Kohlbecker, RG/GSI Water Solutions, Inc.
Rachael Peavler/GSI Water Solutions, Inc.

Date: **June 10, 2011**

Re: **Pollutant Fate and Transport Model Results in Support of the City of Gresham UIC WPCF Permit – Proposed EDLs**

Executive Summary

GSI Water Solutions, Inc. (GSI) performed fate and transport modeling to support the City of Gresham's (City) application for a an Underground Injection Control (UIC) Water Pollution Control Facilities (WPCF) Permit. The objectives of the model simulations were to 1) develop proposed Effluent Discharge Limits (EDLs) and 2) evaluate fate and transport of pollutants in groundwater. Two models [an existing unsaturated zone fate and transport model (i.e., Fate and Transport Tool) and Environmental Protection Agency's (EPA) BIOSCREEN model] were used to achieve the objectives.

The Fate and Transport tool uses a one-dimensional pollutant fate and transport equation [Advection Dispersion Equation (ADE)] to estimate the magnitude of pollutant attenuation during transport through the unsaturated zone. This constant source ADE incorporates sorption, degradation (biotic and abiotic), and dispersion to estimate pollutant concentration at the water table. Two scenarios were evaluated using the Fate and Transport Tool: 1) the average scenario, which is represented by the central tendency or expected mean value of the parameter and 2) the reasonable maximum scenario, which is represented by the upper bound or highest value that could potentially occur.

Proposed EDLs were developed for pentachlorophenol (PCP); di(2-ethylhexyl)phthalate (DEHP); 2,4-D; and toluene; all of which have EDLs in the draft municipal permit template. In addition, a proposed EDL was developed for naphthalene (which does not have an EDL in the draft UIC WPCF template) because naphthalene is detected in 74% of City of Gresham storm water samples collected during 2009 - 2010, and the reasonable maximum scenario indicated a

slight possibility that naphthalene could reach groundwater at detectable concentrations. Proposed EDLs were based on the average scenario of the Fate and Transport Tool, which DEQ considers the most reasonably likely scenario and the basis for regulatory decision-making, and a 10-foot separation distance between the bottom of the UIC and seasonal high groundwater. The proposed EDLs were developed based on the assumption that groundwater is protected when pollutant concentrations just above the water table are below the method reporting limit (MRL). Proposed EDLs were limited to a maximum of 10 times the EDL in the draft UIC WPCF permit template (PCP; DEHP; 2,4-D; toluene) or about 0.05% of the solubility of the pollutant in water (naphthalene, which does not have an EDL). For naphthalene, fate and transport modeling shows that concentrations as high as the solubility (20 mg/L) will attenuate prior to reaching the water table with a 10-foot separation distance; however, 1% of the solubility is suggestive of the presence of free phase hydrocarbons. Therefore, to be conservative and protective, while proposing a concentration that is reasonably achievable in municipal stormwater, a value of about 0.05% of the solubility of naphthalene is proposed. Results from the Fate and Transport Tool indicate that acceptable proposed EDLs for PCP and DEHP are greater than 10 times the EDL listed in the draft UIC WPCF template. However, conservatively, 10 times the EDL listed in the draft UIC WPCF template is proposed as the alternate EDL. The proposed EDLs for 2,4-D and toluene are less than the EDL in the draft UIC WPCF template (2,4-D and toluene proposed EDLs are 4.14 and 9.0 micrograms per liter, respectively) because these pollutants are more mobile.

In addition, fate and transport modeling in the saturated zone was conducted using the EPA's BIOSCREEN model to evaluate pollutant travel distances in groundwater. Under the reasonable maximum scenario of the Fate and Transport Tool, which is considered overly-conservative and to be used as a gage of model sensitivity, PCP, naphthalene, 2,4-D, and toluene require over 10 feet of separation distance to attenuate below MRLs. As such, fate and transport of these pollutants in groundwater were evaluated using the EPA's BIOSCREEN model, an analytical one-dimensional pollutant fate and transport model that simulates pollutant attenuation by dispersion, biodegradation, and retardation under saturated conditions. Two BIOSCREEN simulations were performed for each pollutant: one representing an average transport scenario and the other representing a reasonable maximum transport scenario. Results from the BIOSCREEN simulations indicate that pollutants travel less than 2.5 feet (average scenario) and 8 feet (reasonable maximum scenario) from the UIC. The estimated transport distances in groundwater are shown in Table 19.

1.0 Introduction

This technical memorandum (TM) presents the technical methodology used to evaluate the fate and transport of select stormwater pollutants in the saturated and unsaturated zone. GSI used the Fate and Transport Tool and the BIOSCREEN model, modified specifically for the geologic and stormwater pollutant conditions in Gresham, to determine proposed EDLs that are protective of groundwater and to determine transport distances in groundwater needed for pollutants to reach background concentrations (i.e., the MRL).

The City has applied for a UIC WPCF permit from DEQ. DEQ has agreed that the Fate and Transport Tool is appropriate for use as a basis for recommending alternate EDLs as a part of the UIC WPCF permit application. In addition, DEQ suggested model simulations using the EPA's BIOSCREEN model for saturated zone fate and transport are appropriate to determine the distance that pollutants would migrate in groundwater if pollutant breakthrough were to occur. Both the Fate and Transport Tool and the BIOSCREEN simulation results are to be submitted by the City in support of its UIC WPCF permit application.

1.1 Objectives

The Fate and Transport Tool is useful for risk assessment purposes, and the average transport scenario is considered to represent likely conditions upon which regulatory decisions may be based.

The objectives of this TM are:

- Develop proposed EDLs for vertical separation distances of 10 feet that are protective of groundwater quality in accordance with Oregon Administrative Rules (OAR) 340-040.
- Under the reasonable maximum scenario, determine the distance that pollutants would be transported in groundwater if pollutant breakthrough were to occur above background concentrations.

1.2 UIC Conceptual Model

UICs are used to manage stormwater by infiltrating precipitation (e.g., stormwater runoff) into the ground. For many areas in Gresham, UICs are the only form of stormwater disposal available. Infiltration of stormwater into the ground maintains aquifer recharge in an urbanized area. The conceptual site model for stormwater infiltration fate and transport calculations is shown schematically in Figure 1.

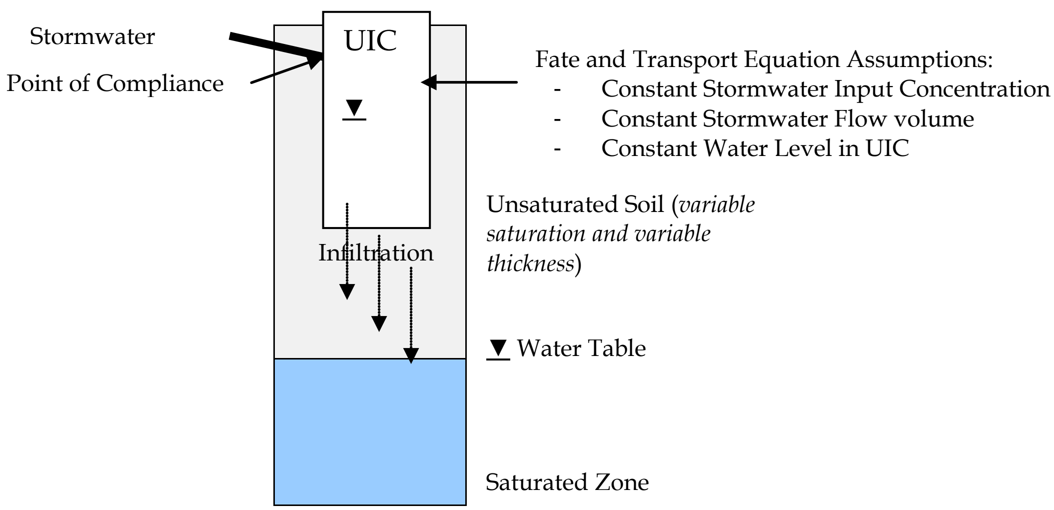


Figure 1. Conceptual model.
City of Gresham, Oregon

A typical City-owned UIC system consists of a stormwater inlet (e.g., catch basin) and the UIC. Most City-owned UICs are generally 4 feet in diameter and range in depth from about 20 feet to 25 feet. In accordance with the draft UIC WPCF permit template, the compliance point for effluent discharge limits is the end-of-pipe (EOP), where stormwater is discharged into the UIC.

As shown in Figure 1, stormwater discharges into the UIC, infiltrates through the unsaturated zone, 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 (for modeling purposes, the duration of the rainy season is estimated to be 7 months). 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, and retardation. Therefore, pollutant concentrations in the vadose zone beneath the UIC are lower than pollutant concentrations measured at the stormwater inlet.

1.3 Technical Memorandum Organization

This TM is organized as follows:

- **Section 1: Introduction**. Outlines the TM's objectives, and discusses the conceptual model for stormwater infiltration fate and transport calculations.
- **Section 2: Unsaturated Zone Fate and Transport Tool.** Describes the Fate and Transport Tool, including fate and transport processes, rationale for choosing pollutants, governing equations, justification for the input parameters, and results from the average and reasonable maximum scenarios of the Fate and Transport Tool.
- **Section 3: Development of Proposed EDLs.** Summarizes the results of the fate and transport modeling in the unsaturated zone with respect to developing proposed EDLs.
- **Section 4: BIOSCREEN Modeling in the Saturated Zone**. Describes how BIOSCREEN was used to determine the distance that pollutants would migrate in groundwater if pollutant breakthrough were to occur; presents justification for the input parameters; and summarizes the results of the modeling.
- **References**

2 Unsaturated Zone Fate and Transport Tool

This section describes the fate and transport processes, rationale for pollutant selection, equations, and input parameters used in the Fate and Transport Tool.

2.1 Conceptual Site Model of UIC Stormwater Infiltration and Pollutant Fate and Transport in Unsaturated Soils

The stormwater EDLs proposed in the draft UIC WPCF permit template are based on Oregon groundwater protection standards (measured in groundwater), federal drinking water standards (measured in drinking water), and other health-based limits. Compliance with EDLs is based on pollutant concentrations detected at the point stormwater enters the top of the UIC (i.e., EOP) and for most pollutants, with the exception of lead, does not account for the treatment/removal (i.e., attenuation) of pollutants by subsurface soils between the point of discharge and seasonal high groundwater. The Fate and Transport Tool approach was developed to estimate pollutant attenuation during transport through the unsaturated zone (i.e., soils above the water table and below the UIC) before reaching groundwater.

Stormwater discharge to a UIC infiltrates into the unsaturated zone and is transported downward by matric forces that hold the water close to mineral grain surfaces. The conceptual site model for stormwater infiltration is shown schematically in Figure 1.

Pollutants are attenuated during transport through the unsaturated zone by:

- **Volatilization.** Volatilization is pollutant attenuation by transfer from the dissolved phase to the vapor phase. Because soil pores 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 the Henry's constant for PCP is low (i.e., 2.44×10^{-8} atm-m^3/mol) and volatilization is not significant at depths below most UIC bottoms (i.e., 25 feet), volatilization is not included for any of the pollutants included in the Fate and Transport Tool (USEPA, 2001).

- **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 soil molecule's surface. Adsorption is a function of f_{oc} (fraction organic compound) and K_{oc} (organic carbon partitioning coefficient). The model ignores adsorption to mineral soils and only considers sorption to organic carbon.

- **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. Degradation is described by a first-order decay constant.

- **Dispersion.** Dispersion describes pollutant attenuation that results from pore water mixing. Dispersion is described by the dispersion coefficient, which is a function of pore water velocity and distance traveled by the contaminant.

2.2 Gresham Geology

Data about shallow geology in the Gresham vicinity were obtained from the Oregon Department of Geology and Mineral Industries (DOGAMI), Oregon Geologic Data Compilation (DOGAMI, 2010). Shallow geology in the Gresham vicinity consists of highly permeable catastrophic flood deposits (Qmf) underlain by cemented gravel of the Troutdale Formation (Madin, 1990), and is described below:

- **Missoula Flood Deposits (Qmf).** Gravel with silt and coarse sand matrix. Gravel size ranges from pebbles to boulders.
- **Troutdale Gravel (QTg).** Cemented gravel with sand and silt matrix. Gravel size ranges from pebbles to boulders.

The Missoula Flood Deposits are equivalent to the Unconsolidated Gravel Aquifer (UGA) or Unconsolidated Sand Aquifer (USA), and the cemented gravels of the Troutdale Gravel are equivalent to the Troutdale Gravel Aquifer (TGA) (USGS 1996a; USGS 1996b; USGS, 1998). Figure 2, which is presented at the end of this TM, presents a Gresham geologic map showing UIC locations.

2.3 Pollutant Selection

Stormwater pollutants for evaluation were developed based on chemical toxicity, frequency of detection, and mobility and persistence in the environment. This is the same process and resulted in selection of the similar chemicals as were modeled for the City of Portland. Chemicals were selected to represent each of the following broad chemical categories: volatile organic compounds (VOC), semivolatile organic compounds (SVOC), pesticides/herbicides, metals, and polycyclic aromatic hydrocarbons (PAH).

The following process was used to rank chemicals according to toxicity, mobility, persistence, and frequency of detection:

1. All chemicals were assigned a toxicity category based on maximum contaminant levels (MCL), where available. Where MCLs were not available, the EPA Preliminary Remediation Goal (PRG) was used. Lower values correspond to higher toxicity. Chemical toxicity was ranked as:

    - High (MCL<10)
    - Medium (MCL 10 to 100)
    - Low (MCL >100)

2. All chemicals were assigned a mobility category based on their EPA groundwater mobility ranking value (for liquid, non-karst). Values were obtained from EPA's Superfund Chemical Data Matrix Methodology, Appendix A (USEPA, 2004). In the absence of an EPA mobility ranking value, mobility categories were assumed on the basis of the chemicals' solubility and partition coefficient using professional judgment. Chemical mobility was ranked as:

    - High (EPA mobility ranking of 1.0)
    - Medium (EPA mobility ranking of 0.01)
    - Low (EPA mobility ranking of <0.01)

    Solubility also was considered when assigning chemicals to mobility categories. Use of EPA mobility ranking and solubility resulted in chemicals being assigned to the same mobility category.

3. All chemicals were evaluated on the basis of their persistence in the environment. Persistence represents the residence time a chemical remains in the system. This is best evaluated through degradation rates because speciation and availability can be reversible. Persistence was ranked on the basis of the chemical half-lives. Chemical half-lives were taken from Canadian Environmental Modeling Center Report No. 200104, as follows:

    - Low (0 to 49 days)
    - Medium (50 to 499 days)
    - High (500 days and greater)
    - Infinite (does not degrade)

4. All chemicals were evaluated with respect to frequency of detection, as determined by the frequency of detection during the Gresham winter 2009 – 2010 stormwater sampling event. Frequency of detection was ranked as:

    - High (75 to 100 percent)
    - Medium (21 to 74 percent)
    - Low (<20 percent)

The information used to assign these categories for each chemical and their resulting ranking by characteristic are included in Table 1, which is presented at the end of this TM.

As noted previously, chemicals were selected by the ranking criteria described above. However, chemicals were included in each of the five broad chemical categories: VOCs, SVOCs, metals, PAHs, and pesticides/herbicides. For each of the five chemical categories, the following characteristics were considered in the following order:

1. Frequency of detection (Chemicals in the "low" category were not considered further, except in the case of VOCs, which all were in the "low" category.)
2. Mobility (Chemicals in the "low" category were not considered further, with the exception of PAHs, which all have low mobility.)
3. Persistence
4. Toxicity

In the event that multiple chemicals had similar scores, chemicals from the common pollutant list were selected instead of chemicals from the priority pollutant list.

Based on the process described above, the following representative chemicals were selected for analysis in the Fate and Transport Tool:

1. VOCs: Toluene
2. SVOCs: Pentachlorophenol and di(2-ethylhexyl)phthalate
3. PAHs: Benzo(a)pyrene and naphthalene
4. Metals: Copper and lead
5. Pesticides/herbicides: 2,4-D

Selection of representative chemicals for the five chemical categories was fairly straightforward, with the exception of the PAHs. Many PAHs have a high frequency of detection and toxicity, but low mobility. Benzo(a)pyrene was selected because it is the only PAH on the common pollutant list. Naphthalene, which is less toxic than benzo(a)pyrene, also was selected because it represents a low molecular weight PAH which is more mobile and therefore has a higher detection frequency than benzo(a)pyrene.

2.4 Data Collection

Based on the pollutants selected using the criteria in section 2.3, City of Gresham staff collected 62 stormwater samples at 60 UICs during the 2009-10 wet season. Sampling locations were collected using the Generalized Random Tessellation Stratified (GRTS) survey design, which is a spatially balanced and random sampling approach that was stratified by traffic patterns (greater than and less than 1000 vehicle trips per day). During sample collection, one sample was collected shortly after oil was illegally dumped into a catch basin. The City notified DEQ and the UIC was cleaned. Data collected at this site was considered to be atypical; the site was resampled and the oily sample was removed from the data utilized in the calculations for this report.

2.5 Governing Equation

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 ADE incorporates sorption, degradation (biotic and abiotic), and dispersion to estimate pollutant concentration at the water table (e.g., Watts, 1998). This equation is provided below:

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

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 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 (1) 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. Because the separation distances that are being evaluated are both short and long, this TM uses the exact solution to the ADE for the Fate and Transport Tool.

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 discharge 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 that 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 above assumptions provide a conservative evaluation of pollutant fate and transport for the following reasons:

- Modern UICs are constructed with a solid concrete bottom so stormwater is discharged horizontally through the sides of the UIC at up to 20 feet above the bottom of the UIC and then migrates vertically downward. Thus, the assumption that stormwater flows vertically downward from the base of the UIC underestimates the travel distance of stormwater in the unsaturated zone.
- Stormwater flow from the UIC is assumed to be constant with a uniform flow through the unsaturated zone, while 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. This will cause variable flow from the UIC. It is not feasible to simulate complex cycles of filling and drainage for each UIC. Thus, the simplified approach is implemented in which the analytical solution is used to predict concentrations at a time corresponding to the period over which the UIC likely contains water. This approach is conservative because it predicts the maximum infiltration that would be expected at the water table sustained for the period during which the UIC contains water.

- 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. In addition, the Fate and Transport Tool 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) before entering the surrounding soil.

The following sections discuss calculation of the retardation factor, dispersion coefficient, and average linear groundwater velocity.

Retardation Factor

The retardation factor, *R*, is estimated by the following equation (Freeze and Cherry, 1979):

$$R = 1 + \frac{(\rho_b)(K_{oc})(f_{oc})}{\eta} \tag{2}$$

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).

Dispersion Coefficient

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

$$D = \alpha_L v \tag{3}$$

where:

v is average linear groundwater velocity (L/T), and
α_L 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):

$$\alpha_L \leq \frac{L}{10} \tag{4}$$

where:

L is the length scale of transport (i.e., separation distance) (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 (4) (Gehlar et al., 1985):

$$\frac{L}{10} \leq \alpha_L \leq \frac{L}{100} \tag{5}$$

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

Vertical Groundwater Velocity

Vertical groundwater velocity in the unsaturated zone is calculated by Darcy's Law (Stephens, 1996):

$$q_y = -K_u \left(\frac{\partial \psi}{\partial y} + \frac{\partial y}{\partial y} \right) \qquad (6)$$

where:

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

In the unsaturated zone, $\left(\frac{\partial y}{\partial y} \right)$ = 1. When the unsaturated zone is stratified and pressure head is averaged over many layers (which is the case in the Qmf flood deposits), $\left(\frac{\partial \psi}{\partial y} \right)$ = 0. Under these conditions, equation (6) reduces to (Stephens, 1996):

$$q_y = -K_u \qquad (7)$$

According to Stephens (1996), the velocity in Equation (7) (called the Darcy flux) should be used to calculate recharge in the unsaturated zone.

2.6 Input Parameters

The Fate and Transport Tool uses available local geology and hydrogeology information. Physical and chemical properties of unsaturated zone soils and pollutants are obtained from selected references and available regulatory guidance, as noted below. Parameter values were chosen to characterize the average and reasonable maximum scenarios. The average scenario parameter values represent the central tendency or expected mean value of the parameter and the reasonable maximum scenario parameter values represent the plausible upper bound or highest value reasonably expected to occur.

The magnitude of pollutant attenuation during transport through the unsaturated zone is controlled by physical and chemical properties of unsaturated zone soil and pollutant, including:

1. **Pore Water Velocity, v.** Pore water velocity is the rate that water moves downward through the unsaturated zone, and is directly proportional to soil moisture content.
2. **Porosity, η.** Porosity is the percent of pore space in soil.
3. **Soil Moisture Content, Θ.** Soil moisture content is the percent of water in soil, and is equal to or less than porosity.
4. **Soil Bulk Density, ρ_b.** Soil bulk density is the density of soil, including soil particles and pore space.
5. **Fraction Organic Carbon, f_{oc}.** Fraction organic carbon is a dimensionless measure of the quantity of organic carbon in soil (i.e., g_{carbon} / g_{soil}), and is used to estimate the capacity of a soil to adsorb pollutants.
6. **Organic Carbon Partitioning Coefficient, K_{oc}.** The organic carbon partitioning coefficient is defined for the pollutant, and specifies the degree to which it will partition between the organic carbon and water phases. In the case of PCP, this parameter is also pH-specific.
7. **Distribution Coefficient, K_d.** The distribution of metals between solid (sorbed to solids or organic materials) and dissolved phases.
8. **Hydraulic Conductivity, K.** Hydraulic conductivity is a proportionality constant that, under unsaturated conditions, is equivalent to groundwater velocity
9. **Degradation Rate Constant, k (Biodegradation Rate).** Microbial process by which organic compounds are broken down into other substances. Degradation rate is a chemical-specific, first-order rate constant, and depends on whether the unsaturated zone is aerobic or anaerobic. Metals (copper and lead) are elements and therefore do not undergo degradation.
10. **Infiltration Time.** Length of time during the year that rainfall occurs and causes runoff into a UIC.

2.6.1 Pore Water Velocity

Of the ten parameters listed above, the most important in fate and transport analysis is average linear groundwater velocity (pore water velocity) in the unsaturated zone. Because estimates of unsaturated zone groundwater velocity are not available for the unsaturated zone in Gresham, unsaturated zone groundwater velocity was estimated using the hydraulic conductivity from pump-in tests conducted on Gresham's UICs. Input parameters are described in detail below.

2.6.2 Total Porosity

Total porosity (η) is the percent of pore space in a material. Porosities are correlated with material type; therefore, porosities of the Missoula Flood Deposits (Qmf) were estimated from references. A typical total porosity of the Qmf (i.e., gravels) is 0.325 (Freeze and Cherry, pg. 37, 1979).

2.6.3 Soil Moisture Content

Soil moisture content is the percent of water in soil, and is equal to or less than porosity.

2.6.4 Soil Bulk Density

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

$$\rho_b = 2.65(1-\eta) \tag{8}$$

Bulk density was calculated using the porosity of a gravel from Freeze and Cherry (1979) discussed above. According to Equation (8), the bulk density for the Qmf is 1.79 g/cm^3.

2.6.5 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 sorb to organic carbon; therefore, pollutant retardation is directly proportional to fraction organic carbon.

Carbon in unsaturated material beneath a UIC is derived from two sources:

- Organic carbon incorporated into the sediments during deposition
- 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

Organic carbon incorporated into the Portland Basin sediments (i.e., Missoula Flood Deposits) during deposition is approximately an order of magnitude less than organic carbon that accumulates in soil as a result of stormwater infiltration (GSI, 2008). Therefore, the fate and transport analysis only considers organic carbon that accumulates in the unsaturated zone materials because of stormwater infiltration.

Accumulation of organic carbon in the unsaturated zone materials beneath a UIC is estimated from total organic carbon (TOC) in stormwater and the amount of stormwater that infiltrates at a typical UIC. The TOC concentration in stormwater was estimated using data from stormwater samples collected at 61 City-owned UICs in Gresham, 15 UICs in Clackamas (collected by Water Environmental Services), and 12 UICs in Portland (collected by Bureau of Environmental Services). TOC concentrations vary during the year, and are highest during leaf fall in October and November and lowest after leaf fall in December and January. To account for the variation in TOC loading that occurs throughout the year, a time-weighted TOC concentration was used to estimate TOC accumulation in vadose zone soil. Assumptions that were used in estimating TOC concentration include:

- TOC loading occurs during the rainy season, which is estimated to be from October through April (i.e., seven months),
- TOC data collected in Milwaukie, Gladstone, and Lake Oswego during the month of November represents TOC loading during "leaf fall". Leaf fall is estimated to occur during October and November (i.e., two of the seven months that TOC loading occurs),
- TOC data collected in Gresham during December and January represents TOC loading during "post leaf fall". Post leaf fall is estimated to occur during December through March (i.e., four of the seven months that TOC loading occurs), and

- TOC data collected in Portland during April represents TOC loading during "leaf out." Leaf out is estimated to occur during April (i.e., one of the seven months that TOC loading occurs).

The weighted mean TOC concentration in stormwater from samples collected at UICs in Gresham, Clackamas, and Portland UICs was used for the average scenario. The weighted minimum TOC concentration in stormwater from samples collected at UICs in Gresham, Clackamas, and Portland UICs was used for the reasonable maximum scenario. Table 2 summarizes the TOC concentration analyses.

Table 2. Total organic carbon in stormwater.
City of Gresham, Oregon

Region	N	Weighting [1]	Mean Concentration (mg/L)	Weighted Mean Concentration (mg/L)	Minimum Concentration (mg/L)	Weighted Minimum Concentration (mg/L)
Gresham	61	4/7 or 57%	2.5	10.0	0.3	1.0
Milwaukie, Gladstone, & LO	15	2/7 or 29%	20.5	41.0	3.1	6.1
Portland	12	1/7 or 14%	9.1	9.1	3.8	3.8
All	**88**	**7/7 or 100%**	**10.7**	**8.6** [2]	**2.4**	**1.6** [3]

Notes:
Half of the detection limit was used for non detects in the Gresham TOC statistics.
mg/L = milligrams per liter
N = number of samples
LO = Lake Oswego
[1] Weighting is based on the assumption that TOC loading occurs 7 months of the year.
[2] The weighted mean concentration was used for the Fate and Transport Tool average scenario.
[3] The weighted minimum concentration was used for the Fate and Transport Tool reasonable maximum scenario.

As stormwater infiltrates into the unsaturated zone surrounding the UIC, the f_{oc} is expected to increase over time because of the ongoing addition of organic carbon. An estimate of f_{oc} based on the filtering of TOC 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 was selected to 1) be consistent with Portland, who selected 10 years based on the age of their newer UICs, and 2) 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:

$$I = (A)(p)(1-e) \tag{9}$$

$$CL = (I)(C)(t)\left(\frac{1\,\text{liter}}{1{,}000\ \text{cm}^3}\right)\left(\frac{1\,\text{gram}}{1{,}000\ \text{milligrams}}\right) \tag{10}$$

$$\rho_{oc} = \frac{CL}{SV} \tag{11}$$

$$f_{oc} = \frac{\rho_{oc}}{\rho_b + \rho_{oc}} \tag{12}$$

where:

I = Average annual stormwater infiltration volume estimated using the average impervious area of a UIC catchment (A), precipitation (p), and losses to evaporation (e) [$I=(A)(p)(1-e)$] (cubic centimeters per year)

A = Area of a typical UIC catchment (square feet)

p = Precipitation (feet per year)

e = Evaporative loss fraction (dimensionless)

CL = Organic carbon loaded into the unsaturated 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 unsaturated 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 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) (cubic centimeters)

f_{oc} = Fraction organic carbon (dimensionless)

ρ_b = Bulk density (grams per cubic centimeter)

Calculations of f_{oc}, based on the filtering of TOC as suspended solids for the average and reasonable maximum scenarios, are shown in Table 3. First, the volume of stormwater that infiltrates into a UIC during a typical year was calculated by Equation (9). Next, Equation (10) was used to calculate the grams of carbon added to the unsaturated zone surrounding the UIC during a 10-year period. Equation (11) was used to calculate the mass of organic carbon per unit volume of material surrounding the UIC (ρ_{oc}), and Equation (12) was used to convert ρ_{oc} to f_{oc}.

Table 3. Estimated f_{oc} in soils beneath City of Gresham's UICs.
City of Gresham, Oregon

	I Calculation (Eq. 9)				*CL* Calculation (Eq. 10)			ρ_{oc} Calculation (Eq. 11)						f_{oc} calculation (Eq. 12)	
	A (ft^2)	*p* (ft/yr)	*e* (-)	*I* (cm^3/yr)	*C* (mg/L)	*t* (years)	*CL* (g)	UIC radius (cm)	UIC radius + 1 foot (cm)	*SV* 3' Above base (cm^3)	*SV* 5' Below base (cm^3)	Total *SV* (cm^3)	ρ_{oc} (g TOC per cm3/soil)	Bulk Density (g/cm3)	f_{oc}
Average Scenario	12,517	3.06	0.26	8.0E+08	8.6	10	69,023	60.96	91.44	1,333,723	4,001,170	5,334,894	0.0129	1.79	0.0072
Reasonable Maximum Scenario	12,517	3.06	0.26	8.0E+08	1.6	10	12,842	60.96	91.44	1,333,723	4,001,170	5,334,894	0.0024	1.79	0.0013

Notes:
A =Area of a typical UIC catchment (square feet)
p= Precipitation (feet per year)
e = Evaporative loss fraction (dimensionless)
I = Average annual stormwater infiltration volume
C = TOC concentration in stormwater (milligrams per liter)
t = Time of carbon loading (years)
CL = Organic carbon loaded into the unsaturated zone beneath a UIC during a 10-year period (grams)
UIC = underground injection control device
SV = Material volume into which the organic carbon would accumulate because of filtration and adsorption (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) (cubic centimeters)
ρ_b = Bulk density (grams per cubic centimeter)
f_{oc} = Fraction organic carbon (dimensionless)
ρ_{oc} = Organic carbon weight per unit unsaturated zone material volume (grams per cubic centimeter)
ft = feet
yr = year
(-) = dimensionless
mg = milligrams
L = liter
g = gram
cm = centimeter
TOC = total organic carbon

The average scenario used the weighted mean TOC concentration in stormwater from the Clackamas, Gresham, and Portland UIC sampling events. The reasonable maximum scenario used the weighted minimum TOC concentration in stormwater from the Clackamas, Gresham, and Portland UIC sampling events.

2.6.6 Organic Carbon Partitioning Coefficient

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 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 at the Fujitsu Ponds Wetlands, Gresham, Multnomah County, Oregon.

- **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).

K_{oc} for each pollutant is listed in Table 4.

Table 4. K_{oc} for stormwater pollutants.
City of Gresham, Oregon

Pollutant	Average Scenario (L/Kg)	Reasonable Maximum Scenario (L/Kg)
Naphthalene	1,300 [1]	830 [3]
PCP	822 [4]	822 [4]
Bis-(2-ethylhexyl) phthalate	12,200 [1]	12,200 [2]
2,4-D	201 [5]	20 [6]
Toluene	162 [7]	37 [8]

Notes:
[1] From Fetter (1994), Table 11.3, pages 467 – 469. For the average scenario, K_{oc} was calculated from two equations in Roy and Griffin (1985). The first equation is an empirical-based equation relating K_{oc} to K_{ow}, and the second equation is an empirical-based equation relating K_{oc} to solubility. K_{oc} results from both equations were averaged together to determine K_{oc} for each constituent. The Roy and Griffin (1985) equation was used because it resulted in a lower (i.e., more conservative) K_{oc} than the regression equations in EPA (1996b) (Equations 70 and 71, pages 140-141).
[2] For reasonable maximum scenarios, K_{oc} was chosen based on the lowest (i.e., most conservative) literature values. However, K_{oc} for this compound was calculated using the empirical equations in Roy and Griffin (1985) because they resulted in lower K_{oc}s (i.e., more conservative) than the lowest-reported literature value.
[3] The lowest K_{oc} reported for naphthalene in the EPA (1996b) review of 20 naphthalene K_{oc}s from field testing. The range of K_{oc} was 830 L/Kg to 1,950 L/Kg
[4] The K_{oc} for pentachlorophenol is pH-dependent. Soil and groundwater pH are in equilibrium; therefore, soil pH can be estimated from groundwater pH. pH has been measured at monitoring wells completed in first-encountered groundwater at the Fujitsu Ponds Wetlands, 201st Avenue and NE Glisan, Gresham, Multnomah County, Oregon. The average groundwater pH at monitoring wells MW3 (6.47), MW7 (6.48), and MW6 (6.41) was 6.45. When pH = 6.45, the K_{oc} for PCP is 822 L/Kg (EPA, 1996b). That value was used for both the Average and Reasonable Maximum Scenarios.
[5] Typical K_{oc} for 2,4-D acid in EPA (2010a), based on a range of 20.0 to 109.1 L/Kg. The "typical" K_{oc} for 2,4-D acid was used because EPA (1996) and Roy and Griffin (1985) did not provide a value of K_{oc} for 2,4-D acid.
[6] The lowest K_{oc} for 2,4-D acid in EPA (2010a), based on a range of 20.0 to 109.1 L/Kg
[7] Calculated from Equation (71) on page 141 of EPA (1996b), which is a regression equation relating K_{oc} to K_{ow} for VOCs, chlorobenzenes, and certain chlorinated pesticides. The log K_{ow} for toluene was taken from EPA (2010c). Equation (70) of EPA (1996) was used because it resulted in a lower K_{oc} than the Roy and Griffin (1985) equations.
[8] The lowest K_{oc} reported for toluene in EPA (2010c). The range of K_{oc} was 37 – 178 L/Kg.

2.6.7 Distribution Coefficient

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

$$K_d = f_{oc} K_{oc} \tag{13}$$

For metals, K_d was estimated from equations in Bricker (1998). The most important solid phases for sorption 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:

$$K_d = \frac{C_s}{C_w} \tag{14}$$

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 over literature-reported K_ds. K_d values can be determined empirically for a particular situation from Equation (14) (Bricker, 1998).

The City of Gresham's winter 2009 – 2010 preliminary stormwater monitoring was not designed for estimating site-specific K_ds for metals (specifically dissolved metals were not analyzed). However, City of Portland stormwater data are sufficiently comprehensive to estimate site-specific K_ds, and were used to estimate site-specific K_ds for the City of Gresham. The City of Portland data can be used only because City of Gresham data for total suspended solids (TSS) and metals are similar to the City of Portland's (see Table 5).

An empirical approach was used to derive site-specific K_ds for lead and copper for the City of Portland. The partitioning coefficients were estimated from total and dissolved metals concentrations and TSS data for 150 stormwater samples collected from 30 different locations during City of Portland's Year 1 and Year 2 stormwater discharge monitoring. The stormwater chemistry data are summarized in Table 5.

For the City of Portland, sorbed concentrations were calculated by normalizing the particulate metals concentrations to the concentration of TSS. For each sample, an apparent K_d value was calculated for each metal from the following equation:

$$K_d = \frac{\left([Me]_t - [Me]_d\right)}{[Me]_d \times TSS} \times 10^6 \tag{15}$$

where:

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

Table 5. Stormwater quality data for Portland UICs (N=150) and Gresham (N=61).
City of Gresham, Oregon

Parameter	Mean		Minimum		Maximum		Median	
	Portland	Gresham	Portland	Gresham	Portland	Gresham	Portland	Gresham
Total Copper (μg/L)	8.17	9.37	0.73	0.66	67.20	63.70	5.15	5.67
Dissolved Copper (μg/L)	2.92	NA	0.20	NA	15.50	NA	2.11	NA
Total Lead (μg/L)	7.34	6.13	0.28	0.01	85.70	68.40	2.93	2.38
Dissolved Lead (μg/L)	0.29	NA	0.10	NA	3.40	NA	0.14	NA
TSS (mg/L)	37	47.45	2	2	415	487	15	20

Notes:
NA = not analyzed

Note that in Equation (15), metals concentrations are in micrograms per liter, and TSS are in units of milligrams per liter. The distribution of calculated K_d values for lead and copper is shown in Figure 3 and summarized in Table 6. The median K_d value for copper (76,000 liters per kilogram [L/Kg]) is substantially lower than for lead (1,000,000 L/Kg). The higher K_d values for lead are expected (Laxen and Harrison, 1977).

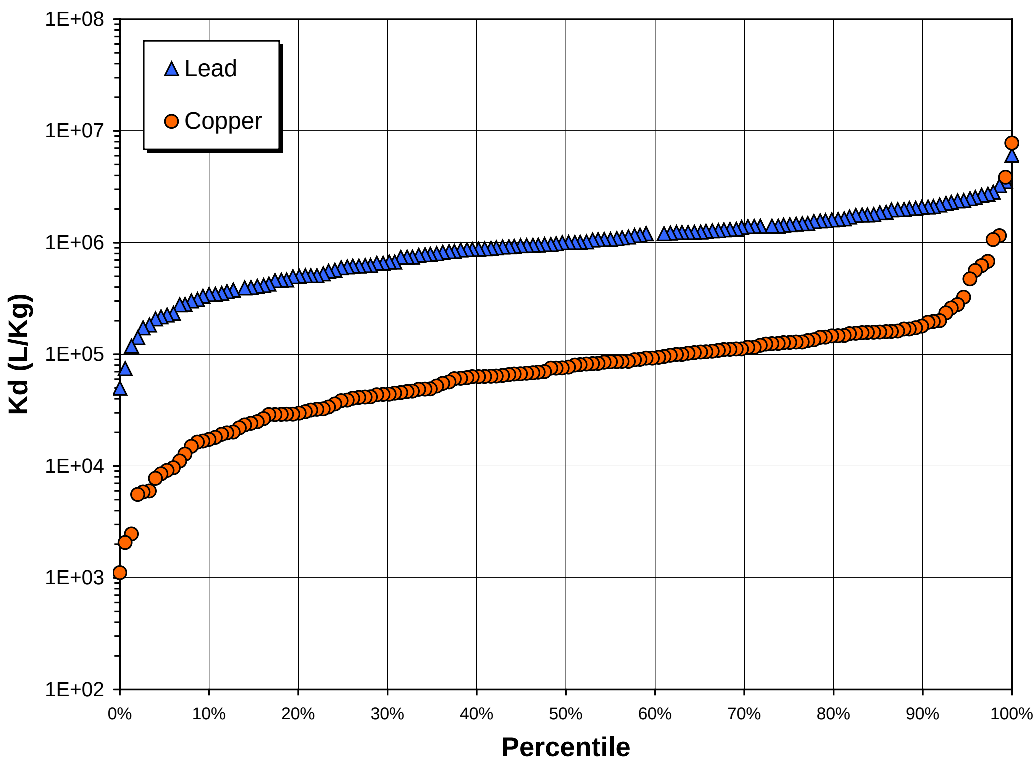


Figure 3. Calculated K_d distributions for lead and copper in Portland stormwater runoff.
City of Gresham, Oregon

Table 6. Calculated K_d values for copper and lead based on Portland stormwater data.
City of Gresham, Oregon

Metal	Minimum (L/kg)	Maximum (L/kg)	Median (L/kg)	10^{th} Percentile (L/kg)
Lead	50,000	6,100,000	1,000,000	340,000
Copper	1,100	7,800,000	76,000	17,000

The average scenario uses median K_d values for lead and copper, and the reasonable maximum scenario uses the 10^{th} percentile K_d values.

The distributions of calculated partition coefficients derived for copper and lead in City of Portland stormwater can be compared to other sources of information to assess the reasonableness of the derived values. A recent EPA compilation provides critically selected K_d value ranges for metals in soil and sediments (Allison and Allison, 2005). This compilation includes K_d values determined from batch and column leaching experiments with natural media, in a pH range of 4 to 10 and low total metal concentrations (Table 7). The ranges of K_d values for lead and copper in the EPA compilation overlap with the values calculated for the City of Portland although the median values are lower. The lower median values in the EPA compilation may reflect leaching under more acidic conditions than are observed in City of Portland stormwater (pH ranges from 5.1 to 8.4).

Table 7. Compiled K_d values for lead and copper (Allison and Allison, 2005).
City of Gresham, Oregon

Metal	Median (L/Kg)	Minimum (L/Kg)	Maximum (L/Kg)
Lead	130,000	100	10,000,000
Copper	13,000	5	1,600,000

Notes:
L/Kg = liter per kilogram

The calculated K_d distributions also be can compared to similarly calculated K_ds from stormwater quality data from other sources. These include data from the National Stormwater Quality Database (NSQD; Pitt et al., 2004), and stormwater runoff data from the City of Seattle, Washington, (Engstrom, 2004) and California (Kayhanian et al., 2007). The data and calculated K_d values are summarized in Table 8.

Table 8. Stormwater quality from various sources and calculated K_d values.
City of Gresham, Oregon

Parameter	*NSQD*	*California*			*Seattle*		
	Median	Min	Max	Median	Min	Max	Median
Total Lead (µg/L)	17	1	2,600.00	12.7	3.9	38.7	11.6
Dissolved Lead (µg/L)	3	1	480	1.2	0.28	14.2	0.96
Total Copper (µg/L)	16	1.2	270	21.1	8.23	44.8	13.85
Dissolved Copper (µg/L)	8	1.1	130	10.2	1.8	28.1	7.1
Total Suspended Solids (mg/L)	58	1	2,988.00	59.1	4	204	40
pH	7.5	4.5	10.1	7	6.3	7.8	6.8
Lead K_d (L/Kg)	80,000			160,000			550,000
Copper K_d (L/Kg)	17,000			18,000			33,000

Notes:
(µg/L) = microgram per liter
mg/L = milligram per liter
L/Kg = liter per kilogram
NSQD = National Stormwater Quality Database

Although the median K_d values for lead and copper derived from the NSQD and California data are lower than the corresponding median values calculated for the City of Portland stormwater, the median values for the City of Seattle are closer to the median City of Portland values. The calculated K_d distributions for lead and copper therefore appear to provide a reasonable representation of sorption of these metals from stormwater onto soil particles.

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.

2.6.8 Hydraulic Conductivity

Hydraulic conductivity is a proportionality constant that, under unsaturated conditions, is equivalent to groundwater velocity (see Equation 7). In the unsaturated zone beneath UICs, groundwater velocity is equivalent to unsaturated hydraulic conductivity (K_u). However, the fate and transport analysis uses saturated hydraulic conductivity (K_s) in Equation (7) to calculate groundwater velocity. Because of the tortuosity of unsaturated flow paths, K_u is always smaller than K_s (usually by several orders of magnitude); therefore, using K_s in Equation (7) is conservative. Saturated hydraulic conductivity, K_s, in the Missoula Flood Deposits (Qmf) was estimated from pump-in tests conducted by the City of Gresham. Note that the pump-in tests are conducted in the unsaturated zone; however, because of the large volumes of water injected during the tests the hydraulic conductivity calculated from the test data is considered "saturated" and is a conservative estimate of unsaturated hydraulic conductivity. Pump-in tests are conducted to estimate UIC infiltration capacity and consist of injecting water into a UIC at a known rate until the water level in the UIC stabilizes. Figure 4 shows a conceptual diagram of a UIC during a pump-in test.

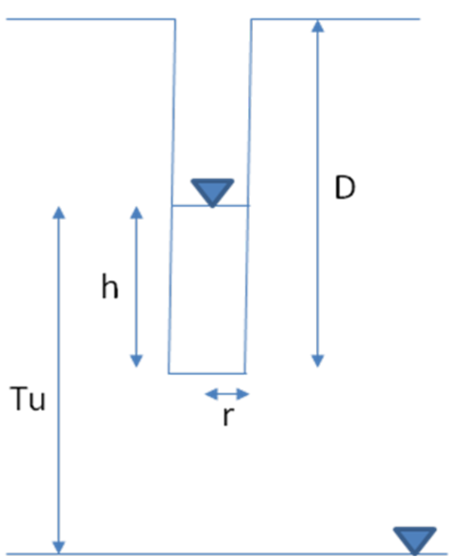


Figure 4. Pump-in test conceptual model.
City of Gresham, Oregon

According to USDI (1993), horizontal hydraulic conductivity in the unsaturated zone is calculated from a pump-in test by the following formulae:

$K_s =$

$$\frac{\left[\ln\left(\frac{h}{r}+\sqrt{\left(\frac{h}{r}\right)^2+1}\right)-1\right]Q}{2\pi h^2} \quad \text{if } T_u \geq 3h \qquad (16)$$

$$\left[\frac{3\ln\left(\frac{h}{r}\right)}{\pi h\left(h+2T_U\right)}\right]Q \quad \text{if } 3h \geq T_u \geq h \qquad (17)$$

where:

K_s is saturated hydraulic conductivity (L/T),

h is the height of the stable water level above the UIC bottom (L),

D is the depth of the UIC from ground surface to bottom (L)

T_u is the separation distance between the water table and stable water level in the UIC (L),

Q is the rate water enters the UIC when the water level is stable (L^3/T), and

r is the radius of the UIC (L).

Because water is transported vertically through the unsaturated zone, the horizontal hydraulic conductivity calculated by the pump-in test must be converted to a vertical hydraulic conductivity. According to USGS (1996a and 1996b), the ratio of horizontal to vertical hydraulic conductivity in the UGA hydrogeologic unit (which contains the Qmf geologic unit) aquifers is 100: 1. Therefore, vertical hydraulic conductivity was calculated by dividing the horizontal hydraulic conductivity by 100.

Hydraulic conductivities were calculated from 37 pump-in tests conducted in Gresham (Figure 5, which is presented at the end of this TM). All 37 pump-in tests were conducted at UICs completed in the Qmf. None of the tests were from the QTg because relatively few UICs are completed in the QTg, which is in part because of the lower permeability of the QTg (USGS 1996a and 1996b). Summary statistics from the pump-in test analyses are provided in Table 9.

Table 9. Hydraulic conductivity in the Qmf geologic unit.
City of Gresham, Oregon

	Number of Tests	Minimum K_v (m/day)	Maximum K_v (m/day)	Median K_v (m/day)	95 Percent UCL K_v [1] (m/day)
Qmf	37	0.17	2.95	1.00	1.45

Notes:
K_v = vertical hydraulic conductivity UCL = upper confidence limit
[1] Data appear lognormal at the 95 percent significant level (i.e., $p>0.10$) and $0.5<\sigma<1.0$. Therefore, 95 percent UCL calculated using the 95 percent H-UCL.

The 95 percent upper confidence limit (UCL) on the mean vertical hydraulic conductivity was calculated with EPA's *ProUCL v. 4.00.02* software. The median vertical groundwater velocity (which is used for the average scenario) was 1.00 m/day for the Qmf facies. The 95 percent UCL velocity (which is used for the reasonable maximum scenario) was 1.45 m/day for the Qmf facies.

Vertical hydraulic conductivities calculated from pump-in testing were compared to the range of hydraulic conductivities in the UGA hydrogeologic unit (which is equivalent to the Qmf geologic unit) summarized in a Portland Basin hydrogeology report (USGS, pg. 18, 1996b). The USGS (1996b) hydraulic conductivities were calculated from multi-well aquifer tests and single-well specific capacity tests. Because USGS (1996b) provides only horizontal hydraulic conductivities, a $K_H : K_V$ anisotropy ratio of 100 : 1 was used to calculate vertical hydraulic conductivities (USGS, pg. 19, 1996b). The range in vertical hydraulic conductivities reported by USGS (1996b) for the UGA is therefore 9×10^{-5} (25^{th} percentile) to 6.1 meters per day (75^{th} percentile). Therefore, the range of vertical hydraulic conductivities calculated from pump-in testing is within the range of values previously reported in the scientific literature.

2.6.9 Degradation Rate Constant (Biodegradation Rate)

The organic pollutants evaluated in this TM 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. Degradation rate is a chemical-specific, first-order rate constant, and depends on whether the unsaturated zone is aerobic or anaerobic. Metals do not undergo biodegradation so are not included in this section.

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. However, 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 10. Summary statistics provided in Table 10 include minimum, maximum, number of measurements, average, 10^{th}, 25^{th}, and 50^{th} percentile (median) values. For the average scenario, the median biodegradation rate was used. For the reasonable maximum, the 25^{th} percentile biodegradation rate was used.

Table 10. Summary of first-order aerobic biodegradation rates.
City of Gresham, Oregon

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
Bis-(2-ethylhexyl)phthalate [2]	34	0.015	0.021	0.082	0.010	0.0040
Naphthalene [3]	22	0.075	0.14	0.39	0.025	ND
Toluene [4]	44	0.33	0.65	4.71	0.082	0.0097
2,4-D [5]	14	0.0053	0.091	0.48	0.0022	0.00012

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 Mackay (2006), Howard et al. (1991), Fogel, et al. (1982), Kaufman (1976), Jury et al., 1987), and Hornsby et al. (1996).
[3] From Aronson et al. (1999); Ashok et al. (1995); Ellis et al. (1991); Flemming et al. (1993); Fogel et al. (1995); Mihelcic and Luthy (1988); Mueller et al. (1991); Park et al. (1990); Pott and Henrysson (1995); Smith (1997); Swindoll et al. (1988); and Wischmann and Steinhardt (1997).
[4] From Aronson et al. (1999); Howard et al. (1991); Davis and Madsen (1996); Fan and Scow (1993); Fuller et al. (1995); Jin et al. (1994); Kjeldsen et al. (1997); McNabb et al. (1981); Mu and Scow (1994); Venkatraman et al. (1998); and Wilson et al. (1981).
[5] From Howard et al. (1991); Mackay et al. (2006); Chinalia and Killham (2006); McCall et al. (1981); Nash (1983); and Torang et al. (2003).

2.6.10 Infiltration Time

Infiltration time is the length of time during the year that stormwater discharges into a UIC and, therefore, migrates downward through the unsaturated zone. Because stormwater discharges 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 assigns a threshold precipitation rate of 0.08 inch/hour for stormwater to discharge into UICs, which is consistent with City of Gresham field staff observations. This fate and transport evaluation conservatively assumes that stormwater discharges into UICs at one-half of the threshold precipitation rate (i.e., 0.04 inch/hour).

Precipitation and infiltration times from 1999 to 2009 in downtown Gresham are shown in Table 11.

Table 11. Precipitation and infiltration time, 1999–2009.
City of Gresham, Oregon

Year	Annual Precipitation (inches)	Hours With ≥ 0.04" Precip	Days With ≥ 0.04" Precip
2009	34.07	309	12.88
2008	35.21	330	13.75
2007	44.17	446	18.58
2006	51.34	469	19.54
2005	40.50	362	15.08
2004	31.64	270	11.25
2003	38.16	348	14.50
2002	29.53	280	11.67
2001	31.19	302	12.58
2000	29.60	273	11.38
1999	45.67	442	18.42
Geometric Mean	**36.76**	**342**	**14.24**

Notes:
Precipitation data from Gresham Fire Department Raingage, located at 1333 NW Eastman Parkway in downtown Gresham (HYDRA, 2010).

The geometric mean number of hours that precipitation rate was equal to or exceeded 0.04 inch/hour from 1999 through 2009 (342 hours or 14.24 days) was used for infiltration time in the fate and transport analysis. Because the fate and transport equation simulates pollutant breakthrough only until the time at which maximum pollutant concentration is reached, infiltration times were reduced for some pollutants (i.e., toluene and 2,4-D) that reached a maximum concentration within a shorter infiltration time. Infiltration times used for each pollutant for the various Fate and Transport Tool scenarios are provided in Appendices A through C.

2.6 Fate and Transport Tool Average and Reasonable Maximum Scenario Results in the Unsaturated Zone

Table 12 presents separation distances in the unsaturated zone that required to meet the MRLs (based on available local laboratory technologies) and EDLs (as listed in the draft UIC WPCF template) using the average and reasonable maximum scenario of the unsaturated zone Fate and Transport Tool. The model calculations for these scenarios are presented in Appendix A. The pollutant concentrations discharging to UICs in the average and reasonable maximum scenarios were equal to the mean and the 95 percent UCL on the mean, respectively, of pollutant concentrations from the Gresham winter 2009 – 2010 stormwater sampling event.

Table 12. Separation distances in the unsaturated zone required to meet the MRL and EDL
City of Gresham, Oregon

AVERAGE SCENARIO				
Pollutant	**MRL** (ug/L)	**Vertical Unsaturated Zone Transport Distance Needed to Reach MRLs** (feet)	**EDL** (ug/L)	**Vertical Unsaturated Zone Transport Distance Needed to Reach EDLs** (feet)
Lead [1]	0.10	0.02	50	NA
Copper [1]	0.20	0.22	1,300	NA
Benzo(a)pyrene	0.01000	0.004	0.2	NA
PCP	0.0400	2.4	1.0	NA
Naphthalene	0.0200	0.94	NA	NA
di-(2-ethylhexyl) phthalate	1.000	0.1	6.0	NA
2,4-D	0.100	NA	70	NA
Toluene	0.50	NA	1,000	NA
REASONABLE MAXIMUM SCENARIO				
Pollutant	**MRL** (ug/L)	**Vertical Unsaturated Zone Transport Distance Needed to Reach MRLs** (feet)	**EDL** (ug/L)	**Vertical Unsaturated Zone Transport Distance Needed to Reach EDLs** (feet)
Lead [1]	0.1	0.08	50	NA
Copper [1]	0.2	1.46	1,300	NA
Benzo(a)pyrene	0.01000	0.037	0.2	NA
PCP	0.0400	17.5	1.0	9.61
Naphthalene	0.0200	10.7	NA	NA
di-(2-ethylhexyl) phthalate	1.000	0.87	6.0	NA
2,4-D	0.100	NA	70	NA
Toluene	0.50	NA	1,000	NA

Notes:
MRL = method reporting limit
EDL = effluent discharge limit
µg/L = micrograms per liter
NA = Not applicable. Initial pollutant concentration is below the MRL or EDL, so the MRL or EDL is met prior to discharge from the UIC.
[1] Metals transport simulations are longer than 14.24 days because metals do not biodegrade over time. Metals transport simulations assume 1000 years of transport at 14.24 days per year = 14,240 days of transport.

As shown in Table 12, under the average scenario, transport distances required to reach MRLs for benzo(a)pyrene, naphthalene, PCP, and di-(2-ethylhexyl)phthalate are less than 5 feet. Toluene and 2,4-D were below the MRL prior to discharging from the UIC because their initial concentrations in the model were below MRLs (due to their low frequency of detection).

Under the reasonable maximum scenario for unsaturated zone transport, PCP and naphthalene require over ten feet of separation distance to attenuate below MRLs. The reasonable maximum scenario represents the worst-case pollutant transport conditions, and is characterized by compounding conservatism of input variables. The purpose of the reasonable maximum scenario is to evaluate model sensitivity, and it does not represent reasonably likely conditions. Fate and transport of PCP and naphthalene in groundwater were evaluated using BIOSCREEN (presented in the Section 4 of this TM).

Even though model results for lead and copper indicate that they would not be groundwater issues long after the life of the UIC, alternate EDLs are not being proposed for these constituents at this time.

3.0 Development of Proposed EDLs

The unsaturated zone Fate and Transport Tool was used to develop proposed EDLs for the City of Gresham's UIC WPCF Permit. The proposed EDLs were developed using the following assumptions:

- Proposed EDLs are limited to maximum concentrations of 10 times the existing EDLs or about 0.05% of the pollutant solubility in water (i.e., naphthalene, which does not have an EDL in the draft permit template),
- The separation distance between the bottom of the UICs and the seasonal high groundwater is 10 feet,
- The average scenario of the Fate and Transport Tool is used,
- Groundwater is protected when pollutant concentrations just above the water table are below the MRL, and
- Pollutant concentrations at or below the proposed EDL measured at the end of pipe are attenuated to the MRL immediately above the water table.

The calculations for proposed EDLs are provided in Appendix B. Table 13 presents the proposed EDLs developed using the average transport scenario of the Fate and Transport Tool and a 10-foot separation distance between the bottom of the UIC and seasonal high groundwater. As shown in Table 13, the proposed EDLs for PCP and DEHP were limited to 10 times the preliminary EDLs proposed in the draft UIC WPCF permit template. The proposed EDLs for 2,4-D and toluene are less than the EDL in the draft UIC WPCF permit template (4.140 and 9.64 μg/L, respectively). The proposed EDLs for 2,4-D and toluene are such that at a separation distance of 10 feet, 2,4-D and toluene attenuate to background concentrations (MRLs) before reaching the groundwater. The proposed EDL for naphthalene, which does not have an EDL in the draft UIC WPCF template, is 10.0 ug/L, which is about 0.05% of its solubility in water at 10.0 degrees Celsius (i.e., the temperature of groundwater, from Bohon and Claussen, 1951).

Appendix C shows calculations for pollutant fate and transport assuming pollutants enter the UIC at concentrations equal to the proposed EDL. The results are summarized in Table 13. Under the average scenario, pollutant concentrations attenuate to below the EDL within ten feet of transport. Under the reasonable maximum scenario, naphthalene, PCP, toluene, and 2,4-D occur above the groundwater table at concentrations above the MRL (DEHP attenuates to below the MRL immediately above the water table under the reasonable maximum scenario). The presence of these pollutants at the water table under reasonable maximum conditions is further discussed in Section 4.0, BIOSCREEN Fate and Transport Modeling.

Table 13. Proposed alternative EDLs (UICs ≥ 10 feet vertical separation distance)
City of Gresham, Oregon

Pollutant	MRL (µg/L) [1]	Current EDL (µg/L) [2]	Proposed EDL (µg/L) [3]	Output Concentration (µg/L) [4]	
				Average Scenario	Reasonable Maximum Scenario
Naphthalene	0.02	NA	10.0000 [5]	0.0000	4.77
PCP	0.040	1.000	10.000	0.000	4.96
DEHP	1.0	6.000	60.000	0.000	0.000
2,4-D	0.100	70.000	4.140	0.100 [6]	2.310 [6]
Toluene	0.50	1,000.0	9.64	0.50 [7]	4.560 [7]

Notes:
µg/L = micrograms per liter
UCL = upper confidence limit
EDL = effluent discharge limits
MRL = method reporting limit
[1] Method Reporting Limit (MRL) based on typically achievable MRLs during the Gresham winter 2009 - 2010 stormwater monitoring event.
[2] Effluent Discharge Limits from Table A.5.1 and Table A.5.2 of the Draft Revised Template for Municipal Stormwater UIC WPCF Permit. There is no established EDL for naphthalene, therefore the EPA Regional Screening Level (RSL) from EPA (2009b) was used.
[3] Proposed EDLs based on the "average transport scenario" of the groundwater protectiveness tool and the assumption that groundwater is protected when pollutant concentrations just above the water table are below the MRL. The proposed EDL is the input concentration of the pollutant entering the UIC in the Fate and Transport Tool.
[4] Output concentration is the concentration below the UIC after 10 feet of transport.
[5] The proposed EDL for naphthalene, which does not have an EDL in the draft UIC WPCF permit template, is about 0.05% of its solubility in water at 10.0 degrees Celsius (Bohon and Claussen, 1951).
[6] Output concentration shown to the thousandths place, based on resolution of laboratory data.
[7] Output concentration shown to the hundreths place, based on resolution of laboratory data.

4.0 BIOSCREEN Fate and Transport Modeling in the Saturated Zone

While the average scenario, which is assumed to most accurately represent real world conditions, shows that the pollutants in Table 13 are attenuated to or below current levels of detection (MRLs), PCP, naphthalene, 2,4-D, and toluene have output concentrations that are greater than the MRL under the reasonable maximum scenario. In an effort to determine whether or not the remaining pollutant load would attenuate within a reasonable distance from the UIC, a separate model was used to evaluate horizontal flow under saturated conditions.

In an effort to meet the goals of protecting human health for water wells in the vicinity of a UIC and to meet the intent of not increasing pollutant loads in groundwater above background, a maximum allowable travel distance of less than 10 feet was selected. It was assumed that if background concentrations were derived by conducting groundwater monitoring, installation of a monitoring well would occur at a distance of at least 10 feet away from an existing UIC to avoid the disturbed soil and rock ballast installed around each device.

BIOSCREEN fate and transport modeling in the saturated zone was performed to assess the distance that pollutants would travel in groundwater before attenuating below MRLs. This analysis presents the "worst case" scenario in that it is assumed that pollutants are discharged to UICs with 10 feet of separation distance and at concentrations equal to the proposed EDLs, and are transported through the unsaturated zone under the reasonable maximum scenario (i.e., most conservative assumptions for input parameter values).

The EPA's BIOSCREEN, a saturated zone solute transport model, was selected to estimate the attenuation distances in groundwater for pollutants that reached groundwater under the reasonable maximum scenario at concentrations above MRLs: PCP, Naphthalene, 2,4-D, and Toluene (Table 13). This section consists of:

- Discussion of the BIOSCREEN analytical model used to perform the analysis and its assumptions;
- Documentation of input parameters used in the BIOSCREEN model; and
- Results of BIOSCREEN modeling.

4.1 BIOSCREEN

The fate and transport of pollutants in groundwater for UICs with 10 feet of separation distance was performed using BIOSCREEN (EPA, 1996a), an analytical model developed by the EPA that simulates pollutant advection, dispersion, degradation, and retardation in the saturated zone. BIOSCREEN is a quasi-three dimensional model that simulates pollutant advection in one dimension, and simulates pollutant dispersion in three dimensions. BIOSCREEN is a Microsoft Excel-based model that uses the following solution to the advection dispersion equation:

$$\frac{C(x,y,z,t)}{C_0} = \frac{1}{8}\exp\left[\frac{x}{2\alpha_x}\left(1-\sqrt{1+\frac{4k\alpha_x}{\frac{v}{R}}}\right)\right] erfc\left[\frac{s-vt\sqrt{1+\frac{4k\alpha_x}{\frac{v}{R}}}}{2\sqrt{\alpha_x\frac{v}{R}t}}\right]\left\{erf\left[\frac{y+Y/2}{2\sqrt{\alpha_y x}}\right]-erf\left[\frac{y-Y/2}{2\sqrt{\alpha_y x}}\right]\right\}\left\{erf\left[\frac{Z}{2\sqrt{\alpha_z x}}\right]-erf\left[\frac{-Z}{2\sqrt{\alpha_z x}}\right]\right\}$$

(18)

where:

M = mass (e.g., milligrams, micrograms, etc.)
L = length (e.g., meters)
t = time (e.g., minutes, hour)
C = concentration at distance x downstream of source and distance y off centerline of plume (M/L^3)
C_0 = concentration in source zone at t = 0 (M/L^3)
x = distance downgradient from source (L)
y = distance from plume centerline of source (L)
z = distance from plume centerline of source (L)
α_x = longitudinal dispersivity (L)
α_y = transverse dispersivity (L)
α_z = vertical dispersivity (L)
v = groundwater velocity (L/T)
R = retardation factor (dimensionless)
k = first order degradation rate constant (T^{-1})
Y = source width (L)
Z = source depth (L)
erf = error function, erfc = complimentary error function

BIOSCREEN requires input of soil/chemical parameters (i.e., velocity, dispersion coefficient, retardation, and biodegradation rate constant) and source characteristics. Soil/chemical parameters can be input directly, or can be calculated from site-specific values of hydraulic conductivity, hydraulic gradient, and porosity. Source characteristics include source thickness, width, and concentration. BIOSCREEN simulates declining source concentrations with time based on source half life, which BIOSCREEN automatically calculates based on user-supplied soluble mass.

BIOSCREEN outputs concentrations along the plume centerline (i.e., along the center of the plume, where z offset = 0, y offset = 0, and x offset varies from 0 to x_{max}).

This fate and transport model is conservative because:

- Initial pollutant concentrations in BIOSCREEN are based on the reasonable maximum scenario of the unsaturated zone fate and transport model (Table 13). Therefore, the initial pollutant concentrations represents the worst-case scenario.
- Dilution occurs when pore water from the unsaturated zone enters the saturated zone and mixes with groundwater. This dilution occurs prior to the solute being transported with groundwater, and is not included in the model. It is important to note that pollutant dilution during transport with groundwater (i.e., dispersion) is included in the model.

The BIOSCREEN simulations use conservative values for input parameters as outlined in the section 4.3.

4.2 Assumptions

The following conservative assumptions were used for simulating the fate and transport of pollutants in groundwater using BIOSCREEN:

- Stormwater pollutant concentrations are conservatively assumed to continuously discharge to UICs at concentrations equal to the proposed EDL.
- An average scenario and reasonable maximum scenario were simulated in BIOSCREEN to assess a conservative range of pollutant fate and transport distances in groundwater.
- The scale of pollutant transport is sufficiently large so that dispersion by molecular diffusion is not significant.

4.3 Input Parameters

Input parameters were selected using site-specific information when possible. This section documents the input parameters used for BIOSCREEN simulations.

Seepage Velocity

Seepage velocity under saturated conditions is calculated by the average linear velocity form of Darcy's Law (Fetter, 1994):

$$\nu = \frac{K}{\eta}\nabla h \qquad (19)$$

where:

K is horizontal hydraulic conductivity (L/T)
v is average linear groundwater velocity (L/T),
η is effective porosity (dimensionless), and
∇h is the horizontal hydraulic gradient (L/L)

Table 14 summarizes the input parameters used to calculate seepage velocity for the average and reasonable maximum scenarios of BIOSCREEN. A discussion of the parameters follows:

- **Horizontal hydraulic conductivity (K).** The horizontal hydraulic conductivity used in the BIOSCREEN model was based on the unconsolidated sedimentary aquifer (USA) hydraulic conductivity data from specific-capacity and aquifer tests determined by the USGS Simulation Analysis of the Groundwater Flow System in the Portland Basin (USGS, 1996b). The USA is equivalent to the UGA, which is the unit in which most City UICs are completed. Because the BIOSCREEN model uses horizontal hydraulic conductivity instead of vertical hydraulic conductivity, the hydraulic conductivity in the BIOSCREEN model is larger than the hydraulic conductivity used in Fate and Transport Tool.
- **Horizontal hydraulic gradient (∇h).** The horizontal hydraulic gradient used in the BIOSCREEN model was based on the range of Portland Basin specific hydraulic gradients given in DEQ's Fact Sheet and Class V Underground Injection Control (UIC) Permit Evaluation, Permit Number 102830 (2005).
- **Effective porosity (η).** The porosity used in the BIOSCREEN model was based on the range of porosity for unconsolidated gravel (Freeze and Cherry, pg. 37, 1979).

The seepage velocity calculated for the BIOSCREEN model is conservatively representative of the most permeable hydrogeologic unit [i.e., highly permeable catastrophic flood deposits (Qmf), equivalent to the unconsolidated gravels hydrogeologic unit (UGA)]. As shown in Table 14, a velocity of 49.4 feet/year (0.14 feet/day) is used in the average scenario and a velocity of 202.2 feet/year (0.55 feet/day) is used in the reasonable maximum scenario for the BIOSCREEN model.

Table 14. Seepage Velocity Calculations for BIOSCREEN Input
City of Gresham, Oregon

BIOSCREEN Transport Scenario	K (ft/day)	η (-)	∇h (-)	v (ft/year)
Average Scenario	220	0.325	0.0002	49.4
Reasonable Maximum Scenario	900	0.325	0.0002	202.2

Notes:
K = hydraulic conductivity
∇h = hydraulic gradient
ft = feet
η = porosity
v = velocity

Dispersion

Dispersion is the spreading of a pollutant plume caused by pore water mixing and differential advection. The dispersion coefficient, D, is defined as (Fetter, 1994):

$$D = \alpha_L v \tag{20}$$

where:

v is average linear groundwater velocity (L/T), and
α_L 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):

$$\alpha_L = L/10 \tag{21}$$

where:

L is the length scale of transport (i.e., horizontal separation distance) (L).

Dispersivity used in the BIOSCREEN model is based on the BIOSCREEN length scale of transport for each simulation. The longitudinal dispersivity is calculated from equation (21). Transverse dispersivity and vertical dispersivity used in the BIOSCREEN model were 10 percent of horizontal dispersivity.

Adsorption

The retardation factor, R, is estimated by the following equation (Freeze and Cherry, 1979):

$$R = 1 + \frac{(\rho_b)(K_{oc})(f_{oc})}{\eta} \tag{22}$$

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).

An in-depth discussion of these parameters is provided in Section 2.5 of this TM. Because only organic carbon incorporated into the material during deposition is considered for the simulation of pollutant transport in the saturated zone, the fraction organic carbon used in the BIOSCREEN model is smaller than the fraction organic carbon used in the Fate and Transport Tool. The fraction organic carbon used in the BIOSCREEN model is the average fraction organic carbon measured in the UGA from 14 samples collected at Baron-Blakeslee site in northeast portland (ECSI No. 1274). Table 15 summarizes the parameter values for calculating the retardation factors. The retardation factor used in the BIOSCREEN model is smaller than the retardation factor used in the Fate and Transport Tool because a smaller fraction organic carbon value was used.

Table 15. Retardation Calculations for BIOSCREEN Input
City of Gresham, Oregon

Pollutant	BIOSCREEN Transport Scenario	ρ_b (g/cm^3)	K_{oc} (L/kg)	f_{oc} (-)	η (-)	R (-)
PCP	Average Scenario	1.79	822	0.00038	0.325	2.7
	Reasonable Maximum Scenario	1.79	822	0.00038	0.325	2.7
Naphthalene	Average Scenario	1.79	1300	0.00038	0.325	3.7
	Reasonable Maximum Scenario	1.79	830	0.00038	0.325	2.7
2,4-D	Average Scenario	1.79	201	0.00038	0.325	1.4
	Reasonable Maximum Scenario	1.79	20	0.00038	0.325	1.0
Toluene	Average Scenario	1.79	162	0.00038	0.325	1.3
	Reasonable Maximum Scenario	1.79	37	0.00038	0.325	1.1

Notes:
ρ_b = bulk density
K_{oc} = organic carbon partitioning coefficient
η = porosity
g = gram
kg = kilogram
(-) indicates dimensionless
PCP = pentachlorophenol
cm^3 = cubic centimeter
R = retardation factor
f_{oc} = fraction organic carbon

Biodegradation

As shown in Table 16, biodegradation for the pollutants evaluated in the BIOSCREEN model was calculated using pollutant half-lives in groundwater (Howard et al., 1991). The biodegradation rates represent conditions expected to be encountered in the saturated zone beneath UICs rather than the unsaturated zone; therefore, the biodegradation rates used in the BIOSCREEN model differ slightly from the biodegradation rates used in the Fate and Transport Tool. The maximum observed half life for biodegradation in groundwater was used for the reasonable maximum scenario, and the median observed half life for biodegradation in groundwater was used for the average scenario.

Table 16. Biodegradation Rates for BIOSCREEN Input
City of Gresham, Oregon

Pollutant	BIOSCREEN Transport Scenario	Half-Life (year)	Biodegradation Rate Constant (year^{-1})
PCP	Average Scenario	2.16	0.32
	Reasonable Maximum Scenario	4.2	0.17
Naphthalene	Average Scenario	0.35	2.0
	Reasonable Maximum Scenario	0.71	0.98
2,4-D	Average Scenario	0.27	2.6
	Reasonable Maximum Scenario	0.50	1.4
Toluene	Average Scenario	0.048	14.0
	Reasonable Maximum Scenario	0.077	9.0

Notes:
PCP = pentachlorophenol

Soluble Mass

The theoretical soluble mass in the source is input into BIOSCREEN so that the mass loading during the fate and transport simulation does not exceed the mass in the source. The maximum amount of soluble mass loaded at a given UIC was calculated by the following equation:

$$M_x = (V_{sw})(C_x) \quad (23)$$

where:

- M_x = soluble mass of x pollutant (M)
- V_{sw} = volume of stormwater that infiltrated at a given UIC (L^3)
- C_x = output concentration from the reasonable maximum scenario of the Fate and Transport Tool analysis [stormwater pollutants discharge to UICs at the proposed EDL (M/L^3)]

Table 17 shows calculations for soluble mass for PCP and naphthalene used in the BIOSCREEN model. The pollutant concentrations reaching the groundwater (C_x) are equal to the output concentrations calculated using a 10-foot separation distance under the reasonable maximum scenario of the unsaturated zone Fate and Transport Tool. As outlined in Section 2.5 of this TM, the infiltration time [i.e., number of days exceeding the threshold precipitation rate for stormwater to discharge into UICs (≥ 0.04 inches/hour of precipitation)] is approximately 14.24 days per year. The volume of stormwater infiltrated into the UIC (V_{sw}) was calculated using the following formula:

$$V_{sw} = \text{(Average Impervious Area per UIC)(Threshold Precipitation Rate)(Infiltration Time)(1 – Evaporative Loss Factor)} \quad (24)$$

Equation (24) calculates an average infiltration volume for UICs based on the average impervious area per UIC, a precipitation rate required for runoff to UICs (≥ 0.04 inches/hour), 14.24 days of average annual precipitation ≥ 0.04 inches/hour, and the evaporative loss factor described in Section 2.5 of this TM.

Table 17. Soluble Mass Calculations for BIOSCREEN Input
City of Gresham, Oregon

Pollutant	V_{sw} (L)	BIOSCREEN Transport Scenario	Concentration, C_x (mg/L)[1]	Soluble Mass, M_x (mg)
PCP	299,000	Average and Reasonable Maximum Scenario	0.00496	1,483
Naphthalene	299,000	Average and Reasonable Maximum Scenario	0.00477	1,426
2,4-D	299,000	Average and Reasonable Maximum Scenario	0.00231	691
Toluene	299,000	Average and Reasonable Maximum Scenario	0.00456	1,363

Notes:
V_{sw} = stormwater volume L = liters kg = kilogram mg = milligram
PCP = pentachlorophenol
[1] Assumes 10 feet separation distance and conservative assumptions as defined by the reasonable maximum scenario of the Fate and Transport Tool.

BIOSCREEN simulates reduction in source concentration by limiting the amount (by weight) of mass that is loaded into the aquifer during transport.

Discretization

BIOSCREEN requires specification of transport time and a maximum extent or dimensions (model domain) of the groundwater area that might be affected by the contaminant plume, including: source thickness (z-direction), source width (y-direction), and modeled area length (x-direction). These parameters and the rationale for using these parameters are summarized in Table 18.

Table 18. BIOSCREEN Discretization
City of Gresham, Oregon

Parameter	Value	Rationale
Modeled Area Length	varies	Distance is greater than pollutants migrate during modeled transport time
Modeled Area Width	40 feet	Distance is greater than the diameter of a UIC
Modeled Area Thickness	10 feet	No significant vertical gradients
Transport Time	0.039 years (14.24 days)	Consistent with mass loading calculation and equal to the infiltration time.

4.4 BIOSCREEN Results and Conclusions

BIOSCREEN was used to simulate fate and transport of PCP, naphthalene, 2,4-D, and toluene under the average and reasonable maximum scenarios. Results of the BIOSCREEN simulations are discussed in the following sections.

PCP Fate and Transport

Results of the BIOSCREEN fate and transport simulations for PCP are shown in Figures 6 and 7 (average scenario) and Figures 8 and 9 (reasonable maximum scenario). The BIOSCREEN simulations indicate that:

- Under the average BIOSCREEN scenario, PCP concentrations are below the MRL after about 2 feet of fate and transport through the saturated zone.
- Under the reasonable maximum BIOSCREEN scenario, PCP concentrations are below the MRL after about 7.5 feet of fate and transport through the saturated zone.

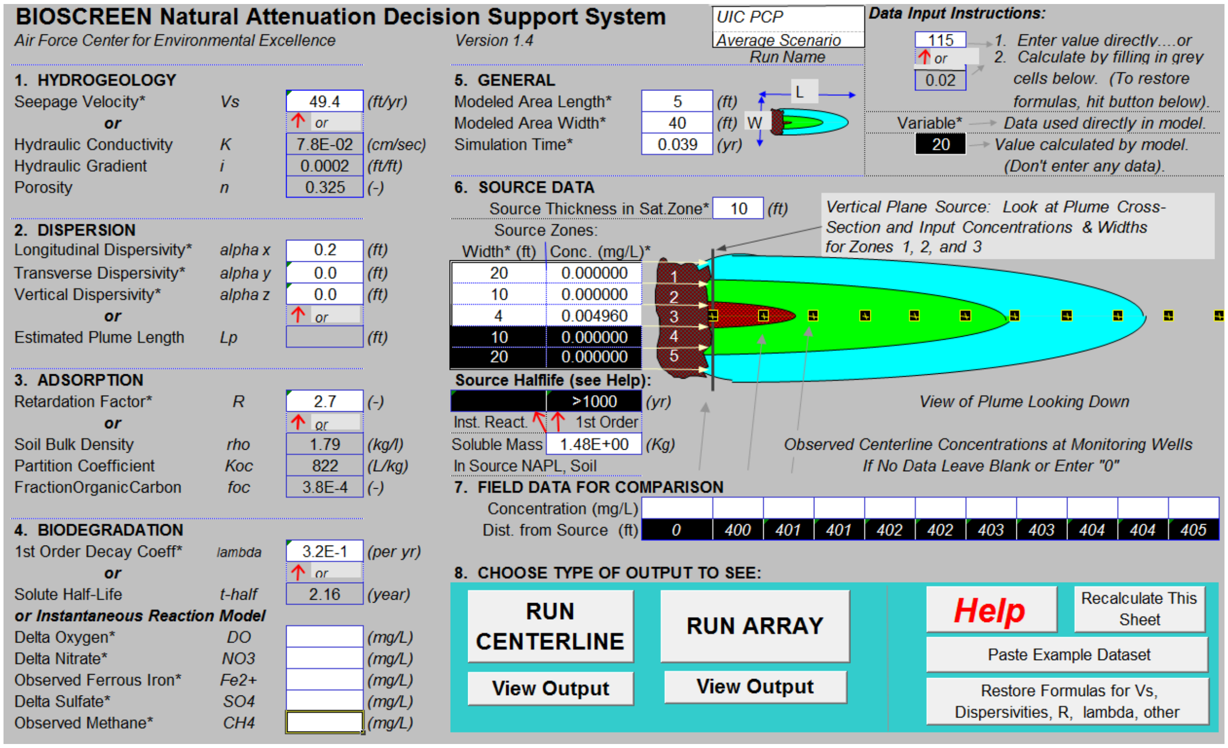


Figure 6. Input parameters for PCP BIOSCREEN model – average scenario.
City of Gresham, Oregon

DISSOLVED PCP CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
No Degradation	4.96E-03	3.24E-03	1.45E-03	3.40E-04	3.78E-05	1.89E-06	4.14E-08	3.89E-10	1.56E-12	2.63E-15	1.93E-18
1st Order Decay	4.96E-03	3.22E-03	1.44E-03	3.37E-04	3.75E-05	1.88E-06	4.10E-08	3.85E-10	1.54E-12	2.60E-15	1.76E-18
MRL (mg/L)	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05
Field Data from Site											

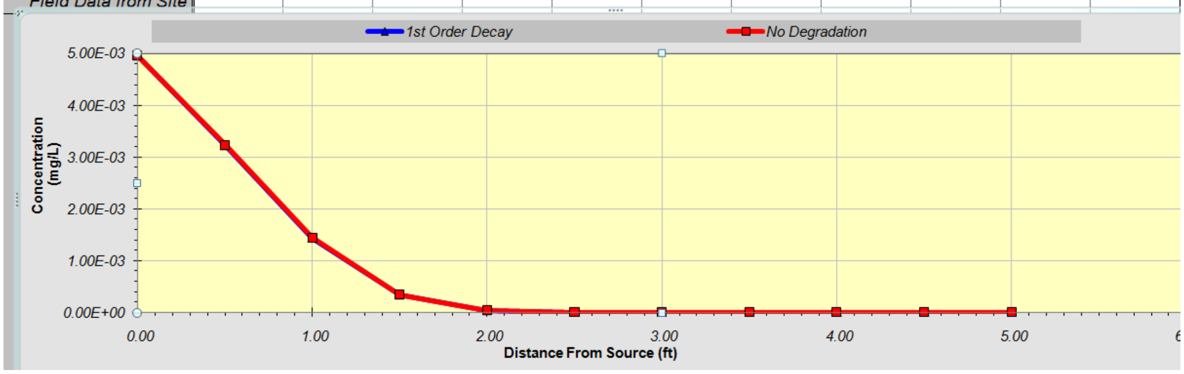


Figure 7. BIOSCREEN model output for PCP – average scenario.
City of Gresham, Oregon

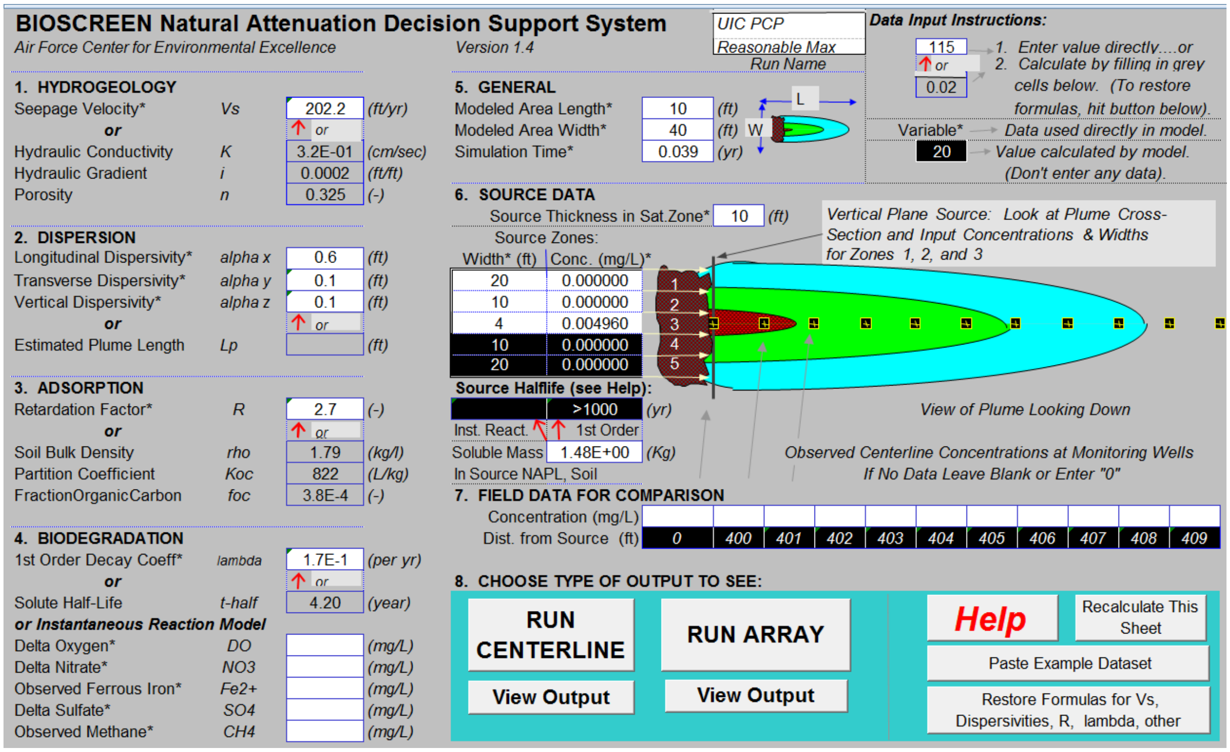


Figure 8. Input parameters for PCP BIOSCREEN model – reasonable maximum scenario.
City of Gresham, Oregon

DISSOLVED PCP CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
No Degradation	4.96E-03	4.19E-03	3.40E-03	2.37E-03	1.37E-03	6.38E-04	2.34E-04	6.70E-05	1.48E-05	2.50E-06	3.24E-07
1st Order Decay	4.96E-03	4.19E-03	3.39E-03	2.36E-03	1.36E-03	6.35E-04	2.33E-04	6.67E-05	1.47E-05	2.49E-06	3.22E-07
MRL (mg/L)	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05	4.00E-05
Field Data from Site											

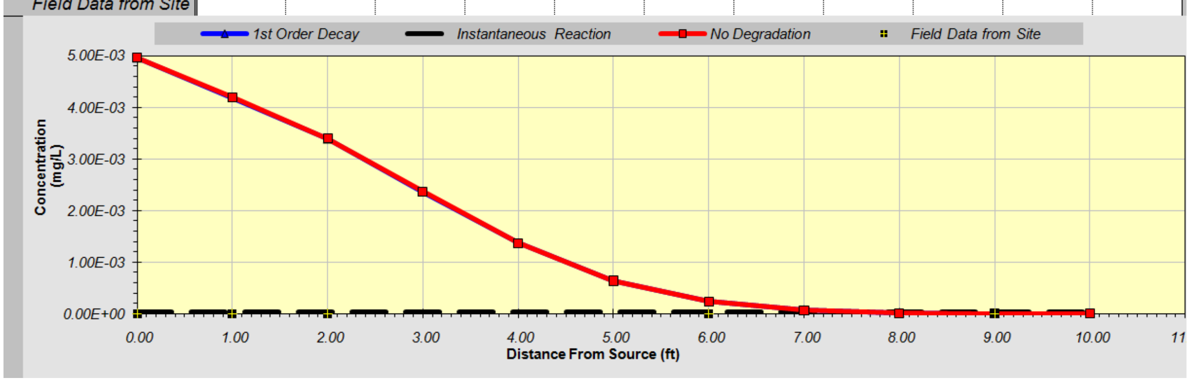


Figure 9. BIOSCREEN model output for PCP – reasonable maximum scenario.
City of Gresham, Oregon

Naphthalene Fate and Transport

Results of the BIOSCREEN fate and transport simulations for Naphthalene are shown in Figures 10 and 11 (average scenario) and Figures 12 and 13 (reasonable maximum scenario). The BIOSCREEN simulations indicate that:

- Under the average BIOSCREEN scenario, naphthalene concentrations are below the MRL after 1.4 feet of fate and transport through the saturated zone.
- Under the reasonable maximum BIOSCREEN scenario, naphthalene concentrations are below the MRL after about 7.5 feet of fate and transport through the saturated zone.

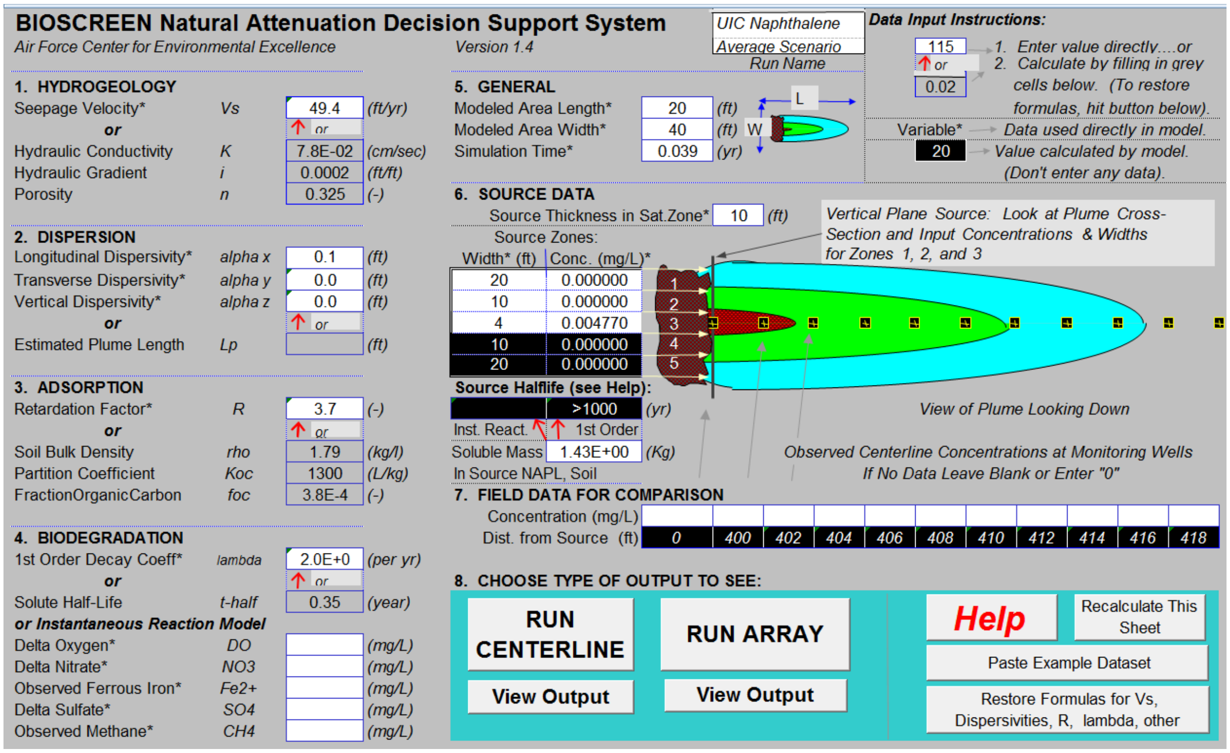
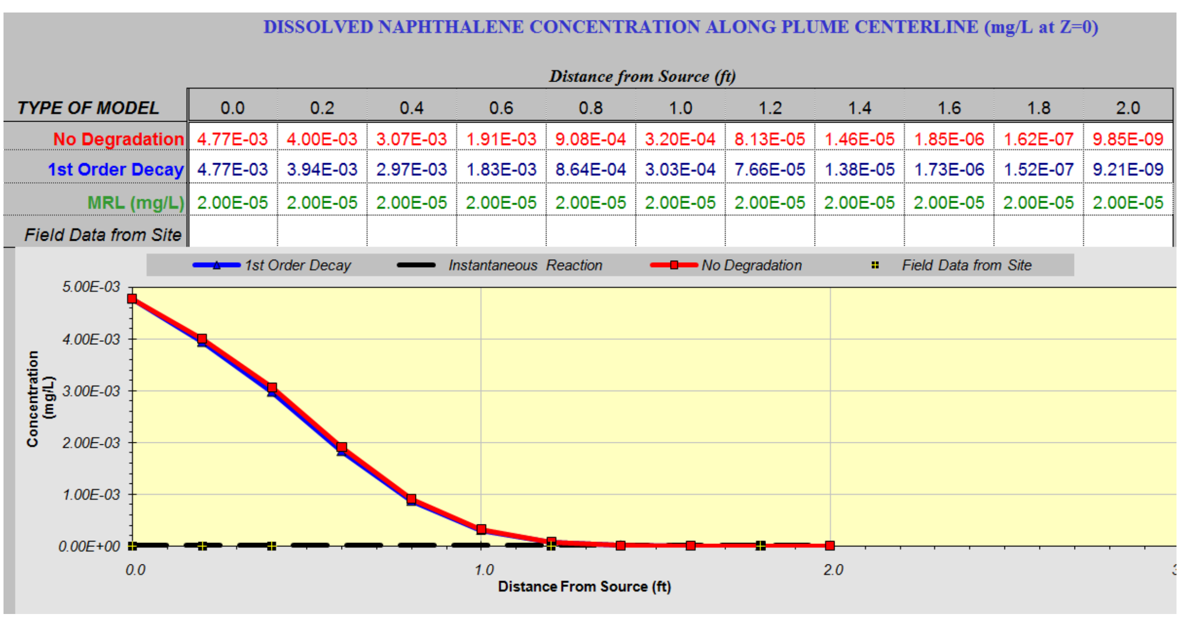


Figure 10. Input parameters for naphthalene BIOSCREEN model – average scenario.
City of Gresham, Oregon



DISSOLVED NAPHTHALENE CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
No Degradation	4.77E-03	4.00E-03	3.07E-03	1.91E-03	9.08E-04	3.20E-04	8.13E-05	1.46E-05	1.85E-06	1.62E-07	9.85E-09
1st Order Decay	4.77E-03	3.94E-03	2.97E-03	1.83E-03	8.64E-04	3.03E-04	7.66E-05	1.38E-05	1.73E-06	1.52E-07	9.21E-09
MRL (mg/L)	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05
Field Data from Site											

Figure 11. BIOSCREEN model output for naphthalene – average scenario.
City of Gresham, Oregon

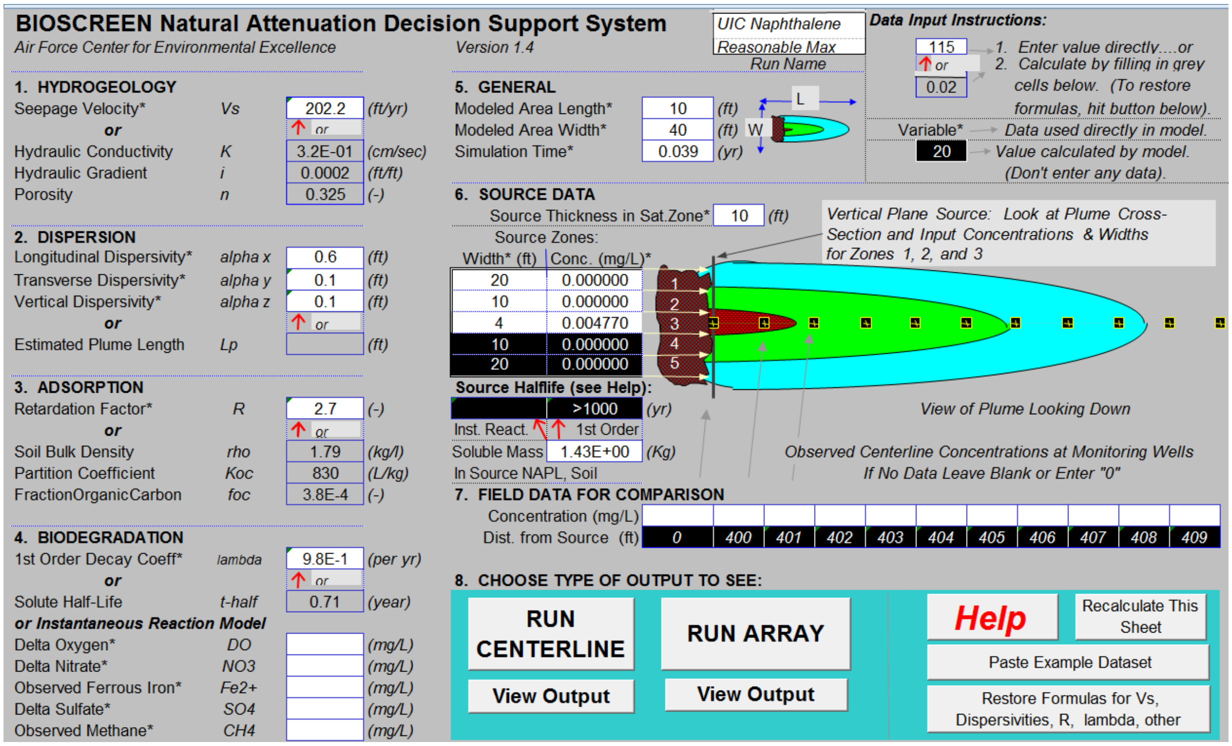


Figure 12. Input parameters for naphthalene BIOSCREEN model – reasonable maximum scenario.
City of Gresham, Oregon

DISSOLVED NAPHTHALENE CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
No Degradation	4.77E-03	4.03E-03	3.25E-03	2.26E-03	1.30E-03	6.00E-04	2.19E-04	6.18E-05	1.35E-05	2.25E-06	2.85E-07
1st Order Decay	4.77E-03	4.00E-03	3.21E-03	2.22E-03	1.27E-03	5.85E-04	2.12E-04	6.00E-05	1.31E-05	2.18E-06	2.76E-07
MRL (mg/L)	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05	2.00E-05
Field Data from Site											

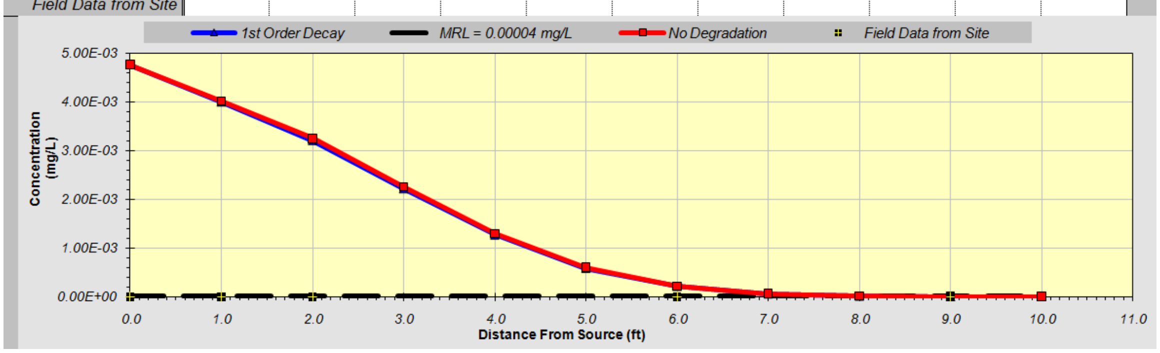


Figure 13. BIOSCREEN model output for naphthalene – reasonable maximum scenario.
City of Gresham, Oregon

2,4-D Fate and Transport

Results of the BIOSCREEN fate and transport simulations for 2,4-D are shown in Figures 14 and 15 (average scenario) and Figures 16 and 17 (reasonable maximum scenario). The BIOSCREEN simulations indicate that:

- Under the average BIOSCREEN scenario, 2,4-D concentrations are below the MRL after just over 2.5 feet of fate and transport through the saturated zone.
- Under the reasonable maximum BIOSCREEN scenario, naphthalene concentrations are below the MRL after about 4 feet of fate and transport through the saturated zone.

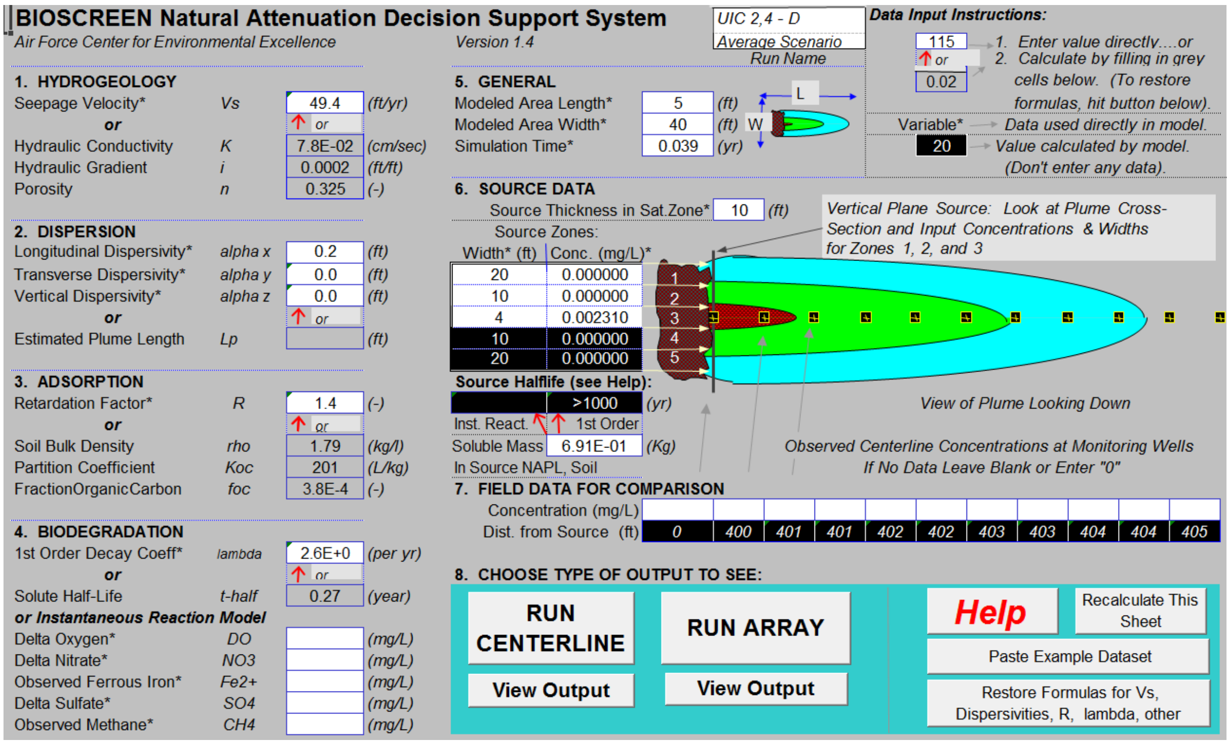


Figure 14. Input parameters for 2,4-D BIOSCREEN model – average scenario.
City of Gresham, Oregon

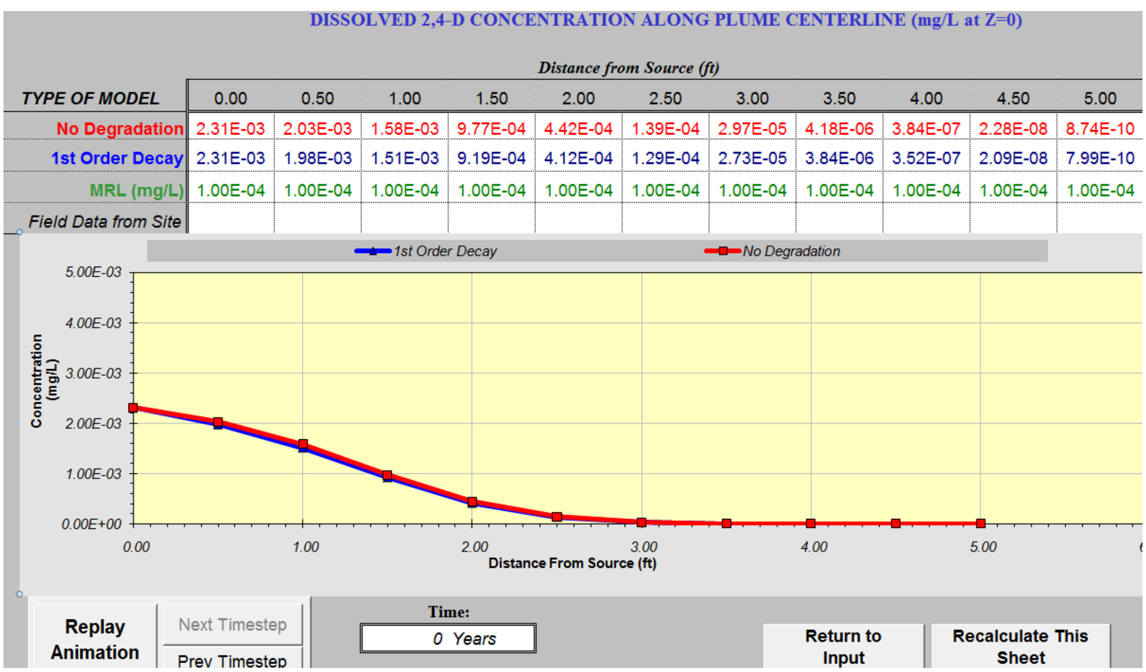


Figure 15. BIOSCREEN model output for 2,4-D – average scenario.
City of Gresham, Oregon

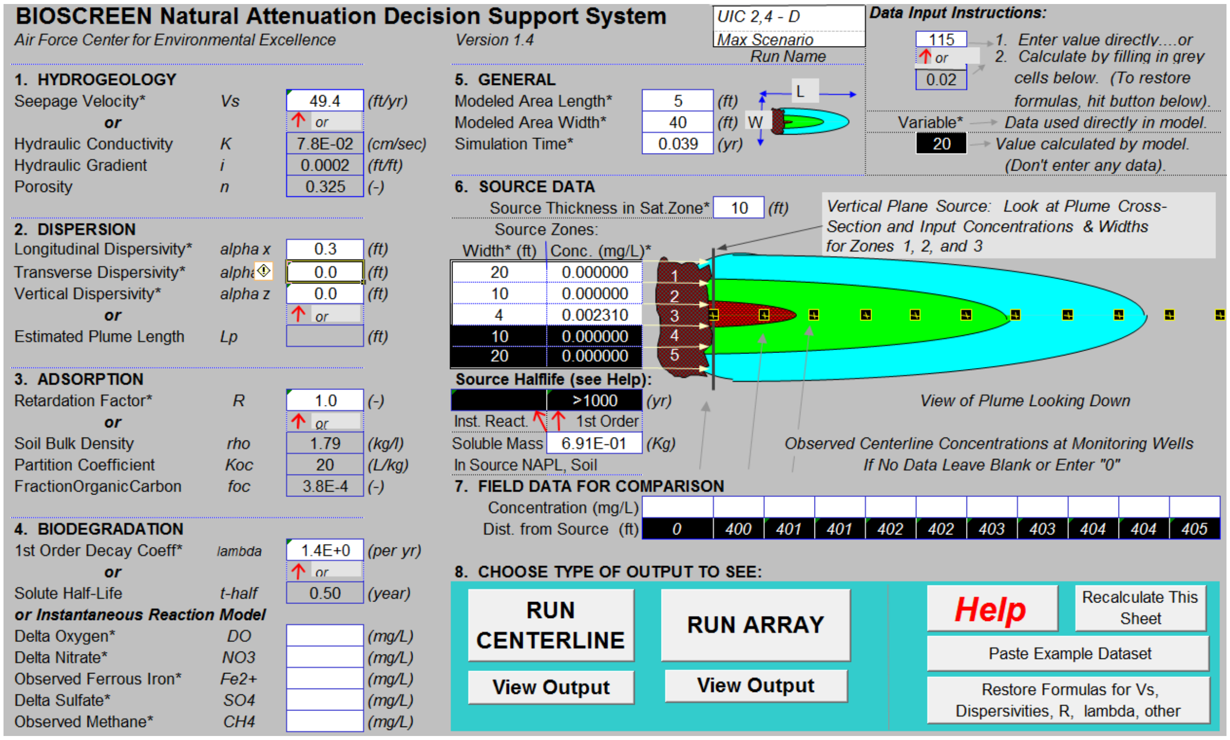


Figure 16. Input parameters for 2,4-D BIOSCREEN model – reasonable maximum scenario.
City of Gresham, Oregon

DISSOLVED 2,4-D CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
No Degradation	2.31E-03	2.08E-03	1.83E-03	1.46E-03	1.02E-03	6.20E-04	3.18E-04	1.35E-04	4.76E-05	1.37E-05	3.22E-06
1st Order Decay	2.31E-03	2.06E-03	1.79E-03	1.42E-03	9.93E-04	5.99E-04	3.06E-04	1.30E-04	4.56E-05	1.31E-05	3.08E-06
MRL (mg/L)	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
Field Data from Site											

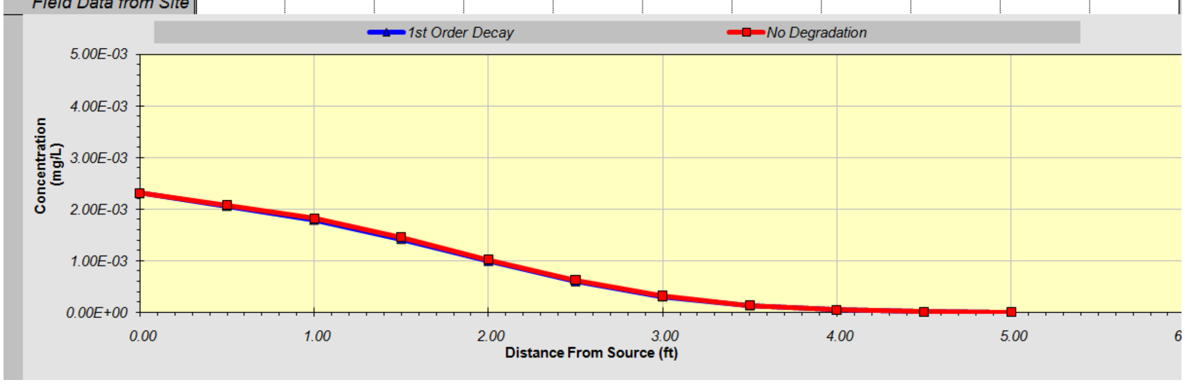


Figure 17. BIOSCREEN model output for 2,4-D – reasonable maximum scenario.
City of Gresham, Oregon

Toluene Fate and Transport

Results of the BIOSCREEN fate and transport simulations for Toluene are shown in Figures 18 and 19 (average scenario) and Figures 20 and 21 (reasonable maximum scenario). The BIOSCREEN simulations indicate that:

- Under the average BIOSCREEN scenario, Toluene concentrations are below the MRL after 2.5 feet of fate and transport through the saturated zone.
- Under the reasonable maximum BIOSCREEN scenario, Toluene concentrations are below the MRL after about 3.0 feet of fate and transport through the saturated zone.

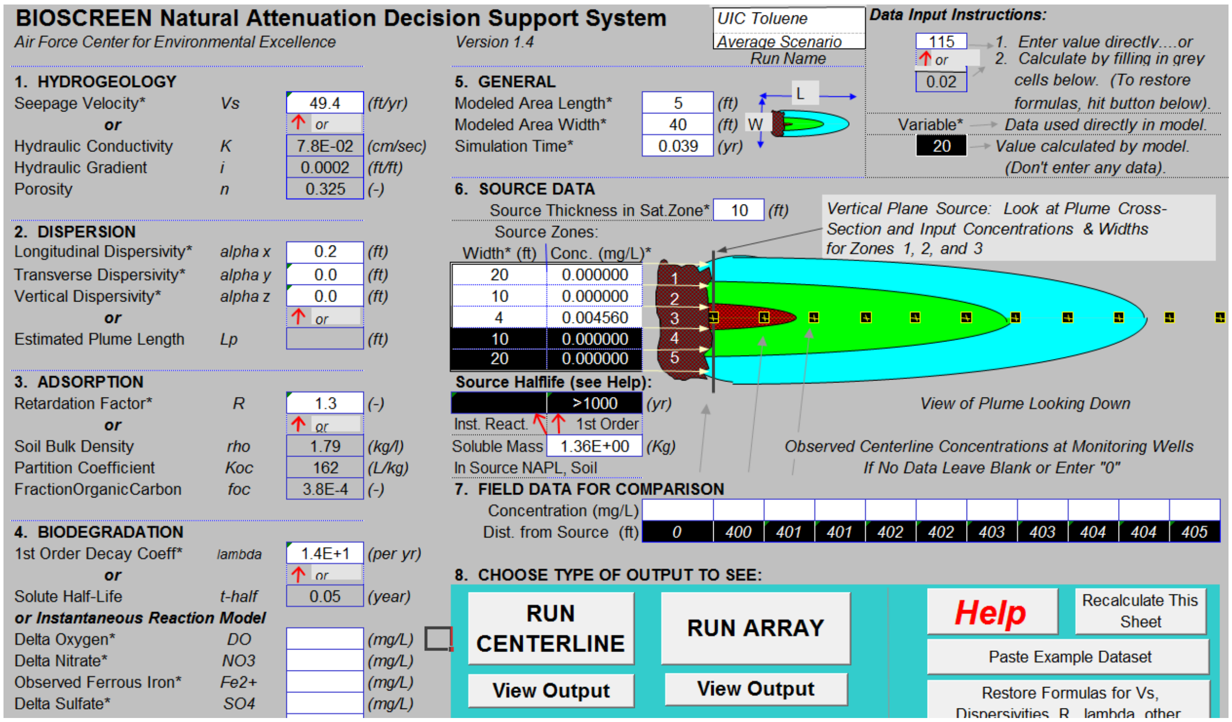
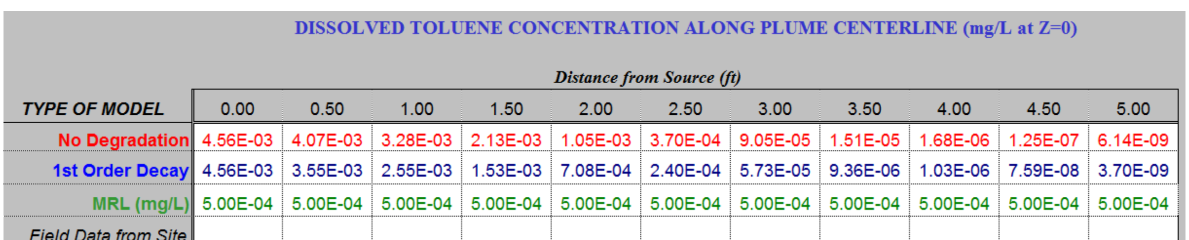


Figure 18. Input parameters for Toluene BIOSCREEN model – average scenario.
City of Gresham, Oregon



DISSOLVED TOLUENE CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
No Degradation	4.56E-03	4.07E-03	3.28E-03	2.13E-03	1.05E-03	3.70E-04	9.05E-05	1.51E-05	1.68E-06	1.25E-07	6.14E-09
1st Order Decay	4.56E-03	3.55E-03	2.55E-03	1.53E-03	7.08E-04	2.40E-04	5.73E-05	9.36E-06	1.03E-06	7.59E-08	3.70E-09
MRL (mg/L)	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Field Data from Site											

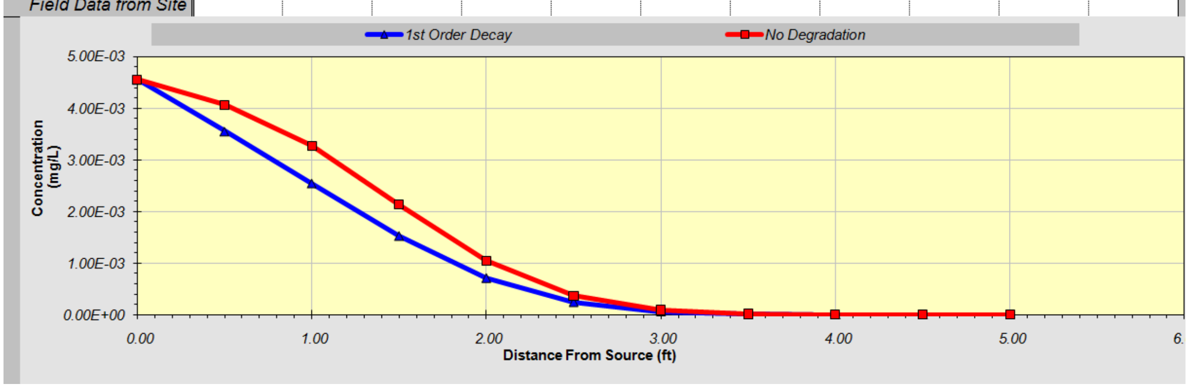


Figure 19. BIOSCREEN model output for Toluene – average scenario.
City of Gresham, Oregon

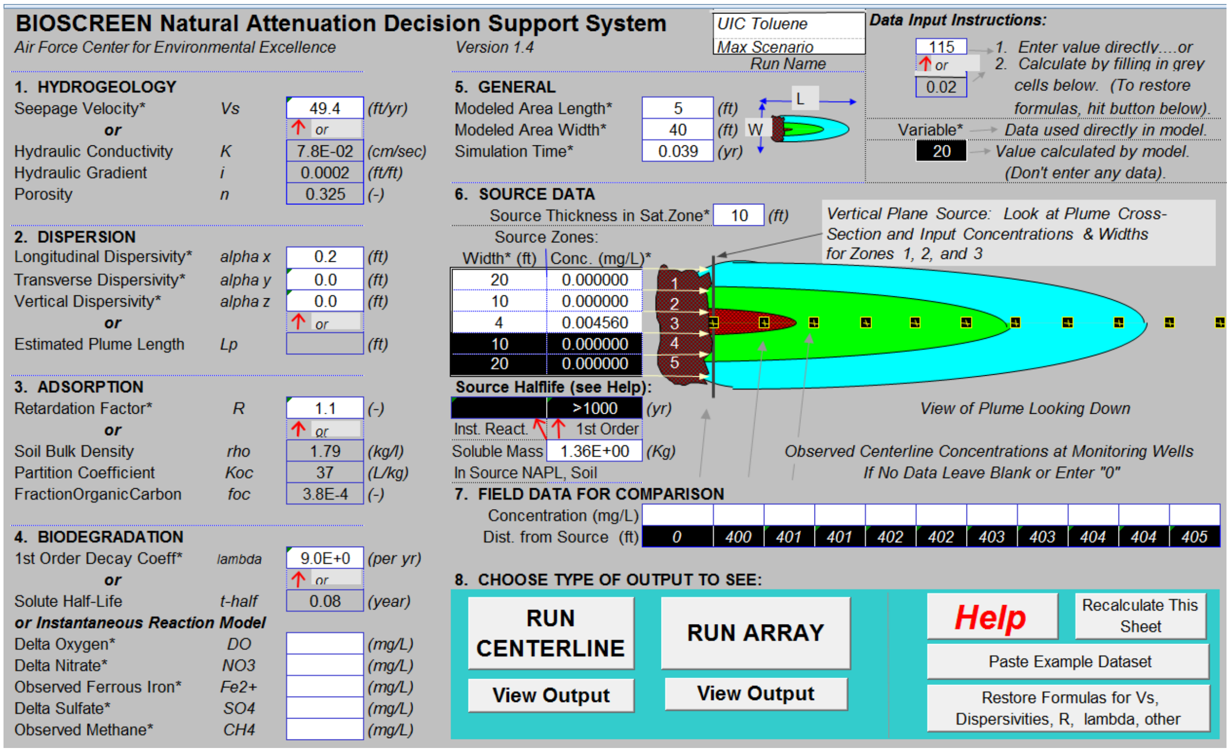


Figure 20. Input parameters for Toluene BIOSCREEN model – reasonable maximum scenario.
City of Gresham, Oregon

DISSOLVED TOLUENE CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
No Degradation	4.56E-03	4.27E-03	3.76E-03	2.89E-03	1.83E-03	9.13E-04	3.47E-04	9.82E-05	2.04E-05	3.08E-06	3.35E-07
1st Order Decay	4.56E-03	3.96E-03	3.26E-03	2.38E-03	1.45E-03	7.05E-04	2.63E-04	7.34E-05	1.51E-05	2.26E-06	2.45E-07
MRL (mg/L)	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Field Data from Site											

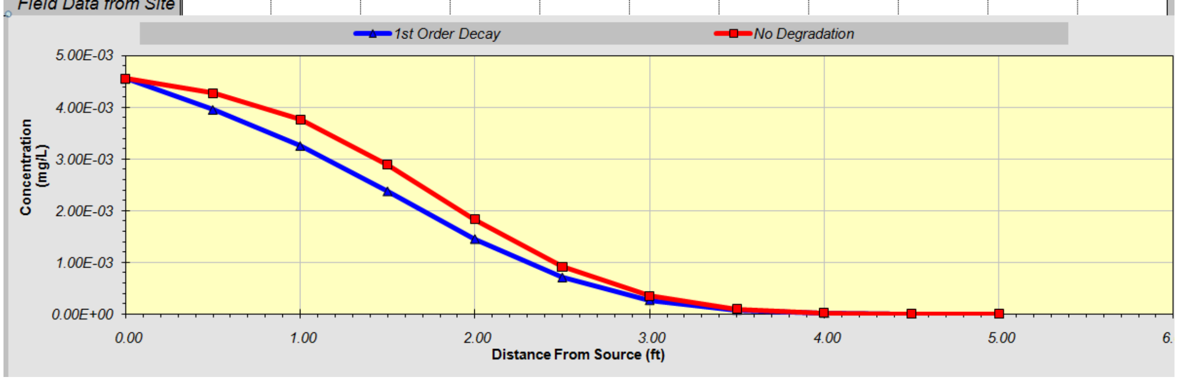


Figure 21. BIOSCREEN model output for Toluene – reasonable maximum scenario.
City of Gresham, Oregon

4.5 Conclusions

Table 19 summarizes the maximum distances that PCP, naphthalene, 2,4-D, and toluene are expected to travel in groundwater before reaching a concentration below the MRL. These estimates are conservative because they assume constant discharge into UICs during seasonal high groundwater levels at pollutant concentrations equal to the proposed EDL. These estimates also are conservative because they do not account for dilution at the point stormwater enters groundwater. Because of the complexities in the hydrogeologic system and variability in stormwater concentrations, both average and reasonable maximum scenarios are provided to assess the uncertainties in the BIOSCREEN fate and transport calculations.

Based on reasonable maximum scenario of the Fate and Transport Tool and the BIOSCREEN analyses, the following conclusions are made:

- Based on the unsaturated zone Fate and Transport Tool, PCP, naphthalene, 2,4-D, and toluene are the only pollutants that reach groundwater at concentrations greater than the MRL when entering the UIC at the proposed EDL under the reasonable maximum transport scenario. The concentrations estimated to reach the groundwater under the reasonable maximum scenario are conservatively used as the input concentrations into the BIOSCREEN model (i.e., no dilution occurs).
- Based on BIOSCREEN, pollutants travel less than 2.5 feet (average scenario) and 8 feet (reasonable maximum scenario) from the UIC. The estimated transport distances in groundwater are shown in Table 19.

Table 19. Estimated Pollutant Travel Distances in Groundwater
City of Gresham, Oregon

Pollutant	**MRL** (ug/L)	**Pollutant Concentration Discharging into UIC** [1] (ug/L)	**Pollutant Input Concentration at Water Table** [2] (ug/L)	**BIOSCREEN Transport Scenario**	**Travel Distance until Concentration is ≤ MRL** (feet)
PCP	0.04	10	4.27	Average	2.0
				Reasonable Maximum	7.5
Naphthalene	0.02	10	4.77	Average	1.4
				Reasonable Maximum	7.5
2,4-D	0.1	4.14	2.31	Average	2.5
				Reasonable Maximum	4.0
Toluene	0.5	9.64	4.56	Average	2.5
				Reasonable Maximum	3.0

Notes:
PCP = pentachlorophenol
EDL = effluent discharge limit
RSL = Environmental Protection Agency Regional Screening Level for tap water
mg = milligrams
L = liters
MRL = analytical laboratory method reporting limit
[1] Pollutant concentration equal to the proposed EDL
[2] Assumes 5 feet separation distance and conservative assumptions as defined by the reasonable maximum scenario.

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FIGURES

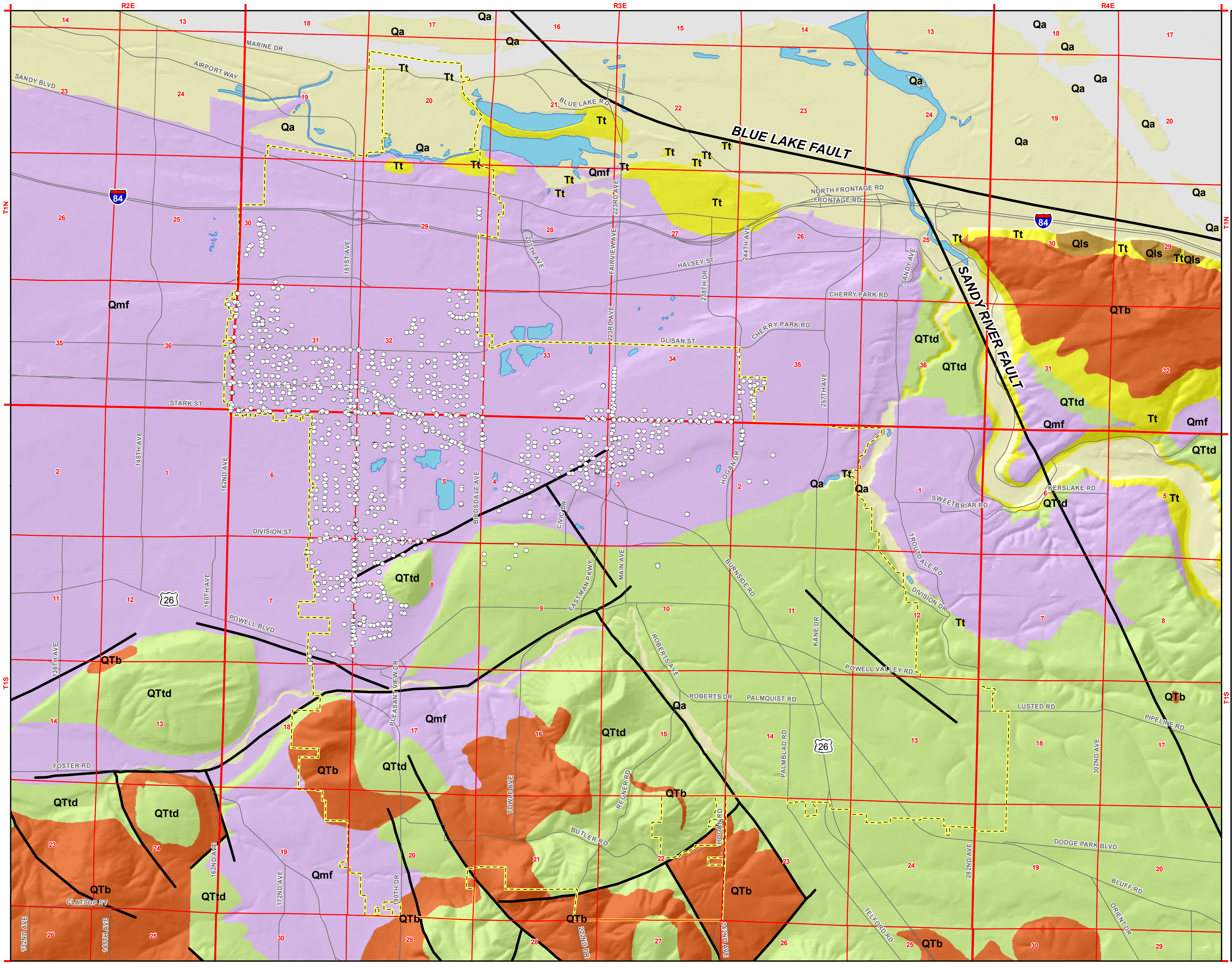

FIGURE 2

UIC Locations and Geology

City of Gresham

LEGEND

- UIC Locations
- Gresham City Limits
- Major Roads

Geology

- Qa - Alluvium
- Qls - Landslide Deposits
- Qmf - Missoula Flood Deposits
- QTb - Boring Lavas (undifferentiated)
- QTtd - Quaternary/Teritary Terrace Deposits
- Tt - Troutdale Formation
- Water
- Faults

0 2000 4000 6000

Feet

N

MAP NOTES:

Projection: Oregon State Plane North Zone
Datum: North American Datum of 1983
Date: July 13, 2010
Data Sources: DOGAMI, USGS, METRO RLIS

GSI Water Solutions, Inc.

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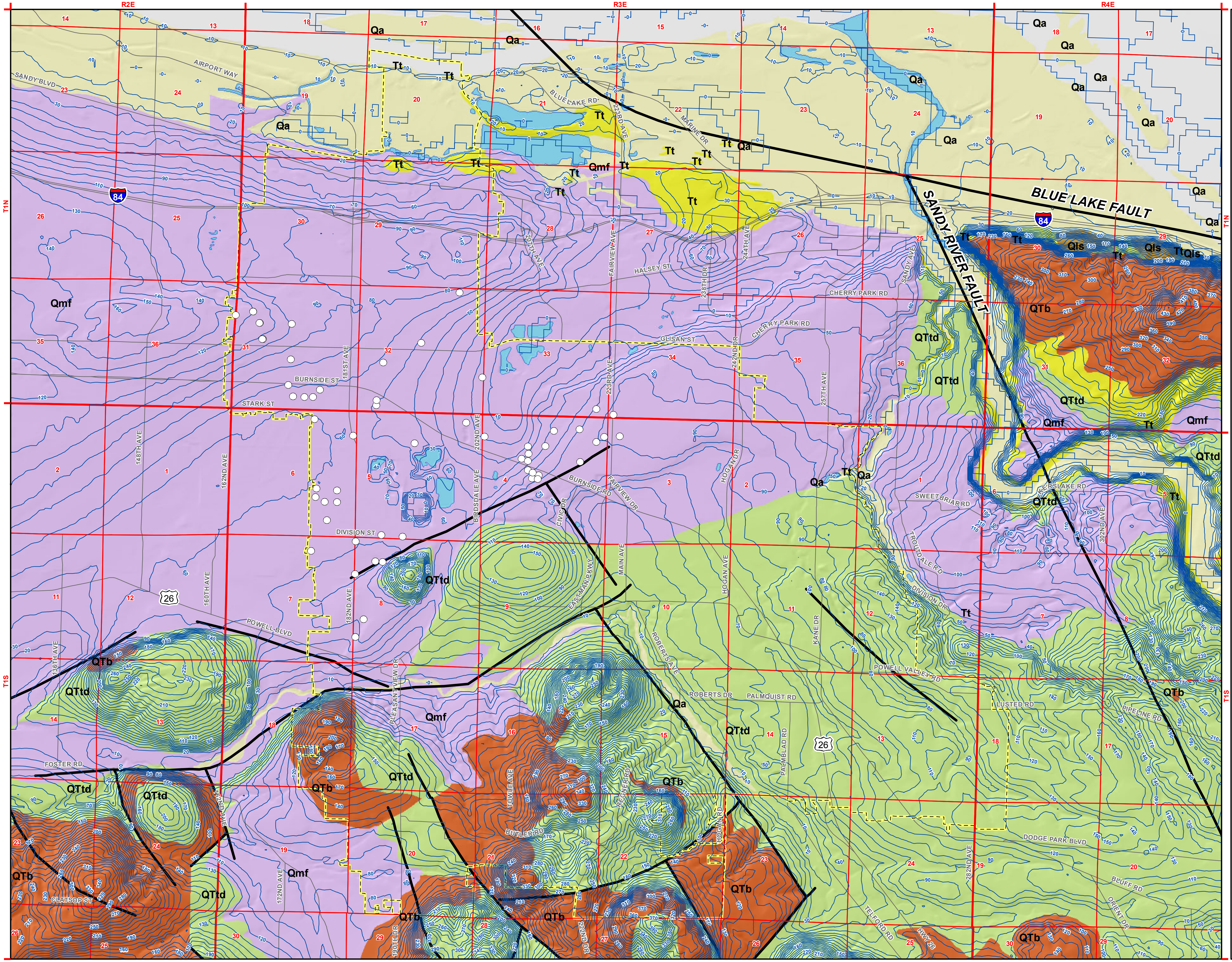

FIGURE 5

UICs with Infiltration Tests

City of Gresham

LEGEND

- UICs with Infiltration Tests
- Depth to Water - 10 foot Contours
- Gresham City Limits
- Major Roads

Geology

- Qa - Alluvium
- Qls - Landslide Deposits
- Qmf - Missoula Flood Deposits
- QTb - Boring Lavas (undifferentiated)
- QTtd - Quaternary/Teritary Terrace Deposits
- Tt - Troutdale Formation
- Water
- Faults

0 2000 4000 6000

Feet

N

MAP NOTES:

Projection: Oregon State Plane North Zone
Datum: North American Datum of 1983
Date: July 13, 2010
Data Sources: DOGAMI, USGS, METRO RLIS

GSI Water Solutions, Inc.

TABLES

Table 1: Properties of WPCF Permit Pollutants Used in Selection of Representative Indicator Pollutants

City of Gresham, Oregon

	EDL [1]	MCL[1]	DEQ RBCs for Ground-water[2]	Toxicity Ranking	Solubility (mg/L)[4]	EPA Mobility Ranking[5]	Mobility of Pollutant	Persistence (half-life [days])[6]	Persistence Ranking	Frequency of Detection (%)[7]	Frequency of Detection Ranking	Frequency of Exceedance (%)	Pollutant Category[8]
	μg/L	μg/L	μg/L										
Common Pollutants													
Benzo(a)pyrene	**0.2**	**0.2**	**0.0029**	**High**	**0.0016**	**0.0001**	**Low**	**300**	**Medium**	**54.3**	**medium**	**1.4**	**PAH**
Di(2-ethylhexyl)phthalate	**6**	**6**	**4.1**	**High**	**0.34**	**0.0001**	**Low**	**14**	**Low**	**67.1**	**medium**	**4.3**	**SV**
Pentachlorophenol	**1**	**1**	**0.47**	**High**	**2000**	**1**	**High**	**100**	**Medium**	**67.1**	**medium**	**14.3**	**SV**
Antimony (Total)	6	6	NR	High	170,000	0.01	Medium	infinite	infinite	88.6	high	0	M
Arsenic (Total)	10	10	0.038	High	120000	0.01	Medium	infinite	infinite	97.1	high	0	M
Cadmium (Total)	5	5	18	High	1700	0.01	Medium	infinite	infinite	24.3	medium	0	M
Copper (Total)	**1300**	**1300**	**1400**	**Low**	**570**	**0.01**	**Medium**	**infinite**	**infinite**	**98.6**	**high**	**0**	**M**
Lead (Total)	**50**	**15**	**15**	**Medium**	**870**	**0.01**	**Medium**	**infinite**	**infinite**	**95.7**	**high**	**1.4**	**M**
Zinc (Total)	5000	NR	NR	Low	1400	0.01	Medium	infinite	infinite	98.6	high	0	M
Screening Pollutants (From draft WPCF UIC Permit *and* additional pollutants of concern in storm water)													
Barium (Total)	2000	2000	7300	Low	2,800	0.01	Medium	infinite	infinite	no data	no data	no data	M
Beryllium (Total)	4	4	73	High	84,000	0.01	Medium	infinite	infinite	no data	no data	no data	M
Chromium VI	100	100	110	Medium	600000	0.01	Medium	infinite	infinite	no data	no data	no data	M
Cyanide (Total)	200	200	730	Medium	NR	1.0	High	infinite	infinite	no data	no data	no data	O
Mercury (Total, inorganic)	2	2	11	High	450	0.01	Medium	infinite	infinite	81.4	high	0	M
Selenium (Total)	50	50	NR	Medium	2.60E+06	1.0	High	infinite	infinite	no data	no data	no data	M
Thallium (Total)	2	2	NR	High	8600	0.01	Medium	infinite	infinite	no data	no data	no data	M
Benzene	5	5	0.35	High	1800	1	High	10	Low	1.3	low	0	V
Toluene	**1000**	**1000**	**2300**	**Low**	**530**	**1**	**High**	**0.5**	**Low**	**11.8**	**low**	**0**	**V**
Ethylbenzene	700	700	1300	Low	170	1	High	0.3	Low	1.3	low	0	V
Xylenes	10,000	10,000	210	Low	180	1	High	17.5	Low	no data	no data	no data	V
Alachlor		2	NR	High	240	0.01	Medium	14	Low	no data	no data	no data	P/H
Atrazine		3	NR	High	70	0.01	Medium	100	Medium	no data	no data	no data	P/H
Carbofuran		40	NR	Medium	351	NR	Medium	110	Medium	no data	no data	no data	P/H
Carbon Tetrachloride		5	0.17	High	790	1.0	High	265	Medium	no data	no data	no data	V
Chlordane		2	0.16	High	0.056	0.01	Medium	812	High	no data	no data	no data	P/H
Chlorobenzene		100	90	Medium	470	1.0	High	110	Medium	no data	no data	no data	V
2,4-D [1, 2]	**70**	**70**	**370**	**Low**	**4500**	**NR**	**High**	**15**	**Low**	**4.3**	**low**	**0**	**P/H**
Dalapon	200	200	NR	Low	800,000	NR	High	16	Low	no data	no data	no data	P/H
Diazinon	7	NR	NR	NR	60	NR	Low	40	Low	no data	no data	no data	P
o-Dichlorobenzene		600	50	Low	4000	1.0	High	slow	High	no data	no data	no data	V
p-Dichlorobenzene		75	0.48	Medium	79	1.0	High	104	Medium	no data	no data	no data	V
1,3-Dichlorobenzene		NR	15	High	125	NR	High	42	Low	no data	no data	no data	V
Bis(2-chloroisopropyl)ether		NR	NR	High	1,700	NR	Medium	100	Medium	no data	no data	no data	SV
Bis(2-chloroethyl)ether	0.3	NR	NR	High	17,200	NR	Medium	100	Medium	no data	no data	no data	SV
Dinoseb	7	7	NR	High	52	NR	High	24	Low	0	low	0	P/H
Diquat		20	NR	Medium	700,000	NR	Low	infinite	Infinite	no data	no data	no data	P/H
Endothall		100	NR	Medium	100,000	NR	Medium	10	Low	no data	no data	no data	P/H
Glyphosate	700	700	NR	Low	11,600	NR	Low	60	Medium	no data	no data	no data	P/H
Lindane[HCH(gamma)]		0.2	0.044	High	7.3	1.0	High	980	High	no data	no data	no data	P/H
Picloram		500	NR	Low	430	NR	Medium	100	Medium	0	low	0	P/H
1,2,4-Trichlorobenzene		70	12	Medium	35	1.0	High	104	Medium	no data	no data	no data	V
Nitrate-nitrogen	10,000	10,000	NR	Low	High in soil & water	NR	High	infinite	infinite	no data	no data	no data	O
Other Pollutants													
Naphthalene	**N/A**	**NR**	**6.2**	**High**	**31**	**0.01**	**Low**	**10**	**Low**	**74.3**	**medium**	**NA**	**PAH**

Table notes:

Pollutants shown in bold and orange highlighting were selected as indicator pollutants for the evaluation of separation distance.

[1] Effluent Discharge Limits (EDL) are based on Table A.5.1 and A.5.2 of the WPCF Permit for Class V UICs -- Municipal Template, Draft, Accessed on March 2, 2011. Maximum contaminant level (MCL). U.S. EPA Drinking Water Contaminants. http://www.epa.gov/safewater/contaminants/index.html (Accessed 12/6/07)

[2] Oregon DEQ Risk Based Concentrations (RBCs) for Groundwater Ingestion and Inhalation from Tapwater, Residential. 7/4/07. http://www.deq.state.or.us/lq/pubs/docs/RBDMTable.pdf (Accessed 5/19/08)

[3] Cancerous (ca); Non-cancerous (nc)

[4,5] U.S. EPA Superfund Chemical Data Matrix Methodology Report, Appendix A (2004). http://www.epa.gov/superfund/sites/npl/hrsres/tools/app_a_1.pdf (Accessed 12/07)USEPA (2006). Groundwater & Drinking Water Technical Factsheets. Available at: http://www.epa.gov/ogwdw/hfacts.html

[6] References for degradation rates:

a) Howard, Phillip; Robert S. Boethling; William F. Jarvis; William M. Meylan; and Edward M. Mickalenko, 1991) Handbook of Environmental Degradation Rates, Lewis Publishers.

b) EPA Technical Fact Sheets

[7] Stormwater data from 2009 - 2010 City of Gresham storm water sampling

[8] Volatile organic compound (V), metal (M), polycyclic aromatic hydrocarbon (PAH), semi-volatile organic compound (SV), pesticide/herbicide (P/H), other (O)

Solubility = the maximum dissolved quantiy of a pollutant in pure water at a given temperature.

Log K_{ow} = octanol/water partition coefficient is the ratio of a compounds concentration in the octanol phase to its concentration in the aqueous phase of a two-phase system. Low Kow values (<10) are considered hydrophlic and tend to have higher water solubility. High Kow values (>104) are very hydrophobic.

K_d = soil/water distibution coefficient. The amount of a chemical adsorbed by a sediment or soil (i.e., the solid phase) divided by the amount of test chemical in the solution phase, which is in equilibrium with the solid phase, at a fixed solid/solution ratio.

K_{oc} = soil/water distibution coefficient. Koc is a measure of the tendency for organic chemicals to be adsorbed to the soil. The higher the Koc value for each compound, the lower the mobility and the higher the adsorption.

Vapor Pressure = pressure exerted by a vapor in equilibrium with the solid or liquid phase of the same substance.

Mobility Ranking = from EPA's SCDM (reference 1). Value used where available; based on solubility and the soil/water distribution coefficient to determine the relative groundwater mobility factor.

Mobility of Pollutant = used in the UIC prioritization procedure to conservatively (assumes no dilution and/or degration) estimate the mobility of stormwater pollutants discharged to a UIC (i.e., through soil) to have adverse impacts on groundwater quality.

APPENDICES

Appendix A

Table 1. Pollutant Fate and Transport

Calculating Transport Distance Needed to Reach MRLs

	Parameter	Symbol	Units	Metals				PAHs				SVOCs				Pesticides/ Herbicides		VOCs	
				Copper		Lead		Benzo(a)pyrene		Naphthalene		PCP		di-(2-ethylhexyl) phthalate		2,4-D		Toluene	
				Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	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	0.07	0.44	0.005	0.0232	0.00133	0.01139	0.29	3.27	0.73	5.35	0.032	0.265	NA	NA	NA	NA
		y	ft	0.22	1.46	0.02	0.08	0.00437	0.03737	0.94	10.72	2.39	17.54	0.10	0.87	NA	NA	NA	NA
	Concentration	C_0	mg/L	0.00937 [1]	0.01206 [2]	0.00612 [1]	0.00890 [2]	1.99E-05 [3]	2.60E-05 [4]	4.20E-05 [3]	5.10E-05 [4]	7.29E-04 [3]	1.17E-03 [4]	2.21E-03 [3]	2.74E-03 [4]	6.30E-05 [3]	6.96E-05 [4]	3.10E-04 [3]	3.50E-04 [4]
	Infiltration Time	t	d	14,240 [5]	14,240 [5]	14,240 [5]	14,240 [5]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]
Chemical Properties	First-Order Rate Constant	k	d^{-1}					1.30E-03 [7]	2.60E-04 [8]	7.50E-02 [7]	2.50E-02 [8]	2.21E-02 [9]	1.39E-02 [10]	1.50E-02 [7]	1.00E-02 [8]	5.30E-03 [7]	2.20E-03 [8]	3.30E-01 [7]	8.20E-02 [8]
	Half-Life	h	d					533.2 [11]	2666.0 [11]	9.2 [11]	27.7 [11]	31.4 [11]	49.9 [11]	46.2 [11]	69.3 [11]	130.8 [11]	315.1 [11]	2.1 [11]	8.5 [11]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]
	Fraction Organic Carbon	f_{oc}	-					0.0072 [14]	0.0013 [14]	0.0072 [14]	0.0013 [14]	0.0072 [14]	0.0013 [14]	0.0072 [14]	0.0013 [14]	0.0072 [14]	0.0013 [14]	0.0072 [14]	0.0013 [14]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg					282,185 [15]	282,185 [15, 16]	1,300 [15]	830 [17]	822 [18]	822 [18]	12,200 [15]	12,200 [15, 16]	201 [19]	20 [20]	162 [21]	37 [22]
	Distribution Coefficient	K_d	L/kg	76,000 [23]	17,000 [24]	1,000,000 [23]	340,000 [24]	2,032 [25]	379 [25]	9.4 [25]	1.1 [25]	5.9 [25]	1.1 [25]	87.8 [25]	16.4 [25]	1.4 [25]	0.026 [25]	1.2 [25]	0.05 [25]
	Pore Water Velocity	v	m/d	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]
Calculations	Retardation Factor	R	-	418,293	93,566	5,503,847	1,871,309	11,183	2,085	53	7.1	33.6	7.1	484	91	9.0	1.1	7.4	1.3
	Dispersion Coefficient	D	m^2/d	3.32E-03	3.22E-02	2.61E-04	1.68E-03	6.66E-05	8.26E-04	1.44E-02	2.37E-01	3.64E-02	3.88E-01	1.60E-03	1.92E-02	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	Normalized Dispersion	D'	m^2/d	7.94E-09	3.44E-07	4.74E-11	8.99E-10	5.96E-09	3.96E-07	2.74E-04	3.32E-02	1.08E-03	5.48E-02	3.30E-06	2.10E-04	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	Normalized Velocity	v'	m/d	2.39E-06	1.55E-05	1.82E-07	7.75E-07	8.94E-05	6.95E-04	1.90E-02	2.03E-01	2.98E-02	2.05E-01	2.06E-03	1.59E-02	1.12E-01	1.27E+00	1.35E-01	1.14E+00
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E-07	1.25E-07	1.43E-03	3.51E-03	6.58E-04	1.97E-03	3.10E-05	1.10E-04	5.91E-04	1.92E-03	4.45E-02	6.44E-02
	A_1	-	-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.73E-06	-2.04E-06	-2.16E-02	-5.62E-02	-1.61E-02	-5.11E-02	-4.80E-04	-1.82E-03	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	A_2	-	-	1.52E+00	1.60E+00	1.60E+00	1.70E+00	1.01E-01	3.13E-01	1.30E-01	2.59E-01	1.22E+00	1.36E+00	1.90E-01	3.46E-01	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.79E-01	9.45E-01	9.84E-01	9.50E-01	1.00E+00	9.98E-01	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	$erfc(A_2)$	-	-	3.12E-02	2.41E-02	2.37E-02	1.62E-02	8.87E-01	6.58E-01	8.54E-01	7.14E-01	8.45E-02	5.37E-02	7.88E-01	6.25E-01	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.01E+01	2.00E+01	2.01E+01	2.00E+01	2.00E+01	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	B_2	-	-	4.72E+00	4.75E+00	4.75E+00	4.78E+00	4.47E+00	4.48E+00	4.48E+00	4.49E+00	4.64E+00	4.69E+00	4.48E+00	4.49E+00	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.96E+08	5.13E+08	4.93E+08	5.11E+08	4.85E+08	4.86E+08	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	$erfc(B_2)$	-	-	2.37E-11	1.88E-11	1.86E-11	1.32E-11	2.51E-10	2.30E-10	2.39E-10	2.11E-10	5.36E-11	3.41E-11	2.45E-10	2.24E-10	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	Concentration Immediately Above Water Table	C	mg/L	2.00E-04	2.00E-04	1.00E-04	1.00E-04	1.00E-05	1.00E-05	2.00E-05	2.00E-05	4.00E-05	4.00E-05	1.00E-03	1.00E-03	#VALUE!	#VALUE!	#VALUE!	#VALUE!
MRL	Concentration	C	mg/L	2.00E-04	2.00E-04	1.00E-04	1.00E-04	1.00E-05	1.00E-05	2.00E-05	2.00E-05	4.00E-05	4.00E-05	1.00E-03	1.00E-03	1.00E-04	1.00E-04	5.00E-04	5.00E-04

NOTES

1 Mean total metals concentration in stormwater measured during winter 2009 - 2010 Gresham stormwater sampling event. See text for details.

2 95% UCL on the mean of total metals in stormwater measured during winter 2009 - 2010 Gresham stormwater sampling event. See text for details.

3 Mean concentration in stormwater measured during winter 2009 - 2010 Gresham stormwater sampling event. See text for details.

4 95% UCL on the mean of pollutant in stormwater measured during winter 2009 - 2010 Gresham stormwater sampling event. See text for details.

5 Infiltration time is based on 1000 years of metals transport @ 14.24 days per year. (1000 years * 14.24 days per year = 14,240 days of transport).

6 Infiltration time is the number of days during the year that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate is equal to or exceeds 0.04 inches/hour. Precipitation data source is the Gresham Fire Department raingage located at 1333 NW Eastman Parkway in downtown Gresham, Oregon (HYDRA, 2010). Annual precipitation data from 1999 to 2009 were used in the analysis, and were averaged using the geometric mean.

7 Median biodegradation rate from a review of scientific literature (see text for references).

8 25th percentile biodegradation rate from a review of scientific literature (see text for references).

9 10 percent of the average biodegradation rate of PCP under aerobic conditions from studies by Schmidt et al. (1999) and D'Angelo and Reddy (2000).

10 10 percent of the minimum biodegradation rate of PCP under aerobic conditions from studies by Schmidt et al. (1999) and D'Angelo and Reddy (2000).

11 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.

12 Evarts and O'Conner (2008) identifies the Missoula Flood Deposits (Qmf) beneath Gresham as a "bouldery and cobbely gravel and sand." Therefore, typical porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.

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

14 Estimate of f_{oc} based on loading of TOC in stormwater; see text for description .

15 Calculated from the equation of Roy and Griffin (1985), which relates K_{oc} to water solubility and K_{ow}, as presented in Fetter (1994).

16 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)

[17] The lowest K_{oc} reported for Naphthalene in the EPA (1996) review of n = 20 Naphthalene K_{oc}s from field-testing. The range of K_{oc} was 830 L/kg - 1,950 L/kg.

[18] The K_{oc} for Pentachlorophenol is pH-dependent. Soil and groundwater pH are in equilibrium; therefore, soil pH can be estimated from groundwater pH. pH has been measured at monitoring wells completed in first-encountered groundwater at the Fujitsu Ponds Wetlands, 201st Avenue and NE Glisan, Gresham, Oregon. The average groundwater pH at monitoring wells MW3, MW7, and MW6 was 6.45. When pH = 6.45, the Koc for PCP is 822 L/Kg (EPA, 1996).

[19] Calculated from equation (71) in EPA (1996), which relates Koc to Kow for VOCs, chlorobenzenes, and certain chlorinated pesticides.

[20] The lowest K_{oc} reported for 2,4-D acid in EPA (2010a).

[21] Calculated from equation (71) in EPA (1996), which relates Koc to Kow for VOCs, chlorobenzenes, and certain chlorinated pesticides. The log Kow for Toluene (2.69) was taken from EPA (2010c)

[22] The lowest K_{oc} reported for Toluene in EPA (2010c). The range of K_{oc} was 37 - 178 L/kg.

[23] Median K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998), based on Year 1 SWDM from the City of Portland.

[24] 10th percentile of K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998), based on Year 1 SWDM from the City of Portland

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

[26] The median hydraulic conductivity calculated using the pump-in method at 37 City of Gresham UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.

[27] The 95% UCL on the mean of hydraulic conductivity based on 37 pump-in tests at City of Gresham UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.

ABBREVIATIONS

PAHs = Polynuclear Aromatic Hydrocarbons
SVOCs = Semi-Volatile Organic Compounds
VOCs = Volatile Organic Compounds
PCP = Pentachlorophenol
NA = Input concentration is less than the MRL, so no transport is necessary to reduce pollutant concentrations to below MRLs.

USGS = United States Geological Survey
EPA = Environmental Protection Agency
DOGAMI = Department of Geology and Mineral Industries

UIC = Underground Injection Control
MCL = Maximum Contaminant Level
UCL = Upper Confidence Level
MRL = Method Reporting Limit

Qmf = Quaternary Missoula Flood Deposits
TOC = Total Organic Carbon
d = days
g/cm^3 = grams per cubic centimeter

m = meters
m/d = meters per day
m^2/d = square meters per day
mg/L = milligrams per liter

Appendix A
Table 2. Pollutant Fate and Transport
Calculating Transport Distance Needed to Reach EDLs

	Parameter	Symbol	Units	Metals				PAHs				SVOCs				Pesticides/ Herbicides		VOCs	
				Copper		Lead		Benzo(a)pyrene		Naphthalene		PCP		di-(2-ethylhexyl) phthalate		2,4-D		Toluene	
				Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	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 EDLs	y	m	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.93	NA	NA	NA	NA	NA	NA
		y	ft	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.61	NA	NA	NA	NA	NA	NA
	Concentration	C_0	mg/L	0.00937 [1]	0.01206 [2]	0.00612 [1]	0.00890 [2]	1.99E-05 [3]	2.60E-05 [4]	4.20E-05 [3]	5.10E-05 [4]	7.29E-04 [3]	1.17E-03 [4]	2.21E-03 [3]	2.74E-03 [4]	6.30E-05 [3]	6.96E-05 [4]	3.10E-04 [3]	3.50E-04 [4]
	Infiltration Time	t	d	14,240 [5]	14,240 [5]	14,240 [5]	14,240 [5]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]	14.24 [6]
Chemical Properties	First-Order Rate Constant	k	d^{-1}					1.30E-03 [7]	2.60E-04 [8]	7.50E-02 [7]	2.50E-02 [8]	2.21E-02 [9]	1.39E-02 [10]	1.50E-02 [7]	1.00E-02 [8]	5.30E-03 [7]	2.20E-03 [8]	3.30E-01 [7]	8.20E-02 [8]
	Half-Life	h	d					533.2 [11]	2666.0 [11]	9.2 [11]	27.7 [11]	31.4 [11]	49.9 [11]	46.2 [11]	69.3 [11]	130.8 [11]	315.1 [11]	2.1 [11]	8.5 [11]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]	0.325 [12]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]	1.79 [13]
	Fraction Organic Carbon	f_{oc}	-					0.0072 [14]	0.0013 [14]	0.0072 [14]	0.0013 [14]	0.0072 [14]	0.0013 [14]	0.0072 [14]	0.0013 [14]	0.0072 [14]	0.0013 [14]	0.0072 [14]	0.0013 [14]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg					282,185 [15]	282,185 [15, 16]	1,300 [15]	830 [17]	822 [18]	822 [18]	12,200 [15]	12,200 [15,16]	201 [19]	20 [20]	162 [21]	37 [22]
	Distribution Coefficient	K_d	L/kg	76,000 [23]	17,000 [24]	1,000,000 [23]	340,000 [24]	2,032 [25]	379 [25]	9.4 [25]	1.1 [25]	5.9 [25]	1.1 [25]	87.8 [25]	16.4 [25]	1.4 [25]	0.026 [25]	1.2 [25]	0.05 [25]
	Pore Water Velocity	v	m/d	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]	1.00 [26]	1.45 [27]
Calculations	Retardation Factor	R	-	418,293	93,566	5,503,847	1,871,309	11,183	2,085	53	7.1	33.6	7.1	484	91	9.0	1.1	7.4	1.3
	Dispersion Coefficient	D	m^2/d	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	2.12E-01	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	Normalized Dispersion	D'	m^2/d	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	3.00E-02	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	Normalized Velocity	v'	m/d	2.39E-06	1.55E-05	1.82E-07	7.75E-07	8.94E-05	6.95E-04	1.90E-02	2.03E-01	2.98E-02	2.05E-01	2.06E-03	1.59E-02	1.12E-01	1.27E+00	1.35E-01	1.14E+00
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E-07	1.25E-07	1.43E-03	3.51E-03	6.58E-04	1.97E-03	3.10E-05	1.10E-04	5.91E-04	1.92E-03	4.45E-02	6.44E-02
	A_1	-	-	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	-2.80E-02	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	A_2	-	-	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	7.22E-05	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	e^{A1}	-	-	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	9.72E-01	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	$erfc(A_2)$	-	-	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	1.00E+00	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	B_1	-	-	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	2.00E+01	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	B_2	-	-	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	4.48E+00	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	e^{B1}	-	-	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	4.99E+08	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	$erfc(B_2)$	-	-	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	2.40E-10	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
	Concentration Immediately Above Water Table	C	mg/L	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	6.39E-04	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
Regulatory Standards	EDLs		mg/L	1.30E+00 [28]		5.00E-02 [28]		2.00E-04 [28]		NA		1.00E-03 [28]		6.00E-03 [28]		7.00E-02 [28]		1.00E+00 [28]	

NOTES

[1] Mean total metals concentration in stormwater measured during winter 2009 - 2010 Gresham stormwater sampling event. See text for details.
[2] 95% UCL on the mean of total metals in stormwater measured during winter 2009 - 2010 Gresham stormwater sampling event. See text for details.
[3] Mean concentration in stormwater measured during winter 2009 - 2010 Gresham stormwater sampling event. See text for details.
[4] 95% UCL on the mean of pollutant in stormwater measured during winter 2009 - 2010 Gresham stormwater sampling event. See text for details.
[5] Infiltration time is based on 1000 years of metals transport @ 14.24 days per year. (1000 years * 14.24 days per year = 14,240 days of transport).
[6] Infiltration time is the number of days during the year that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate is equal to or exceeds 0.04 inches/hour. Precipitation data source is the Gresham Fire Department raingage located at 1333 NW Eastman Parkway in downtown Gresham, Oregon (HYDRA, 2010). Annual precipitation data from 1999 to 2009 were used in the analysis, and were averaged using the geometric mean.
[7] Median biodegradation rate from a review of scientific literature (see text for references).
[8] 25th percentile biodegradation rate from a review of scientific literature (see text for references).
[9] 10 percent of the average biodegradation rate of PCP under aerobic conditions from studies by Schmidt et al. (1999) and D'Angelo and Reddy (2000).
[10] 10 percent of the minimum biodegradation rate of PCP under aerobic conditions from studies by Schmidt et al. (1999) and D'Angelo and Reddy (2000).
[11] 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.
[12] Evarts and O'Conner (2008) identifies the Missoula Flood Deposits (Qmf) beneath Gresham as a "bouldery and cobbely gravel and sand." Therefore, typical porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.
[13] Calculated by formula 8.26 in Freeze and Cherry (1979): $\rho_b = 2.65(1-\eta)$.
[14] Estimate of f_{oc} based on loading of TOC in stormwater; see text for description .

[15] Calculated from the equation of Roy and Griffin (1985), which relates K_{oc} to water solubility and K_{ow}, as presented in Fetter (1994).
[16] 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)
[17] The lowest K_{oc} reported for Naphthalene in the EPA (1996) review of n = 20 Naphthalene K_{oc}s from field-testing. The range of K_{oc} was 830 L/kg - 1,950 L/kg.
[18] The K_{oc} for Pentachlorophenol is pH-dependent. Soil and groundwater pH are in equilibrium; therefore, soil pH can be estimated from groundwater pH. pH has been measured at monitoring wells completed in first-encountered groundwater at the Fujitsu Ponds Wetlands, 201st Avenue and NE Glisan, Gresham, Oregon. The average groundwater pH at monitoring wells MW3, MW7, and MW6 was 6.45. When pH = 6.45, the Koc for PCP is 822 L/Kg (EPA, 1996).
[19] Calculated from equation (71) in EPA (1996), which relates Koc to Kow for VOCs, chlorobenzenes, and certain chlorinated pesticides. The log Kow for Toluene (2.69) was taken from EPA (2010c)
[20] The lowest K_{oc} reported for 2,4-D acid in EPA (2010a). The range of K_{oc} is 20.0 to 109.1 L/kg.
[21] Calculated from equation (71) in EPA (1996), which relates Koc to Kow for VOCs, chlorobenzenes, and certain chlorinated pesticides. The log Kow for Toluene (2.69) was taken from EPA (2010c)
[23] The lowest K_{oc} reported for Toluene in EPA (2010c). The range of K_{oc} was 37 - 178 L/kg.
[24] Median K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998), based on Year 1 SWDM from the City of Portland.
[25] 10th percentile of K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998), based on Year 1 SWDM from the City of Portland
[26] K_d calculated from the following equation: $Kd = (f_{oc})(K_{oc})$ (e.g., Watts, pg. 279, 1998).
[27] The median hydraulic conductivity calculated using the pump-in method at 37 City of Gresham UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.
[28] The 95% UCL on the mean of hydraulic conductivity based on 37 pump-in tests at City of Gresham UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.
[29] Effluent Discharge Limits from Table A1 and Table A2 of the 1st Draft UIC WPCF Municipal Stormwater Permit Template

ABBREVIATIONS

PAHs = Polynuclear Aromatic Hydrocarbons
SVOCs = Semi-Volatile Organic Compounds
VOCs = Volatile Organic Compounds
PCP = Pentachlorophenol
NA = Input concentration is less than the EDL, so no transport is necessary to reduce pollutant concentrations to below EDLs.
USGS = United States Geological Survey
EPA = Environmental Protection Agency
DOGAMI = Department of Geology and Mineral Industries
UIC = Underground Injection Control
MCL = Maximum Contaminant Level
UCL = Upper Confidence Level
MRL = Method Reporting Limit
Qmf = Quaternary Missoula Flood Deposits
TOC = Total Organic Carbon
d = days
g/cm^3 = grams per cubic centimeter
m = meters
m/d = meters per day
m^2/d = square meters per day
mg/L = milligrams per liter

Appendix B
Table 1. Pollutant Fate and Transport
Proposed EDLs: Calculating Input Concentrations using Output Concentrations Equal to MRLs and 10-Foot Separation Distance

	Parameter	Symbol	Units	PAHs	SVOCs		Pesticides/ Herbicides	VOCs
				Naphthalene	PCP	di-(2-ethylhexyl) phthalate	2,4-D	Toluene
				Average Scenario	Average Scenario	Average Scenario	Average Scenario	Average Scenario
UIC Properties	Transport Distance	y	m	3.05	3.05	3.05	3.05	3.05
		y	ft	10.00	10.00	10.00	10.00	10.00
	Proposed EDL	C_0	mg/L	0.01 [1]	1.00E-02 [1]	6.00E-02 [1]	4.14E-03 [1]	9.64E-03 [1]
	Infiltration Time	t	d	14.24 [2]	14.24 [2]	14.24 [2]	14.24 [2]	14.24 [2]
Chemical Properties	First-Order Rate Constant	k	d^{-1}	7.50E-02 [3]	2.21E-02 [4]	1.50E-02 [3]	5.30E-03 [3]	3.30E-01 [3]
	Half-Life	h	d	9.2 [5]	31.4 [5]	46.2 [5]	130.8 [5]	2.1 [5]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [6]	0.325 [6]	0.325 [6]	0.325 [6]	0.325 [6]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [7]	1.79 [7]	1.79 [7]	1.79 [7]	1.79 [7]
	Fraction Organic Carbon	f_{oc}	-	0.0072 [8]	0.0072 [8]	0.0072 [8]	0.0072 [8]	0.0072 [8]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg	1,300 [9]	822 [10]	12,200 [9]	201 [11]	162 [12]
	Distribution Coefficient	K_d	L/kg	9.4 [13]	5.9 [13]	87.8 [13]	1.4 [13]	1.2 [13]
	Pore Water Velocity	v	m/d	1.00 [14]	1.00 [14]	1.00 [14]	1.00 [14]	1.00 [14]
Calculations	Retardation Factor	R	-	53	33.6	484	9.0	7.4
	Dispersion Coefficient	D	m^2/d	1.52E-01	1.52E-01	1.52E-01	1.52E-01	1.52E-01
	B_2	-	-	8.18E+00	6.83E+00	2.30E+01	4.71E+00	4.76E+00
	e^{B1}	-	-	6.08E+08	5.19E+08	5.08E+08	4.93E+08	1.27E+09
	$erfc(B_2)$	-	-	0.00E+00	0.00E+00	0.00E+00	2.61E-11	1.64E-11
	Concentration Immediately Above Water Table	C	mg/L	0.00E+00	1.45E-15	0.00E+00	1.00E-04	5.00E-04
MRL	Concentration	C	mg/L	2.00E-05	4.00E-05	1.00E-03	1.00E-04	5.00E-04
Regulatory Standards	EDLs		mg/L	NA	1.00E-03 [15]	6.00E-03 [15]	7.00E-02 [15]	1.00E+00 [15]

NOTES

1 Alternate Effluent Discharge Limits (EDLs). EDLs are such that the concentration immediately above the water table is equal to the MRL. Alternate EDLs were limited to 10 times the EDL in the Draft UIC WPCF Municipal Stormwater Permit Template. The proposed EDL for naphthalene, which does not have an EDL in the Draft UIC WPCF Municipal Stormwater Permit Template, is equal to about 0.05% of its solubility in water at 10.0 degrees Celsius (Bohon and Claussen, 1951).

2 Infiltration time is the number of days during the year that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate is equal to or exceeds 0.04 inches/hour. Precipitation data source is the Gresham Fire Department raingage located at 1333 NW Eastman Parkway in downtown Gresham, Oregon (HYDRA, 2010). Annual precipitation data from 1999 to 2009 were used in the analysis, and were averaged using the geometric mean.

3 Median biodegradation rate from a review of scientific literature (see text for references).

4 10 percent of the average biodegradation rate of PCP under aerobic conditions from studies by Schmidt et al. (1999) and D'Angelo and Reddy (2000).

5 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.

6 Evarts and O'Conner (2008) identifies the Missoula Flood Deposits (Qmf) beneath Gresham as a "bouldery and cobbely gravel and sand." Therefore, typical porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.

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

[8] Estimate of f_{oc} based on loading of TOC in stormwater; see text for description .

[9] Calculated from the equation of Roy and Griffin (1985), which relates K_{oc} to water solubility and K_{ow}, as presented in Fetter (1994).

[10] The K_{oc} for Pentachlorophenol is pH-dependent. Soil and groundwater pH are in equilibrium; therefore, soil pH can be estimated from groundwater pH. pH has been measured at monitoring wells completed in first-encountered groundwater at the Fujitsu Ponds Wetlands, 201st Avenue and NE Glisan, Gresham, Oregon. The average groundwater pH at monitoring wells MW3, MW7, and MW6 was 6.45. When pH = 6.45, the Koc for PCP is 822 L/Kg (EPA, 1996).

[11] Calculated from equation (71) in EPA (1996), which relates Koc to Kow for VOCs, chlorobenzenes, and certain chlorinated pesticides. The log Kow for Toluene (2.69) was taken from EPA (2010c)

[12] Calculated from equation (71) in EPA (1996), which relates Koc to Kow for VOCs, chlorobenzenes, and certain chlorinated pesticides. The log Kow for Toluene (2.69) was taken from EPA (2010c)

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

[14] The median hydraulic conductivity calculated using the pump-in method at 37 City of Gresham UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.

[15] Effluent Discharge Limits from Table A1 and Table A2 of the 1st Draft UIC WPCF Municipal Stormwater Permit Template

ABBREVIATIONS

PAHs = Polynuclear Aromatic Hydrocarbons
SVOCs = Semi-Volatile Organic Compounds
VOCs = Volatile Organic Compounds
PCP = Pentachlorophenol
EPA = Environmental Protection Agency
UIC = Underground Injection Control
MRL = Method Reporting Limit
Qmf = Quaternary Missoula Flood Deposits
TOC = Total Organic Carbon
d = days
g/cm^3 = grams per cubic centimeter
EDL = Effluent Discharge Limit
m = meters
m/d = meters per day
m^2/d = square meters per day
mg/L = milligrams per liter

Appendix C

Table 1. Pollutant Fate and Transport

Calculating Concentration Above the Water Table With Initial Concentrations Equal to the Proposed EDLs

	Parameter	Symbol	Units	PAHs		SVOCs				Pesticides/ Herbicides		VOCs	
				Naphthalene		PCP		di-(2-ethylhexyl) phthalate		2,4-D		Toluene	
				Average Scenario	Reasonable Maximum Scenario	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	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05
		y	ft	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
	Concentration	C_0	mg/L	1.00E-02 [1]	1.00E-02 [1]	1.00E-02 [1]	1.00E-02 [1]	6.00E-02 [1]	6.00E-02 [1]	4.14E-03 [1]	4.14E-03 [1]	9.64E-03 [1]	9.64E-03 [1]
	Infiltration Time	t	d	14.24 [2]	14.24 [2]	14.24 [2]	14.24 [2]	14.24 [2]	14.24 [2]	14.24 [2]	2.405 [2]	14.24 [2]	2.631 [2]
Chemical Properties	First-Order Rate Constant	k	d^{-1}	7.50E-02 [3]	2.50E-02 [4]	2.21E-02 [5]	1.39E-02 [6]	1.50E-02 [3]	1.00E-02 [4]	5.30E-03 [3]	2.20E-03 [4]	3.30E-01 [3]	8.20E-02 [4]
	Half-Life	h	d	9.2 [7]	27.7 [7]	31.4 [7]	49.9 [7]	46.2 [7]	69.3 [7]	130.8 [7]	315.1 [7]	2.1 [7]	8.5 [7]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [8]	0.325 [8]	0.325 [8]	0.325 [8]	0.325 [8]	0.325 [8]	0.325 [8]	0.325 [8]	0.325 [8]	0.325 [8]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [9]	1.79 [9]	1.79 [9]	1.79 [9]	1.79 [9]	1.79 [9]	1.79 [9]	1.79 [9]	1.79 [9]	1.79 [9]
	Fraction Organic Carbon	f_{oc}	-	0.0072 [10]	0.0013 [10]	0.0072 [10]	0.0013 [10]	0.0072 [10]	0.0013 [10]	0.0072 [10]	0.0013 [10]	0.0072 [10]	0.0013 [10]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg	1,300 [11]	830 [12]	822 [13]	822 [13]	12,200 [11]	12,200 [11, 14]	201 [15]	20 [16]	162 [17]	37 [18]
	Distribution Coefficient	K_d	L/kg	9.4 [19]	1.1 [19]	5.9 [19]	1.1 [19]	87.8 [19]	16.4 [19]	1.4 [19]	0.026 [19]	1.2 [19]	0.05 [19]
	Pore Water Velocity	v	m/d	1.00 [20]	1.45 [21]	1.00 [20]	1.45 [21]	1.00 [20]	1.45 [21]	1.00 [20]	1.45 [21]	1.00 [20]	1.45 [21]
Calculations	Retardation Factor	R	-	53	7.1	33.6	7.1	484	91	9.0	1.1	7.4	1.3
	Dispersion Coefficient	D	m^2/d	1.52E-01	2.21E-01	1.52E-01	2.21E-01	1.52E-01	2.21E-01	1.52E-01	2.21E-01	1.52E-01	2.21E-01
	Normalized Dispersion	D'	m^2/d	2.90E-03	3.10E-02	4.54E-03	3.12E-02	3.15E-04	2.43E-03	1.70E-02	1.93E-01	2.05E-02	1.74E-01
	Normalized Velocity	v'	m/d	1.90E-02	2.03E-01	2.98E-02	2.05E-01	2.06E-03	1.59E-02	1.12E-01	1.27E+00	1.35E-01	1.14E+00
	Normalized Degradation	k'	d^{-1}	1.43E-03	3.51E-03	6.58E-04	1.97E-03	3.10E-05	1.10E-04	5.91E-04	1.92E-03	4.45E-02	6.44E-02
	A_1	-	-	-2.26E-01	-5.24E-02	-6.71E-02	-2.92E-02	-4.56E-02	-2.10E-02	-1.61E-02	-4.62E-03	-9.60E-01	-1.71E-01
	A_2	-	-	6.81E+00	1.03E-01	5.15E+00	8.95E-02	2.25E+01	7.59E+00	1.48E+00	1.43E-04	8.73E-01	3.75E-04
	e^{A1}	-	-	7.98E-01	9.49E-01	9.35E-01	9.71E-01	9.55E-01	9.79E-01	9.84E-01	9.95E-01	3.83E-01	8.43E-01
	$erfc(A_2)$	-	-	0.00E+00	8.84E-01	3.11E-13	8.99E-01	0.00E+00	0.00E+00	3.62E-02	1.00E+00	2.17E-01	1.00E+00
	B_1	-	-	2.02E+01	2.01E+01	2.01E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.10E+01	2.02E+01
	B_2	-	-	8.18E+00	4.49E+00	6.83E+00	4.48E+00	2.30E+01	8.81E+00	4.71E+00	4.47E+00	4.76E+00	4.51E+00
	e^{B1}	-	-	6.08E+08	5.11E+08	5.19E+08	5.00E+08	5.08E+08	4.95E+08	4.93E+08	4.87E+08	1.27E+09	5.76E+08
	$erfc(B_2)$	-	-	0.00E+00	2.26E-10	0.00E+00	2.37E-10	0.00E+00	0.00E+00	2.61E-11	2.52E-10	1.64E-11	1.79E-10
	Concentration Immediately Above Water Table	C	mg/L	0.00E+00	4.77E-03	1.45E-15	4.96E-03	0.00E+00	0.00E+00	1.00E-04	2.31E-03	5.00E-04	4.56E-03
MRL	Concentration	C	mg/L	2.00E-05	2.00E-05	4.00E-05	4.00E-05	1.00E-03	1.00E-03	1.00E-04	1.00E-04	5.00E-04	5.00E-04

NOTES

1 Initial concentration is equal to the proposed EDL in Table 13 of the text.

2 Infiltration time is the number of days during the year that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate is equal to or exceeds 0.04 inches/hour. Precipitation data source is the Gresham Fire Department raingage located at 1333 NW Eastman Parkway in downtown Gresham, Oregon (HYDRA, 2010). Annual precipitation data from 1999 to 2009 were used in the analysis, and were averaged using the geometric mean. Where infiltration shorter than 14.24 days occur, the maximum pollutant concentration immediately above the water table occurs prior to the maximum number of the days that stormwater infiltrates into the UIC (reaches steady state).

3 Median biodegradation rate from a review of scientific literature (see text for references).

4 25th percentile biodegradation rate from a review of scientific literature (see text for references).

5 10 percent of the average biodegradation rate of PCP under aerobic conditions from studies by Schmidt et al. (1999) and D'Angelo and Reddy (2000).

6 10 percent of the minimum biodegradation rate of PCP under aerobic conditions from studies by Schmidt et al. (1999) and D'Angelo and Reddy (2000).

7 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.

8 Evarts and O'Conner (2008) identifies the Missoula Flood Deposits (Qmf) beneath Gresham as a "bouldery and cobbely gravel and sand." Therefore, typical porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.

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

10 Estimate of f_{oc} based on loading of TOC in stormwater; see text for description .

11 Calculated from the equation of Roy and Griffin (1985), which relates K_{oc} to water solubility and K_{ow}, as presented in Fetter (1994).

12 The lowest K_{oc} reported for Naphthalene in the EPA (1996) review of n = 20 Naphthalene K_{oc}s from field-testing. The range of K_{oc} was 830 L/kg - 1,950 L/kg.

13 The K_{oc} for Pentachlorophenol is pH-dependent. Soil and groundwater pH are in equilibrium; therefore, soil pH can be estimated from groundwater pH. pH has been measured at monitoring wells completed in first-encountered groundwater at the Fujitsu Ponds Wetlands, 201st Avenue and NE Glisan, Gresham, Oregon. The average groundwater pH at monitoring wells MW3, MW7, and MW6 was 6.45. When pH = 6.45, the Koc for PCP is 822 L/Kg (EPA, 1996).

[14] 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)
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MRL = Method Reporting Li

ATTACHMENT C

***City of Gresham WPCF Permit Application Update, Proposed Alternate EDLs*, Letter from Bill Mason (DEQ) to Steve Fancher (City of Gresham), February 13, 2012**

Oregon
John A. Kitzhaber, MD, Governor

Department of Environmental Quality
Western Region Eugene Office
165 East 7th Avenue, Suite 100
Eugene, OR 97401
(541) 686-7838
FAX (541) 686-7551
TTY 711

February 13, 2012

Steve Fancher, PE
Environmental Services Director
City of Gresham
1333 NW Eastman Parkway
Gresham, OR 97030

RE: City of Gresham WPCF Permit Application Update
Proposed Alternative EDLs

Dear Mr. Fancher,

DEQ staff have reviewed the application update entitled *Update to City of Gresham WPCF Permit Application:Proposed Alternate EDLs for Lead and Benzo(a)pyrene*, dated November 21, 2011, and the *Technical Memorandum Pollutant Fate and Transport Model Results in Support of the City of Gresham UIC WPCF Permit – Proposed EDLs,*dated June 10, 2011.

The proposed EDLs were developed using the average transport scenario of the groundwater protectiveness tool at a separation distance of 10 feet, and are based on pollutant attenuation to zero (i.e., the method reporting limit) above the water table. In addition, the proposed EDLs were capped at 10 times the EDL in the UIC WPCF Permit Template, 0.05% of the pollutant's solubility in groundwater (naphthalene only, because it does not have an EDL in the UIC WPCF Permit Template), or 10 times the EPA maximum contaminant level (lead only).

We agree with your proposal, and the application update and the technical memorandum are approved as submitted. Please feel free to contact me if you have any questions concerning our review via email at mason.bill@deq.state.or.us or by phone at 541-687-7427.

Sincerely,

Bill Mason, RG
Western Region – Eugene

ec: Lynne Kennedy, City of Gresham, lynne.kennedy@greshamoregon.gov
Barbara Sellars, DEQ-Portland
Heidi Blishke, RG, GSI Water Solutions, Inc., hblischke@gsiws.com
Matt Kohlbecker, RG, GSI Water Solutions, Inc., mkohlbecker@gsiws.com
Rachael Peavler, GSI Water Solutions, Inc.

GSI Water Solutions, Inc.

Technical Memorandum

To: Jennifer Belknap - Williamson / City of Gresham Department of Environmental Services
Thomas McCausland / City of Gresham Department of Environmental Services
Lynne Kennedy / City of Gresham Department of Environmental Services
Torrey Lindbo / City of Gresham Department of Environmental Services

From: Ari Petrides, Ph.D. / GSI Water Solutions
Matthew Kohlbecker, RG / GSI Water Solutions
Heidi Blischke, RG / GSI Water Solutions

Copy: Krista Reininga, PE / Brown and Caldwell, Inc.

Date: September 2, 2012

Re: **Determination of Waste Management Areas for UICs by Numerical Simulation of Pollutant Fate and Transport, City of Gresham, Oregon**

This technical memorandum documents the methods used to delineate waste management areas for UICs in the City of Gresham. The waste management areas will be used to support the City's Underground Injection Control (UIC) Water Pollution Facilities (WPCF) permit application. Specifically, the waste management areas define the horizontal distance from a UIC to where contaminants in stormwater discharges are conservatively shown to be below analytical method reporting limits; and thus, are protective of potable wells outside of the waste management area (based on drinking water standards that exceed the analytical method reporting limits).

1 Introduction

The City of Gresham (City) has approximately 1,100 UICs that accept stormwater runoff from public rights-of-way and infiltrate the water into the subsurface. UICs can be implemented and used as an essential element of stormwater management. UICs used for stormwater management result in runoff patterns that more closely mimic pre-development conditions as runoff is infiltrated back into the ground as opposed to being routed directly to surface water bodies. In some areas of the City of Gresham, UICs have been used as the only form of stormwater management.

The City applied for a UIC WPCF Permit from the Department of Environmental Quality (DEQ) in July of 2000, and anticipates permit issuance in the Fall of 2012. The City's individual UIC WPCF permit will be based on the draft UIC WPCF permit template issued by DEQ on July 20, 2012 (DEQ, 2012a).

UICs that are within water well setbacks (i.e., 500 feet from a water well or within the two year time of travel zone) cannot be rule-authorized under Oregon Administrative Rules (OAR) 350 - 044. However, UICs within water well setbacks can be permitted under the July 2012 draft UIC WPCF permit template if the permittee provides "a protectiveness demonstration to show that the existing underground injection system does not impair groundwater quality or supply" (Section 6(b)(i)). There are two approaches for demonstrating protectiveness. Both approaches consist of modeling pollutant attenuation, but differ based on whether they model unsaturated, vertical pollutant attenuation or saturated, horizontal pollutant attenuation.

- **Unsaturated Zone Groundwater Protectiveness Demonstration (GWPD)**. Unsaturated Zone GWPDs are based on modeling pollutant fate and transport *vertically* through the *unsaturated* soils beneath a UIC using conservative assumptions. Groundwater protectiveness is demonstrated by showing that the pollutants attenuate to below background levels before reaching the groundwater table, and therefore that the pollutants do not impair groundwater supply.

- **Saturated Zone GWPD - Delineation of Waste Management Areas.** Waste Management Areas for UICs are based on modeling *horizontal* pollutant fate and transport through *saturated* soils. As defined under OAR 340-040-0010(19), a waste management area is "any area where waste or material that could become waste if released to the environment, is located or has been located." The waste management area is used to specify the location at which groundwater quality parameters must be at or below permit-specific concentration limits [OAR 340-040-0030(2)(e)]. In the context of stormwater discharges from UICs, a waste management area is comprised of the area where groundwater contains stormwater pollutants above background levels (i.e., zero, or the method reporting limit). Protectiveness is demonstrated by showing that the waste management area does not include a receptor (e.g., water wells), and therefore that pollutants do not impair groundwater supply.

The City of Gresham conducted an unsaturated zone GWPD in 2011, and demonstrated that there is no change in groundwater quality as a result of UIC discharges when the vertical separation distance between the bottom of the UIC and the average seasonal high groundwater is greater than 5 feet (GSI, 2011a). The DEQ accepted the results of Gresham's unsaturated zone GWPD in a letter dated February 13, 2012 (DEQ, 2012b).

Based on the City's Phase I UIC Evaluation in the Spring of 2012, 34 UICs were identified as having less than five feet of vertical separation distance (see Table 5-1 of the Phase I Evaluation Report). A determination of no impairment to groundwater cannot be made at these UICs based on the City's unsaturated zone GWPD. Therefore, delineation of a waste management area for these UICs (i.e., saturated zone GWPD) was necessary to continue operating the UICs based on the July 2012 UIC WPCF permit template. This technical memorandum documents the numerical fate and transport modeling that was used to delineate a waste management area by simulating horizontal pollutant transport in saturated soils (i.e., the saturated zone).

1.1 Objectives

The objectives of modeling pollutant fate and transport in the saturated zone included the following:

- Determine the waste management area for a City UIC to support the City's UIC WPCF permit.
- Develop a science-based, technical rationale that can be used to identify UICs (i.e., UICs with less than five feet of vertical separation distance) that need to be decommissioned or retrofit.
- Determine the sensitivity of the waste management area to aquifer properties (permeability and dispersivity).
- Evaluate a "worst case" scenario for pollutant transport, including the possibility for overlapping pollutant discharges from closely-spaced UICs.

1.2 Conceptual Model for Horizontal GWPD

The Phase I UIC Evaluation indicated that 20 of the 34 UICs with less than 5 feet of vertical separation distance are wet feet UICs (i.e., UICs with no vertical separation distance), and 14 of the 34 UICs are dry-bottom UICs (i.e., between 0 and 5 feet of vertical separation distance). For the 14 UICs with between 0 and 5 feet of vertical separation to groundwater, there is some treatment that is expected to occur within the unsaturated zone. However, the conceptual model for waste management areas in the City conservatively assumes no unsaturated zone treatment (i.e., wet feet UICs) so that a single waste management area can be applied to all City UICs – both wet feet and dry bottom.

After discharge into groundwater, pollutants are transported in the direction of groundwater flow. Total organic carbon in the stormwater (from pollen, leaf debris, etc.) is also filtered out of the water and accumulates, through filtration and sorption, in soils within a short distance of the UIC. During transport, pollutant concentrations are attenuated by macrodispersion, diffusion and biodegradation. Pollutants are retarded primarily due to sorption on the organic carbon added to the soil from stormwater, and organic carbon incorporated in native sediments during deposition. The amount of pollutant dilution and attenuation depends on soil properties of the aquifer, hydraulic properties of the aquifer, and pollutant properties.

2 Methods

Pollutant fate and transport from a typical wet foot UIC was simulated with transient three-dimensional finite difference numerical models for groundwater flow and pollutant fate and transport. The UIC was simulated as an injection well that discharges stormwater into the aquifer over a 35 year period. Pollutant discharge 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 five feet of vertical separation distance in Gresham. Specifically, the modeling assumptions included the following:

- The UIC was assumed to discharge directly to groundwater.

- Pollutant concentrations down-gradient of the UIC were measured in the direction of groundwater flow, which is where the highest concentrations would occur.

- Groundwater flow direction was constant and did not exhibit seasonal changes, which underestimates dilution of the pollutant concentrations (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 July 2012 draft UIC WPCF permit template, which is greater than any observed PCP concentration observed from stormwater sampling in the City of Gresham. In addition, the 95% upper confidence limit (UCL) on the mean for PCP concentration in Gresham stormwater is 1.19 ug/L of PCP, 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.

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[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 20, 2012 permit template uses the term Action Levels. The Action Levels take into account results of the unsaturated zone model, whereas the MADLs were equal to state and federal drinking water standards—except for lead, for which the MADL was 50 rather than the drinking water standard of 15.

- 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 assumed to result in stormwater infiltration cited in the City of Portland UIC WPCF Permit Evaluation report (DEQ, 2005b).

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 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 6.15 (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.

Model boundaries that were used for delineating waste management areas are shown in Figure I-1. 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 I-1.

The aerial extent of the model domain (1,500 feet by 500 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 1,500 feet by 500 feet model domain did not affect simulation results. Cell sizes were chosen based on a Peclet number of 1 in order to prevent numerical dispersion. 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 I-2 and Table I-3, respectively.

2.4.1 Aquifer Properties

Aquifer properties are hydraulic characteristics of the aquifer that govern groundwater flow, and are summarized in Table I-2. Based on a subsurface investigation during the Phase I UIC Evaluation and geologic maps from the Oregon Department of Geology and Mineral Industries (DOGAMI), most of the City's UICs are completed in the Unconsolidated Sedimentary Aquifer (USA). Relatively few UICs are located in the underlying Troutdale Gravel Aquifer (TGA), likely because of the unit's lower permeability and capacity to accept stormwater runoff. Therefore, the aquifer properties used in the waste management area delineation are representative of hydrogeologic conditions in the USA. Aquifer properties that are representative of the TGA were used as a part of the sensitivity analysis.

Hydraulic Gradient

Hydraulic gradient is the slope of the water table. Hydraulic gradient (0.01 feet/foot) was calculated based on groundwater elevations measured in the spring of 2012 at the temporary monitoring wells that were installed as a part of the Phase I UIC Evaluation.

Hydraulic Conductivity

Hydraulic conductivity describes the ease with which groundwater moves through subsurface soils. The hydraulic conductivity used in the model (100 ft/day) is the median hydraulic conductivity based on analysis of a multiple well pumping test at the Fujitsu Ponds (GSI, 2011b). The Fujitsu Ponds are located adjacent to most of the 80 UICs identified for further evaluation (see Figure 1-1 of the Phase I UIC Evaluation Report). The aquifer test was conducted at monitoring well MW-1-20 (completed in first-encountered groundwater) and analyzed using the Theis (1935) and Cooper-Jacob (1946) methods. Transmissivity estimates were converted to hydraulic conductivity assuming an aquifer thickness of 22 feet (see next section).

Aquifer Thickness

Aquifer thickness is the portion of a hydrogeologic unit that is saturated. The USGS has interpreted total hydrogeologic unit thicknesses (i.e., including both the saturated and unsaturated portions) from well driller logs for water wells drilled in the Portland Basin (Swanson et al., 1993). Aquifer thickness was calculated by subtracting the depth to water in the USA from the USGS' hydrogeologic unit thickness for the USA. As is shown in Table I-2, depth to groundwater in the USA and hydrogeologic thicknesses for the USA were based on data near UIC Group 4, where most of the City's wet feet UICs are located.

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 USA where most of the City's UICs are located. The effective porosity and specific yield (0.20) were taken from McFarland and Morgan (1996) for the USA.

Dispersivity

Dispersivity (α) is related to the spreading of a solute plume as pollutants are transported by the average groundwater flow velocity. 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 I-4. Stormwater infiltration volume was estimated from the following equation:

$$I = (A)(p)(1-e) \qquad (1)$$

Where:

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

A = Average area of a UIC catchment in Gresham (square feet)

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

e = Evaporative loss factor (dimensionless and equal to 0.26 for the Portland Basin based on [Snyder, 1994])

Impervious Area (A)

In 2010, the City of Gresham delineated impervious areas in UIC drainage basins as a part of developing the unsaturated zone GWPD model. The City's delineations indicated that impervious area in UIC drainage basins fall into two size categories—"large" and "small." The size categories relate to land use, which relates to vehicle trips per day of streets within the drainage area. However, inclusion of additional delineations not completed in time for the unsaturated zone GWPD have resulted in a mean for the two size classes that is statistically indistinguishable. The new, more robust average was used for the purposes of the saturated zone GWPD. (No change is proposed for the unsaturated zone GWPD because the original values are more conservative when applied to the unsaturated zone.) Based on a total of 34 UIC drainage basins, the City has determined that the average impervious area in UIC drainage basins is 14,233 ft^2.

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 I-4, approximately 2.4 feet of precipitation is produced annually by storm intensities greater than or equal to 0.04 inches per hour.

Infiltration Volumes (I)
As shown in Table I-4, the annual infiltration volume in an average UIC drainage basin is approximately 25,500 ft^3

Stormwater Infiltration Time
Stormwater infiltration time is shown on Table I-4. On average, precipitation intensity is equal to or exceeds 0.04 inches per hour for about 374 hours per year. In the model, the UIC is estimated to discharge the entire year's volume of stormwater runoff to the aquifer over 16, one day-long storms that were distributed equally from October through May of each year. The day-long storm duration was a conservative assumption because rain events with greater than 0.04 inches/hour intensity are often less than 24 hours in duration; therefore, the model simulates a larger volume of pollutant loading over a shorter amount of time (which results in higher initial concentrations in groundwater). 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, 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} (i.e., due to incorporation of organic carbon in soil during deposition) was estimated to be 0.001826 g_{carbon}/g_{soil}. The background f_{oc} was calculated from the average TOC in three soil samples that were collected from temporary borings in the USA (see Table 4-8 of the Phase I UIC Evaluation report).

An estimate of f_{oc} based on accumulation of TOC in 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 (GSI 2011a.). The following equations were used in the analysis:

$$I = (A)(p)(1-e) \quad (1)$$

$$CL = (t)\left[\sum_{i=1}^{n} I_i C\right] \frac{1\ \text{liter}}{1{,}000\ \text{cm3}} \frac{1\ \text{gram}}{1{,}000{,}000\ \text{milligrams}} \quad (2)$$

$$\rho_{oc} = \frac{CL}{SV} \quad (3)$$

$$f_{oc} = \frac{\rho_{oc}}{\rho_b + \rho_{oc}} \quad (4)$$

Where the variables in Equation (1) 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 a cell where the UIC is located) (cubic centimeters)

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

ρ_b = Bulk density (grams per cubic centimeter)

Calculation of $f_{oc,}$ based on the filtering of TOC as suspended solids is shown in Table I-5. First, the volume of stormwater that infiltrates into a UIC each month was calculated by Equation (1). Next, Equation (2) was used to calculate the grams of carbon added to the saturated zone surrounding the UIC during a 10-year period. Equation (3) was used to calculate the mass of organic carbon per unit volume of material surrounding the UIC (ρ_{oc}), and Equation (4) was used to convert ρ_{oc} to f_{oc}. The calculated f_{oc} level in sediments immediately around the UIC was 0.00625 g_{carbon}/g_{soil}.

2.4.2 Pollutant Properties

Pollutant properties are summarized in Table I-3. With the exception of half-life, the pollutant properties used for modeling saturated transport from wet feet UICs are the same as used in the City's unsaturated zone GWPD (GSI, 2011a). 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). Other pollutant properties have been previously documented in the *Pollutant Fate and Transport Model Results in Support of the City of Gresham UIC WPCF Permit – Proposed EDLs* (GSI, 2011a). Pollutant properties were peer-reviewed by S. S. Papadopoulos and Associates (SSPA) (SSPA, 2008).

The maximum observed pollutant concentrations and 95% Upper Confidence Limit (UCL) on the mean were calculated based on stormwater samples collected by the City during its 2009 – 2010 stormwater discharge monitoring, and are shown in Table I-3. The 95% UCL on the mean and maximum concentrations for lead, benzo(a)pyrene, PCP and DEHP in the City of Gresham's stormwater data are below the action levels in the July 2012 draft UIC WPCF permit template. Therefore, to be conservative, as shown on Table I-3, the pollutant input concentrations were set as equal to the action level in the July 2012 draft UIC WPCF permit template.

2.4.3 Waste Management Area Delineation

The waste management area was comprised of the area where groundwater contains stormwater pollutants above background levels (i.e., zero, or the method reporting limit. To determine the distance at which the pollutant concentration is below the designated MRL, concentrations were interpolated linearly between observation points (i.e., model grid cells).

3 Simulation Results

Fate and transport simulations were conducted for determining the waste management area for City UICs. Sensitivity analyses were conducted to evaluate the sensitivity of the waste management area to aquifer properties (hydraulic conductivity, dispersivity). An additional simulation was conducted to evaluate a worst case scenario in which multiple UICs were located close together.

3.1 Waste Management Areas

Results modeling to determine the waste management area for a UIC are summarized in Table I-6, and shown graphically in Figure I-2. A concentration versus distance plot for lead is not included in Figure I-2 because lead remains in the grid cell where the UIC is located; therefore, a plot of lead concentration versus distance would be based on one data point (i.e., at the UIC). PCP migrates significantly further than DEHP, lead, and B(a)P during the transport scenarios, and is therefore the driver for determining the waste management area. This is because PCP has the lowest retardation of the four pollutants. DEHP, lead, and B(a)P, which have the highest retardation factors, are sequestered within several tens of feet of the UIC.

PCP concentrations stabilized within three years of pollutant discharge from the UICs (i.e., the waste management area reached steady-state conditions, meaning that it did not increase or decrease after the first three years of transport simulation). PCP concentrations decrease to below the EPA Maximum Contaminant Level (MCL) approximately 31 feet downgradient of the UIC, and are below the MRL approximately 335 feet downgradient of the UIC. **Therefore, the waste management area for a UIC in the City of Gresham extends from the UIC to 335 feet downgradient of the UIC.**

3.2 Sensitivity Analysis

The sensitivity analysis was conducted to determine the sensitivity of the waste management area to the following input parameters:

- **Hydraulic Conductivity.** The sensitivity analysis involved increasing and decreasing hydraulic conductivity:
  - **Effect of decreasing Hydraulic Conductivity.** Hydraulic conductivity was lowered from the Portland Basin median value of 200 ft/day by an order of magnitude to 20 ft/day (which is representative of hydraulic conductivity in the Troutdale Gravel Aquifer).
  - **Effect of increasing Hydraulic conductivity.** Hydraulic conductivity was doubled to 200 ft/day, which is the median hydraulic conductivity for the USA in the Portland Basin (Morgan and McFarland, 1996), and was also used in the City of Portland's UIC WPCF Permit Evaluation Fact Sheet (DEQ, 2005b).

- **Dispersivity.** Dispersivity was increased from 18 feet to 100 feet. The dispersivity of 100 feet is based on Gelhar et al., 1992 and a transport scale of 100 feet.

Results of the sensitivity analysis for pollutant transport distances (i.e., waste management area) are shown on Table I-6. This discussion of the sensitivity of transport results to hydraulic conductivity focuses on PCP, which is the most mobile of the four pollutants modeled and therefore the driver for determining the waste management area.

Hydraulic Conductivity

The sensitivity analysis indicates that the simulated waste management area is sensitive to hydraulic conductivity.

- **Effect of decreasing hydraulic conductivity.** An order of magnitude decrease in hydraulic conductivity (i.e., decreased to 20 feet/day) reduced the transport distance required for PCP to attenuate to below MRLs to 190 feet.
- **Effect of increasing hydraulic conductivity.** Doubling the hydraulic conductivity from 100 ft/day to 200 ft/day (which represents the median hydraulic conductivity in the USA) only increased the waste management area by about 15 feet.

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

Dispersivity

The sensitivity analysis indicates that the simulated waste management area is sensitive to dispersivity. Increasing dispersivity from 18 feet to 100 feet decreases the waste management area by about 55 feet. Therefore, the lower dispersivity that was used to delineate waste management areas (and recommended by EPA [1996]) is conservative.

3.3 Worst Case Scenario (Multiple, Closely-Spaced UICs Parallel to the Direction of Groundwater Flow)

The objective of the worst case scenario was to determine the sensitivity of the waste management area to overlapping pollutant discharges from closely-spaced UICs. The worst case scenario considers three UICs, with the first UIC located directly 25 feet upgradient of the second UIC, and the third UIC located 50 feet directly upgradient of the second UIC. As a simplifying and conservative assumption, the UICs would be located parallel to the groundwater flow direction (i.e., the second and third UICs would be directly upgradient of the first UIC).

Results of the multiple UIC scenario are summarized in Table I-6. The waste management area is driven by PCP. The PCP concentrations from each UIC overlap, which extends the waste management area about 165 feet from the furthest down-gradient UIC relative to the single UIC scenario (i.e., the waste management area extends 500 feet from the furthest downgradient UIC). Therefore, the waste management are is sensitive to overlapping pollutant discharges from closely-spaced UICs, assuming that the UICs intersect groundwater and are located parallel to the groundwater flow direction.

4.0 Conclusions and Recommendations

The pollutant fate and transport model was developed using conservative assumptions with the objective of estimating the waste management area from a City-owned UIC. The pollutant fate and transport simulations indicate that:

- PCP is the driver for determining the waste management area because it exhibits a low sorption to soil relative to lead, DEHP and benzo(a)pyrene.
- Based on model results, PCP concentrations from a single UIC attenuate to zero (i.e, the MRL) within 335 feet of the UIC. Therefore, the waste management area was selected to be 335 feet.

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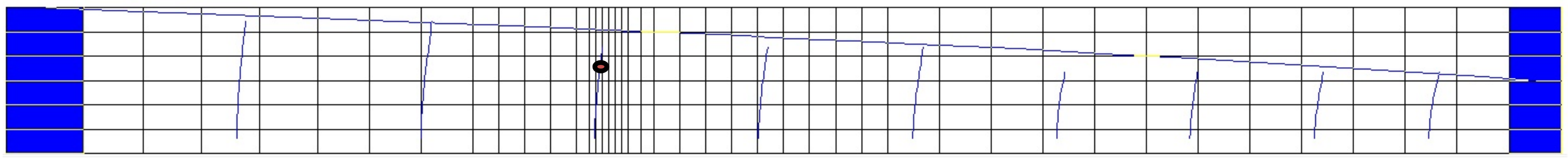
CROSS SECTIONAL VIEW

West | *East*



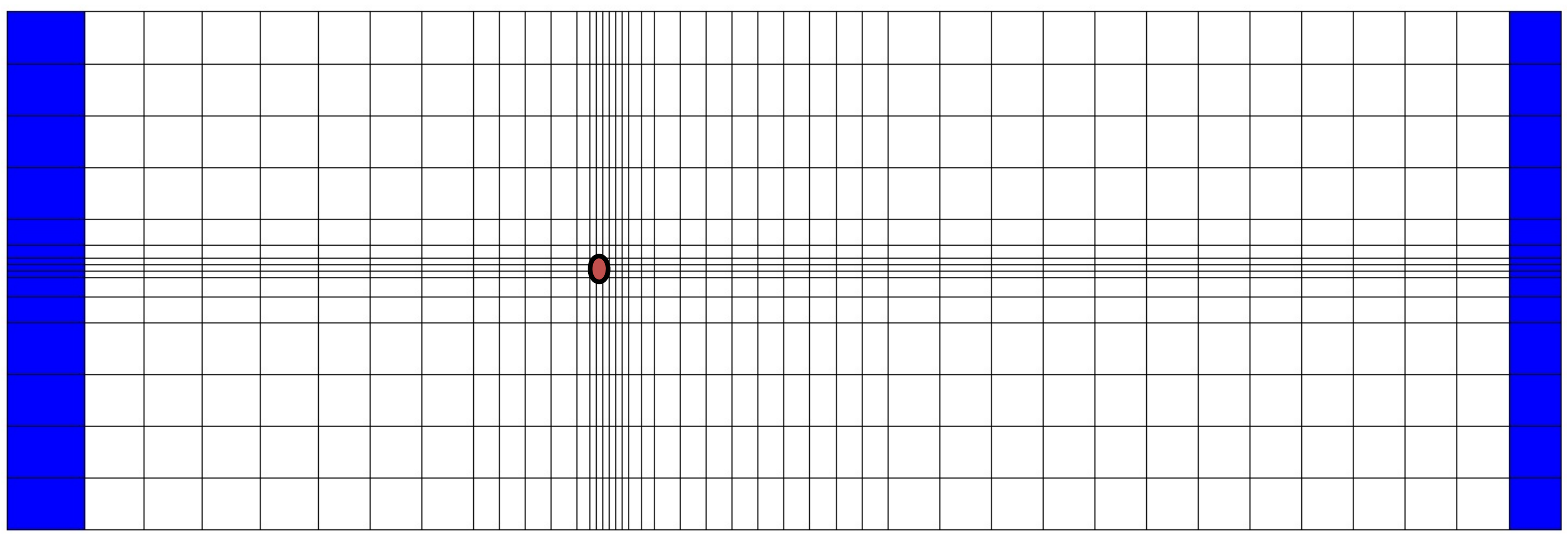
LEGEND

- UIC
- Constant Head Boundary

BIRD'S EYE VIEW

NO FLOW BOUNDARY

h_1 = 30 Feet



h_2 = 15 Feet

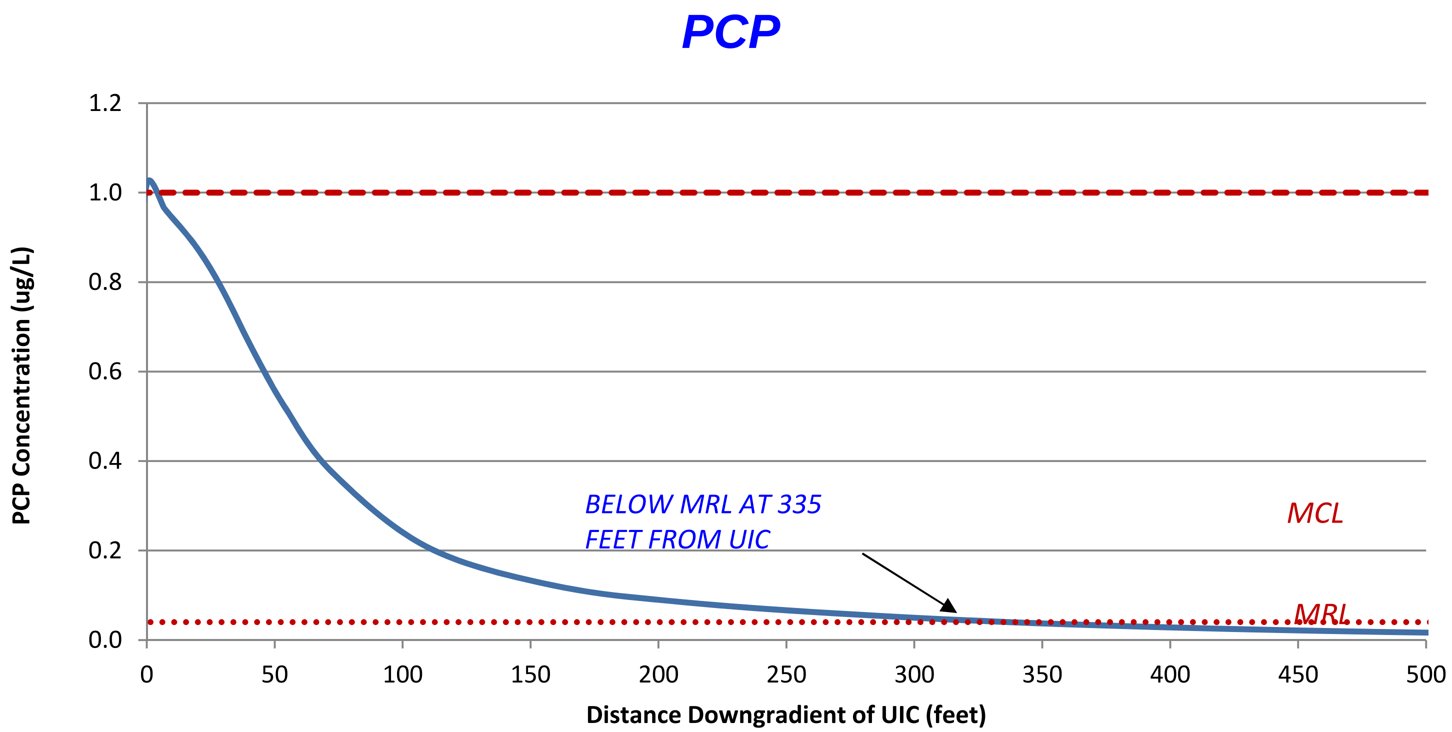
NO FLOW BOUNDARY

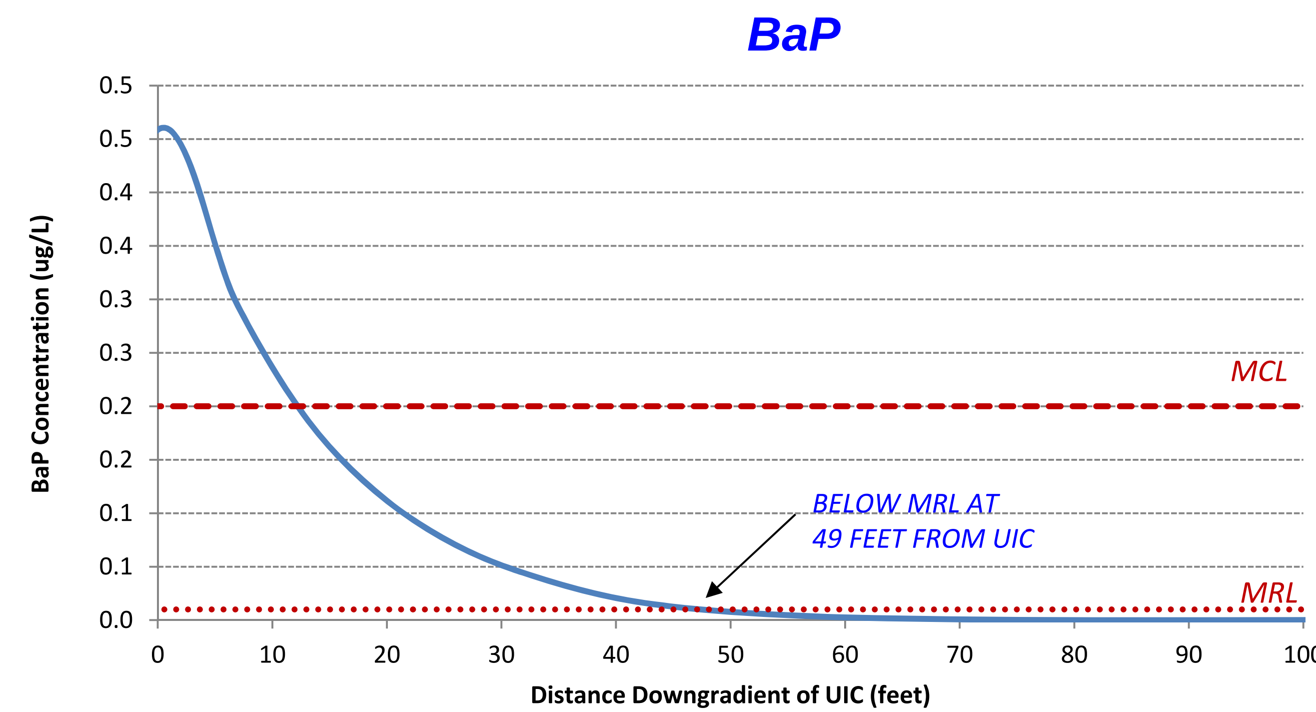
GROUNDWATER FLOW

GRADIENT = 0.01 FT/FT

GSI Water Solutions, Inc.
223 N 6th Street, Suite 325
Boise, ID 83702
P: 208.246.8840 info@gsiws.com www.gsiws.com

FIGURE I-1
Model Discretization
City of Gresham, Oregon





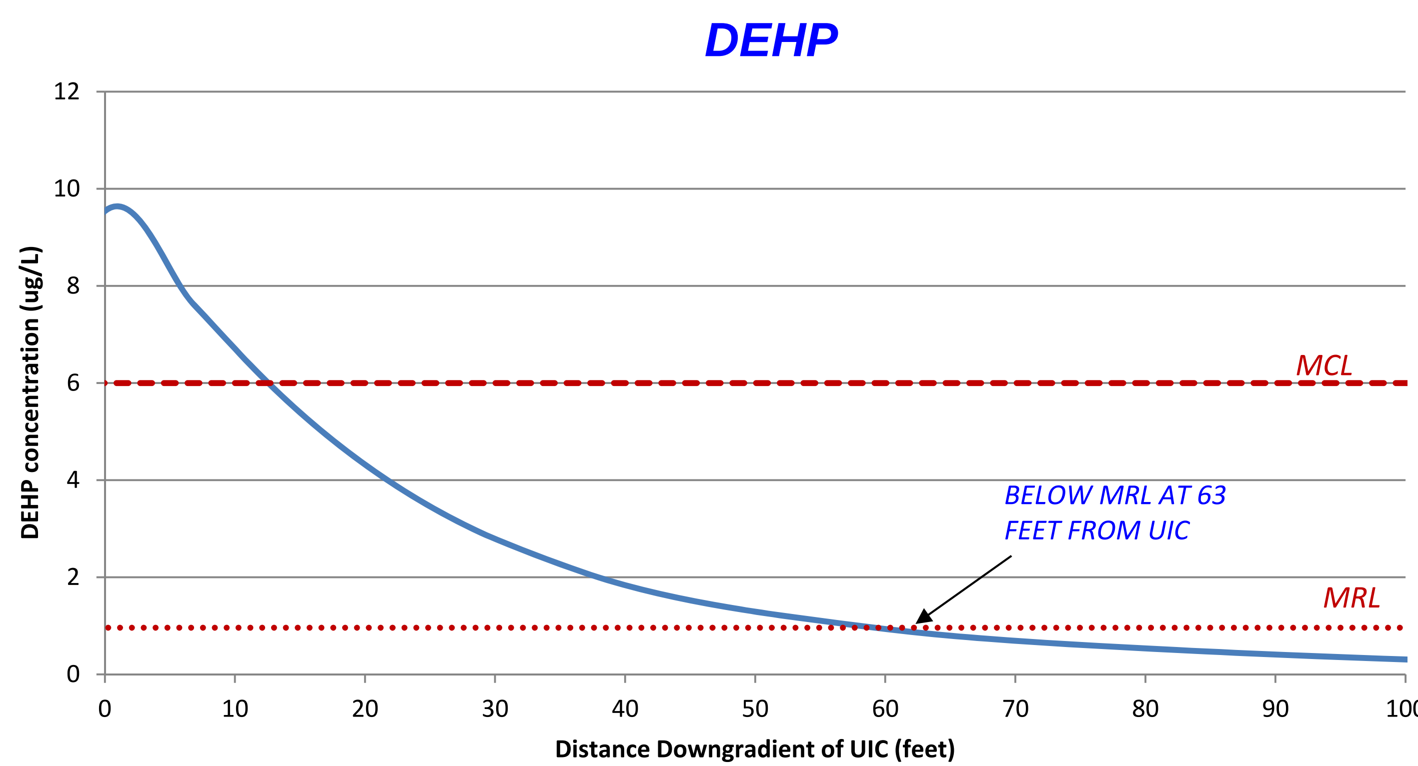


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FIGURE I-2

Pollutant Concentrations vs. Distance

City of Gresham Wet Feet Transport

Table I-1

Model Discretization

Saturated Fate and Transport at Wet Feet UICs

Variable	Reference
Spatial Discretization	
Horizontal *x* -extent	1500 feet
Horizontal *y* -extent	500 feet
Vertical Exent	30 feet
Number of Rows	18
Number of Columns	33
Number of Layers	6
Total Number of Cells	2,652
Cell Size	6 feet to 50 feet
Temporal Discretization	
Simulation Length	35 years (32 years of pollutant loading)
Number of Time Steps	12,970
MODFLOW Time Step Length	1 day
MT3D Time Step Length	0.1 day

Table I-2

Aquifer Properties

Saturated Fate and Transport at Wet Feet UICs

Variable	Symbol	Units	Value	Reference
Hydraulic Gradient	h	feet/foot	0.01	Based on groundwater elevations in Group 4 measured during the Phase I UIC Evaluation in Spring 2012
Hydraulic Conductivity	K_h	feet/day	100	Median hydraulic conductivity from a muliple well pumping test at MW-1-20 at the Fujitsu Ponds
Anisotropy	$K_h:K_v$	dimensionless	100:1	McFarland and Morgan (pg. 1, 1996)
Average Hydrogeologic Unit Thickness	b_{HGU}	feet	37.5	Average thickness of the USA based on wells 01N/03E/33ADDA1, 01N/03E/33BBCA1, 01S/03E/05ADB, and 01S/03E/05BDD, located near City of Gresham wet feet UICs, as reported in Swanson et al. (1993)
Average Depth to Groundwater	DTW	feet bgs	15.2	Average depth to water measured at temporary wells in borings B4, B5, B6 and B8 (GSI, 2012). The borings are located near City of Gresham wet feet UICs.
Average Saturated Thickness	b	feet	22	Calculated from hydrogeologic unit thickness and depth to water
Porosity	η	dimensionless	0.325	Midrange of porosity for a gravel in Freeze and Cherry (Table 2.4, pg. 37, 1979)
Effective Porosity	η_e	dimensionless	0.20	McFarland and Morgan (pg. 20, 1996) for the Unconsolidated Sediments
Specific Yield	S_y	dimensionless	0.20	McFarland and Morgan (pg. 20, 1996) for the Unconsolidated Sediments
Longitudinal Dispersivity	α_L	feet	17.93	Calculated using Xu and Eckstein (1995). $a_L = (3.28)(0.83)[\log(L_p/3.28)]^{2.414.}$ A transport distance (L_p) of 500 feet was used in the calculation)
Transverse Dispersivity (y-direction)	α_T	feet	5.92	Calculated using EPA (1986). $a_T = 0.33(a_L)$
Vertical Dispersivity (z-direction)	α_V	feet	1.79	Calculated using EPA (1986). $a_v = 0.10(a_L)$
Fraction Organic Carbon	f_{oc}	dimensionless	0.00625	f_{oc} near UIC due to carbon loading from stormwater. See text for calculations.
			0.001826	f_{oc} in native sediments, calculated from the average of three (3) TOC analyses in soil. Soils were collected from borings in the USA (GSI, 2012).

Table I-3
Pollutant Properties
Saturated Fate and Transport at Wet Feet UICs

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	822	The K_{oc} for PCP is pH-dependent. Soil and groundwater pH are in equilibrium; therefore, soil pH can be estimated from groundwater pH. pH has been measured at monitoring wells completed in first-encountered groundwater at the Fujitsu Ponds wetlands, 201st Avenue and NE Glisan, Gresham, Multnomah County, Oregon. The average pH at monitoring wells was 6.45. When pH = 6.45, the K_{oc} for PCP is 822 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. Calculations are documented in GSI (2011).
			B(a)P	515 (Native Sediments) 1,764 (Near UIC, reflects loading from stormwater)	Calculated from the relationship: $K_d = (f_{oc})(K_{oc})$ (Watts, 1998)
			PCP	1.5 (Native Sediments) 5.1 (Near UIC, reflects loading from stormwater)	Calculated from the relationship: $K_d = (f_{oc})(K_{oc})$ (Watts, 1998)
			DEHP	22.3 (Native Sediments) 76.3 (Near 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) 9,717 (Near 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	9.3 (Native Sediments) 29.0 (Near 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) 421 (Near 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)
95% UCL Observed Pollutant Concentration	C_{Obs}	ug/L	Lead	9.0	95% UCL on the mean based on N=61 data points, wet season 2009-2010 stormwater discharge monitoring
			B(a)P	0.026	95% UCL on the mean based on N=61 data points, wet season 2009-2010 stormwater discharge monitoring
			PCP	1.19	95% UCL on the mean based on N=61 data points, wet season 2009-2010 stormwater discharge monitoring
			DEHP	2.7	95% UCL on the mean based on N=61 data points, wet season 2009-2010 stormwater discharge monitoring
Maximum Observed Pollutant Concentration	C_{max}	ug/L	Lead	68.4	Based on N=61 data points, wet season 2009-2010 stormwater discharge monitoring
			B(a)P	0.14	Based on N=61 data points, wet season 2009-2010 stormwater discharge monitoring
			PCP	9.1	Based on N=61 data points, wet season 2009-2010 stormwater discharge monitoring
			DEHP	10.4	Based on N=61 data points, wet season 2009-2010 stormwater discharge monitoring
Action Levels	C_{AL}	ug/L	Lead	500	DEQ (2012a)
			B(a)P	2	DEQ (2012a)
			PCP	10	DEQ (2012a)
			DEHP	60	DEQ (2012a)

Table I-4

Infiltration Volume and Rate

Saturated Fate and Transport at Wet Feet UICs

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)
14,233	373.9	15.58	2.36	25,572

Notes

(1) Based on precipitation records from the Gresham Fire Department rain gage at 1333 NW Eastman Parkway. Value is based on precipitation data from 1999 to 2011. Values calculated using the geometric mean.

(2) Assumes an evaporative loss factor of 26% based on Snyder (1994).

Table I-5

Carbon Loading Calculations

Saturated Fate and Transport at Wet Feet UICs

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} (-)
724,118,488	8.60	10	1,000,000	62,274	190.5	190.5	152.4	5,529,824	0.0113	1.79	0.00625

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