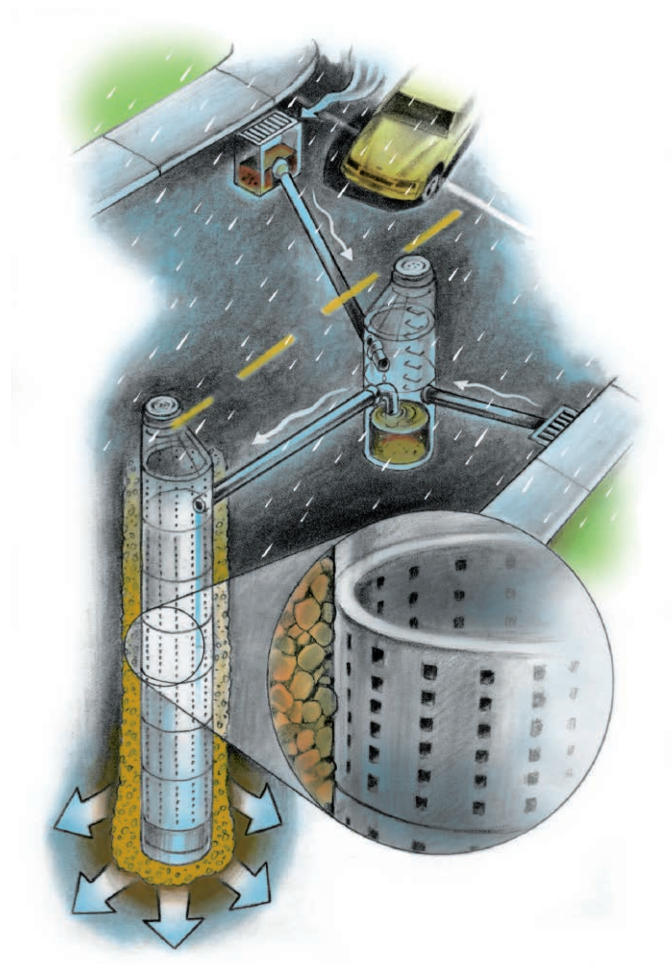
Decision Making Framework for Groundwater Protectiveness Demonstrations

Underground Injection Control System Evaluation and Response



June 2008

Water Pollution Control Facilities (WPCF) Permit

Class V Stormwater Underground Injection Control Systems

DEQ Permit Number 102830

Prepared by

Environmental Services
City of Portland
working for clean rivers

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City of Portland, Oregon

Water Pollution Control Facilities (WPCF) Permit For
Class V Stormwater Underground Injection Control Systems

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Executive Summary

The purpose of this *Decision Making Framework for Groundwater Protectiveness Demonstrations* (GWPD) document is to provide a consistent, streamlined decision making framework for evaluating the potential impacts (*i.e.*, risks) to groundwater quality associated with the discharge of urban right-of-way stormwater into permitted City-owned Underground Injection Control systems (UICs). The Framework determines when groundwater is protected in accordance with Oregon Administrative Rules (OAR) 340-040 and the Water Pollution Control Facility (WPCF) permit issued by the Oregon Department of Environmental Quality (DEQ) to the City of Portland (City) Bureau of Environmental Services (BES) in June 2005 for the operation of Class V Stormwater UICs.

The Framework includes a GWPD Tool for assessing the potential "risk" to groundwater posed by the discharge of urban stormwater runoff into City-owned UICs. The GWPD Tool is a solute transport spreadsheet model developed to evaluate the reduction of stormwater pollutant concentrations entering the UIC by unsaturated soil prior to the infiltrating stormwater reaching groundwater. The Tool can be used to evaluate the fate and transport of pollutants in different geologic units by modifying the appropriate physical and chemical input parameters to characterize the properties of the geologic materials and pollutants.

The GWPD Tool was developed using a phased approach; two work phases were completed under DEQ oversight as the foundation of the Tool. The purpose of the phased approach was to allow the Tool to be developed in a methodical manner. Phase 1 focused on the development of the methodology and assumptions to be used in evaluating a limited number of UICs with a single issue (exceedance of a Maximum Allowable Discharge Limit [MADL]) and a single pollutant (pentachlorophenol [PCP]). Phase 2 built on the results of Phase 1 and incorporated DEQ's comments on the Phase 1 results. Phase 2 expanded the Phase 1 methodology to evaluate two issues (vertical separation distance and potential MADL exceedance) and multiple pollutants representative of stormwater entering Portland's UIC system. Phase 1 and Phase 2 results were developed with DEQ oversight and subsequently approved by DEQ.

The last phase of work involved developing the generic GWPD Framework, based on the methodology, assumptions, and results of the Phase 2 analyses. The framework applies the results of Phase 2 to a wider range of UIC issues and conditions that might be expected to exist in Portland. In addition, a groundwater fate and transport analysis was performed to demonstrate that identified domestic and public water wells located within permit UIC setbacks (*i.e.*, Category 2 and Category 3 UICs, both non-compliant due to inadequate vertical separation distances), are protected pending the completion of corrective actions.

The GWPD Tool and Framework are generally used to:

1) Evaluate UIC stormwater discharge monitoring results in order to determine if groundwater quality is protected.
2) Determine if vertical separation distances less than the permit specified distances are protective of groundwater quality.
3) Identify UICs for further evaluation or corrective action.
4) Define generic conditions (*e.g.*, pollutant concentrations, soil characteristics, separation distance) under which groundwater is protected for ubiquitous pollutants. One intent of the GWPD is to evaluate the potential risk posed by ubiquitous low-level pollutants in stormwater entering the UICs.
5) Determine if stormwater discharges to UICs within permit specified setbacks from domestic or public water wells are protective of groundwater as a drinking water resource and potential well users.
6) Evaluate and/or address regional UIC issues.
7) Support GWPD and no further action (NFA) decisions as a corrective action for identified non-compliant UICs.

GWPD Tool and Framework Limitation

The assumptions and parameters presented in this document are not specifically intended to be applied to UICs that have been subject to spills of hazardous substances or petroleum products (*i.e.*, non-aqueous phase liquid), or may receive stormwater runoff from heavily industrialized properties. Spills will be managed in accordance with the *Spill Prevention and Pollution Control Plan* contained in the *UIC Management Plan* (UICMP; BES, 2006a).

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2,4-D	2,4-dichlorophenoxyacetic acid
BES	City of Portland Bureau of Environmental Services
bgs	below ground surface
BMP	Best management practice
CAP	Corrective Action Plan
CDF	cumulative distribution function
CFR	Code of Federal Regulations
City	City of Portland
CSM	conceptual site model
DEHP	di(2-ethylhexyl)phthalate or bis(2-ethylhexyl)phthalate
DEQ	Oregon Department of Environmental Quality
EPA	U.S. Environmental Protection Agency
GRTS	Generalized Random Tessellation Stratified
GWPD	Groundwater Protection Demonstration
IMD	Internal Management Directive
MADL	Maximum Allowable Discharge Limit
MCL	maximum contaminant level
mg/L	milligrams per liter
MRL	method reporting limit
µg/L	micrograms per liter
NFA	no further action
OAR	Oregon Administrative Rules
ORS	Oregon Revised Statutes
PAH	polycyclic aromatic hydrocarbon
PCP	pentachlorophenol
PPS	Priority Pollutant Screen
QTg	Upper Troutdale gravels
Qff	fine-grained facies
Qfc	coarse-grained facies
RBC	risk based concentration
SDMP	Stormwater Discharge Monitoring Plan
SDWA	Safe Drinking Water Act
SLV	screening level value
SVOC	semi-volatile organic compound
SWMM	Stormwater Management Manual

List of Acronyms (Continued)

TOT	time-of-travel
TPD	trips per day
TGA	Troutdale sandstone aquifer
TSA	Troutdale gravel aquifer
UCL	upper confidence limit
UG	unconsolidated gravel aquifer
UIC	Underground Injection Control
UICMP	UIC Management Plan
USGS	United States Geological Survey
VOC	volatile organic compound
WPCF	Water Pollution Control Facility

Section

1

1 Introduction

The City of Portland (City) prepared this document, *Decision Making Framework for Groundwater Protectiveness Demonstrations* (GWPD), to support the implementation of Water Pollution Control Facilities Permit (WPCF) No. 102830 (DEQ, 2005a). The permit was issued by the Oregon Department of Environmental Quality (DEQ) to the City Bureau of Environmental Services (BES) in June 2005 for the operation of Class V Stormwater Underground Injection Control Systems (UICs).

The permit requires the City to identify compliance response and corrective actions for UICs that do not meet stormwater discharge limits, minimum requirements for vertical separation distance[1], or other permit conditions. The permit and the DEQ's "*Fact Sheet and Class V Underground Injection Control (UIC) Permit Evaluation*" report (DEQ, 2005a; DEQ, 2005b) identify several types of activities that the City may use to evaluate and/or demonstrate that groundwater is protected in accordance with Oregon Administrative Rules (OAR) 340-040. These activities include groundwater monitoring, "risk assessment", structural retrofitting of UICs, UIC decommissioning, or other actions as directed or approved by DEQ.

The term "risk assessment" as referenced in the permit and as used in the UIC Management Plan (UICMP; BES, 2006a) is a broadly defined and multifaceted term. For the purposes of the City's UIC Program, the term "risk assessment" is used to indicate the evaluation of potential risk for adverse impacts to groundwater quality, as defined by OAR 340-040 and OAR 340-044, associated with stormwater discharged into City-owned UICs. One or more of the following activities may be used to evaluate potential stormwater impacts to groundwater:

- Pollutant fate and transport analyses;
- Additional stormwater discharge monitoring to identify pollutant sources or facilitate data interpretation; or
- Evaluation/modification or development of permit stormwater discharge limits or groundwater compliance limits to assure protection of groundwater as a drinking water resource, human health, and the environment.

This document presents an evaluation tool for assessing the potential "risk" to groundwater posed by the discharge of urban stormwater runoff into City-owned UICs. The tool presented and discussed in this document is referred to as the GWPD Tool. The

[1] Separation distance is defined as the approximate depth in feet from the bottom-most perforation in the UIC to the approximate seasonal-high groundwater level. The bottom-most perforation is defined as the bottom of the UIC minus 2 feet. Two feet were added to all separation distance calculations to account for the standard depth of the sediment trap ring on the standard City UIC design. This information is reported to DEQ by the City as "Depth to groundwater" in quarterly UIC database reports for inclusion in DEQ's UIC database. Separation distances are reported to the nearest foot.

approach (*i.e.*, decision making protocols) for applying the GWPD Tool in order to make groundwater protectiveness decisions is referred to as the GWPD Framework.

The general approach for GWPDs is described in the *UICMP - Evaluation and Response Guideline No. 6* (BES, 2006a). As used here and described in the UICMP, a GWPD is an analysis used to evaluate and document whether stormwater discharges to City-owned UICs are protective of groundwater as a drinking water resource in accordance with OAR 340-040 (i.e., groundwater quality will not be adversely impacted).

Definitions of Key Terms

Groundwater Protectiveness Demonstration (*GWPD*)- an analysis used to evaluate and document that stormwater discharges to City-owned UICs are protective of groundwater as a drinking water resource in accordance with OAR 340-040.

GWPD Tool – a DEQ approved, analytical solute transport equation in the form of a Portland specific spreadsheet model used to evaluate the reduction of stormwater pollutant concentrations entering the UIC by unsaturated soil prior to the infiltrating stormwater reaching groundwater.

***GWPD Framework* –** the overall approach (*i.e.*, decision making protocols) for applying the GWPD Tool in order to make groundwater water protectiveness decisions.

This document is intended to be used in conjunction with the *UICMP* (BES, 2006a) and the Corrective Action Plan (CAP; BES, 2006b) prepared in compliance with the requirements of the permit.

1.1 Purpose

The overall purpose of this document is to provide a consistent, streamlined decision making Framework for evaluating the potential impacts (*i.e.*, risks) to groundwater quality associated with the discharge of urban right-of-way stormwater into permitted City-owned UICs, by applying the GWPD Tool, to ensure the protection of human health and the environment. Specifically, this document will:

1) Describe the development of the analytical GWPD Tool.
2) Define how the GWPD Tool will be applied to assess potential impacts to groundwater quality.
3) Present a decision making Framework applicable to all City-owned UICs (*i.e.*, generic) to identify:
    - Conditions that are protective of groundwater (*e.g.*, stormwater pollutant concentrations, soil types, separation distances, etc.) in accordance with OAR 340-040;
    - Conditions where additional investigation or evaluation is needed to determine if groundwater is protected or corrective action is required; and
    - Conditions where corrective action is required.
4) Provide protocols for evaluating whether groundwater is protected in accordance with OAR 340-040. Specifically, the following protocols for evaluating UIC

issues (*i.e.*, potential threats to groundwater quality) identified during permit development and implementation are provided:

- o UICs with inadequate separation distance between the bottom of the UIC and groundwater;
- o UICs with stormwater concentrations exceeding permit specified maximum allowable discharge limits (MADLs);
- o UICs located within permit specified setbacks from drinking water wells (private or public); and
- o Ubiquitous stormwater pollutants (*e.g.*, pentachlorophenol [PCP]).

Ubiquitous Stormwater Pollutants

Pollutants frequently detected in urban stormwater as a result of their wide-spread, non-point source origin; such as PCP associated with wood treated utility poles found through the urban environment.

The permit requires the City to implement corrective actions for UICs that are not compliant with permit requirements to protect groundwater quality in accordance with OAR 340-040. Corrective action, as defined by the permit, can consist of groundwater monitoring, risk assessment using DEQ-approved protocols, or structural retrofitting at the UIC. The CAP (BES, 2006b) provides the process for evaluating and selecting corrective action alternatives that will bring the subject UIC into compliance with the permit. This document builds on the CAP and provides the methodology for performing a GWPD (*i.e.*, risk assessment) to support “no further action” as an appropriate corrective action for selected UICs.

This document also describes when and how this Framework may be applied. The assessment provided through use of this Framework and the GWPD Tool can be used to determine whether a particular set of site conditions is protective of groundwater or where these conditions may not meet permit requirements. This report establishes how the Framework and GWPD Tool can be used to support a no further action (NFA) determination or to identify where corrective actions are needed.

1.2 Applicability

The permit, UICMP, and CAP require the City to identify response actions and/or corrective actions for UICs that do not meet permit requirements. The GWPD Framework and Tool are generally used to:

1) Evaluate UIC stormwater discharge monitoring results in order to determine if groundwater is protected.
2) Determine if vertical separation distances less than the permit specified distances are protective of groundwater quality.

GWPD Tool and Framework Limitation

The assumptions and parameters presented in this document are not specifically intended to be applied to UICs that have been subject to spills of hazardous substances or petroleum products (*i.e.*, non-aqueous phase liquid), or may receive stormwater runoff from heavily industrialized properties. Spills will be managed in accordance with the *Spill Prevention and Pollution Control Plan* contained in the *UICMP* (BES, 2006a).

3) Identify UICs needing further evaluation or corrective action. These evaluations will aid the City in prioritizing needed corrective actions for non-compliant UICs.
4) Define generic conditions (*e.g.*, pollutant concentrations, soil characteristics, separation distance) under which groundwater is protected for ubiquitous pollutants. One intent of the GWPD is to evaluate the potential risk posed by ubiquitous low-level pollutants in stormwater entering the UICs.
5) Determine if stormwater discharges to UICs within permit specified setbacks from domestic or public water wells are protective of groundwater as a drinking water resource and potential well users.
6) Evaluate and/or address regional UIC issues.
7) Support GWPD and NFA decisions as a corrective action for identified non-compliant UICs.

1.3 Regulatory Requirements

DEQ's *Fact Sheet and Class V Underground Injection Control (UIC) WPCF Permit Evaluation* report (DEQ, 2005b) describes the basis of the permit and introduces applicable regulatory requirements. This section provides a summary of regulatory requirements and a brief description of how the requirements are met by the permit and City's UICs Program.

Class V UICs

EPA defines Class V UICs as UICs used to inject non-hazardous fluids (*i.e.*, stormwater) underground.

1.3.1 Federal Regulations

Summary of Federal Regulations: Underground injection of fluids is regulated under the following:

- Title 40 CFR Part 144.24 requires Class V UIC to be either authorized by rule or under a permit.
- Title 40 CFR Parts 144 through 147. 40 CFR 144.12(a) prohibits injection that allows movement of fluid containing any contaminant into underground sources of drinking water if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR Part 142 or may otherwise adversely affect the health of persons.
- Title 40 CRF Part 136 establishes analytical methods and monitoring requirements for drinking water.
- Title 42 United States Code §300f *et seq.* of the federal Safe Drinking Water Act (SDWA). The SDWA establishes maximum contaminant levels (MCLs) for pollutants in public drinking water supplies, including underground sources of drinking water in 40 Code of Federal Regulations (CFR) Parts 141through 143.

> The SDWA prohibits the injection of fluids which endanger an underground source of drinking water (*i.e.*, groundwater). "Underground injection endangers drinking water sources if such injection may result in the presence in underground water that supplies, or can reasonably be expected to supply, a public water system of any contaminant, and if the presence of the contaminant may result in such system's not complying with any national primary drinking water regulation or may otherwise adversely affect the health of persons" (EPA, 2002).

Permit Addresses Federal Requirements: Stormwater discharges to City-owned UICs are authorized under a DEQ issued permit developed with significant input from U.S. Environmental Protection Agency (EPA) Region 10.

The permit requires protection of groundwater as a drinking water resource in accordance with OAR 340-040. Permit discharge limits (*i.e.*, MADLs) are equivalent to Oregon groundwater protection standards (typically measured in groundwater at a predetermined compliance boundary), federal drinking water standards measured in drinking water (*e.g.*, MCLs), and other health based limits.

Permit compliance is demonstrated through the City's stormwater monitoring program. The UIC sampling program was developed with Tony Olsen, National EPA Sampling Design expert. UIC sampling and analyses uses established EPA sampling and analyses methods. These methods are described in detail in the *Stormwater Discharge Monitoring Plan* (SDMP; BES, 2006c).

MADLs

Permit defined maximum allowable discharge limits (MADLs) are equivalent to Oregon groundwater protection standards (typically measured in groundwater at a predetermined compliance boundary), federal drinking water standards measured in drinking water (e.g., MCLs), and other health based limits. Permit compliance is based on pollutant concentrations detected at the point stormwater enters the top of the UIC (*i.e.*, end-of pipe). MADLs do not account for the treatment and/or removal (*i.e.*, attenuation) of pollutants by physical, chemical, or biological processes in subsurface soils between the point of discharge and seasonal high groundwater. The permit requires vertical separation between the bottom of the UIC and seasonal high groundwater.

UIC compliance is conservatively based on pollutant concentrations, meeting concentrations equivalent to federal MCLs, at the point stormwater enters the top of the UIC (*i.e.*, end-of pipe) in order to protect naturally existing background water quality.

1.3.2 State Regulations

Summary of State Regulations: Oregon's Groundwater Protection Act of 1989 (Oregon Revised Statutes [ORS] 468B.150-190) sets a broad goal to prevent groundwater contamination while striving to restore and maintain the high quality of Oregon's groundwater resources for present and future uses (DEQ, 2001). ORS 468B.050 requires a permit to discharge into waters of the state. Because stormwater carries pollutants that may adversely affect waters of the state, stormwater discharges to UICs must be permitted. Municipalities with more than 50 UICs are required to obtain a permit under OAR 340-044.

Water quality standards for groundwater are established under ORS 468B in OAR 340-040. For new facilities (*e.g.*, City's UIC permit), DEQ rules require that the groundwater quality standard for permit compliance is natural background levels (OAR 340-040-0030(3)(b)). However, DEQ can establish groundwater compliance limits up to the federal MCLs for public drinking water systems under the provisions of OAR 340-040-0030(4).

DEQ regulates UICs under OAR 340-044 and operates Oregon's UIC Program through authorization from the EPA. Under this program, DEQ issues permits to UIC system operators, handles enforcement of systems to make sure they work properly, and conducts rule revisions when program changes are necessary. DEQ's UIC program was established to meet federal SDWA requirements.

Important aspects of the groundwater protection statutes and rules include (DEQ, 2007a):

- Most discharges of wastewater to waters of the state are prohibited without first obtaining a permit.
- Groundwater is identified as a critical natural resource in the state that provides domestic, industrial, and agricultural water supply, as well as provides base flow to rivers, lakes, streams, and wetlands [OAR 340-040-0020(1)].
- It is recognized that groundwater, once polluted, is difficult and sometimes impossible to clean up. An anti-degradation policy was established to control discharges to groundwater so that the highest possible water quality is maintained [OAR 340-040-0020(2)].
- All groundwaters of the state are protected from pollution that could impair existing or potential beneficial uses [OAR 340-040-0020(3)].
- Established numerical groundwater reference levels obtained from the SDWA that indicate when groundwater may not be suitable for human consumption [OAR 340-040-0020(4) and (5)].
- A policy protects all groundwater quality throughout the state, but with the recognition that DEQ needs to concentrate its groundwater quality protection implementation efforts in areas where pollution would have the greatest impact on beneficial uses [OAR 340-040-0020(8)].
- A case-by-case determination is allowed concerning the highest and best practicable methods of wastewater treatment and disposal necessary to protect human health and the environment while taking into account the method's cost effectiveness, the site's physical characteristics, and the effluent's toxicity and persistence [OAR 340-040-0020(11)].
- DEQ has the authority use permits to achieve groundwater protection requirements [OAR 340-040-0020(12)].

Permit Addresses State Requirements: Stormwater discharges to City-owned UICs are authorized under a DEQ issued permit. The permit was specifically developed to protect groundwater as a drinking water resource and meet the requirements of OAR 340-040.

1.3.3 City of Portland Requirements

Summary of City Regulations: The *Portland Watershed Management Plan* (BES, 2005a) was adopted by the Portland City Council in March 2006. The Plan describes the approach used to evaluate conditions in the City's urban watersheds and implement projects to improve watershed health. An overarching theme of the Plan is to achieve improved watershed health through watershed friendly development, installation of new stormwater infrastructure, and repair and maintenance of existing infrastructure in new ways that will improve watershed health. The Plan presents the science behind the need for these approaches and a management system to track City progress toward well-defined watershed health goals.

Another major component of the Plan is an integrated City response to local, state, and federal environmental requirements. Citywide implementation of the watershed plan provides Portland with the flexibility to respond to regulations differently and more effectively. Instead of the traditional mandate-by-mandate approach, the City's regulatory responses are based on the root causes of problems and not just symptoms. This provides Portland with the means to solve current environmental problems without creating future ones.

The City's *Stormwater Management Manual* (SWMM; BES, 2004) establishes a hierarchy for the design of appropriate stormwater management and disposal methods. The SWMM is an enforceable City ordinance. It establishes a hierarchical protocol to manage stormwater disposal. The SWMM requires surface infiltration, unless site specific-conditions are such that underground injection is the only reasonable available alternative to stormwater disposal. The SWMM also requires new developments to retain stormwater disposal within the property boundary in order to reduce flows to the City's stormwater systems.

The hierarchy applies to all new developments on private and public lands within the City's jurisdiction. Under the hierarchy, surface infiltration must be considered before discharge to a UIC is allowed. The stormwater hierarchy was developed in cooperation with DEQ prior to the issuance of the permit[2]. The hierarchical approach meets the condition of OAR 340-044-0012(2) and allows use of UICs when site-specific constraints preclude the use of surface infiltration options. DEQ has approved application of the stormwater hierarchy and the SWMM as one of the primary ways to design stormwater facilities in a way that meets the intent of Oregon's Groundwater Protection Rules for highest and best practical treatment method.

The SWMM is available at the following web site:
http://www.portlandonline.com/bes/index.cfm?c=35122.

Permit Addresses City Requirements: The permit recognizes that the underground injection of stormwater has the beneficial effect of groundwater recharge and that in

[2] The SWMM is currently in the process of being updated. DEQ staff are involved in the review of this document. The revised document is scheduled to be finalized in September 2008.

urban areas, where impervious surfaces have reduced natural recharge from rainfall infiltration, underground injection becomes an important substitute for recharge and an integral part of watershed health. The CAP (BES, 2006b) emphasizes solutions that provide multiple watershed benefits and that are selected following the SWMM hierarchy for the design of appropriate stormwater management and disposal. The hierarchy emphasizes vegetated, multi-objective stormwater management techniques. DEQ has approved application of the stormwater hierarchy in the SWMM as one of the primary tools to design stormwater facilities in a way that meets the intent of Oregon's Groundwater Protection Rules for highest and best.

1.4 Technical Background Requirements

This document integrates a wide variety of information sources (including UIC regulations, permit requirements, City's UIC permit implementation, and risk assessment concepts) and data for the purpose of developing the GWPD Framework and Tool. This document is not intended to address all DEQ rules and/or groundwater protectiveness demonstration (*e.g.*, risk assessment) options. Therefore, the reader should have working knowledge of the following:

- WPCF Permit (DEQ, 2005a);
- *UICMP* (BES, 2006a);
- *UIC Decommissioning Procedure (*BES, 2006d);
- *Year 1 and Year 2 Stormwater Discharge Monitoring Reports* (BES, 2006e; BES, 2007a);
- *Year 1 and Year 2 UICMP Reports* (BES, 2006f; BES, 2007b);
- Oregon Water Quality Protection rules (OAR 340-040);
- Oregon UIC Rules (OAR 340-044);
- Oregon Environmental Cleanup Program rules (OAR 340-122);
- Applicable federal regulations;
- DEQ Site Assessment methods;
- Human health risk assessment principles and procedures (see list of documents below);
- Knowledge of risk-based decision making; and
- Pollutant fate and transport processes.

This document was prepared using the following technical guidance documents, as appropriate:

- *Risk-Based Decision Making for the Remediation of Petroleum-Contaminated Sites* (DEQ, 2003; revised DEQ, 2007b);

- *Guidance for Conduct of Deterministic Human Health Risk Assessments* (DEQ, 2000);
- *Guidance for Ecological Risk Assessment, Level 1 – Scoping* (DEQ, 1998);
- *Soil Screening Guidance: Technical Background Document* (EPA, 1996); and
- *Risk Assessment Guidance for Superfund: Volume 1 – Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)* (EPA, 1991).

1.5 Document Organization and Content

The sections that follow in this document discuss the background, development, and applications of the decision making Framework and GWPD Tool:

Section 2: City of Portland's UIC Program. This section describes the City's UIC system, UIC Program and key elements of the permit. This section focuses on those areas of the permit and program related to demonstrating groundwater quality protection.

Section 3: UIC Summary Data. This section summarizes of the results of the City's stormwater discharge monitoring performed in Years 1 and 2 of the permit. The data are used to characterize the quality of the water entering the UICs and demonstrate that in general, the stormwater discharges meet the discharge limits (MADLs) defined by the permit. This section also presents a summary and discussion of vertical separation distances in the City-owned UIC system.

Section 4: Pollutant Selection for Fate and Transport Analyses. This section describes the selection of representative stormwater pollutants for use in the fate and transport analyses. The selected pollutants are used to evaluate potential adverse impacts to groundwater associated with urban stormwater discharge to UICs.

Section 5: GWPD Tool Development. This section provides a general description of the GWPD Tool and the process used to develop it. The GWPD Tool was developed using a phased approach completed under DEQ oversight including:

- Phase 1 focused on the development of the methodology and assumptions to be used in developing the GWPD Tool. The preliminary GWPD Tool was used to evaluate a limited number of UICs with a single issue (MADL exceedance) and a single pollutant (PCP).
- Phase 2 built on the results of the Phase 1 and incorporated DEQ's comments on the Phase 1 results. Phase 2 expanded the Phase 1 methodology to evaluate two issues (vertical separation distance and potential MADL exceedance) and multiple pollutants representative of stormwater entering Portland's UIC system. The DEQ approved GWPD Tool was the outcome of the Phase 2 work.
- Phase 3 involved developing the Framework for application of the GWPD Tool, based the methodology, assumptions, and results of the Phase 2 analyses.

Section 6: Environmental Setting. This section presents a summary of the environmental setting used in developing the conceptual site model (CSM) and selecting input parameters for the GWPD Tool.

Section 7: Conceptual Site Model. This section discusses the CSM that is the basis for development of the GWPD Tool. The CSM describes potential sources of stormwater pollutants, considers how and where the pollutants may move (migration pathways), and identifies who or what may be affected by pollutants (receptors). At its most basic level, the CSM can be thought of as a "picture" of a UIC that shows the relationships between pollutant sources, exposure pathways, and receptors.

Section 8: GWPD Technical Methodology and Results: UICs with ≥ 5 Feet of Separation Distance. This section describes the GWPD Tool as applied to UICs with a separation distance of 5 feet or greater. The result of the Tool application, using a range of representative parameter values, is a generic groundwater protectiveness look-up table. This table can be used to evaluate any City UIC or group of UICs with a separation distance of five feet or greater to determine if the site-specific conditions associated with the UIC in question could result in a potential risk to groundwater.

Section 9: Protectiveness Evaluations for UICs with < 5 Feet of Separation Distance. This section presents "worst case" analyses of the potential fate and transport of pollutants in groundwater for UICs with < 5 feet of separation distance. The purpose of these analyses is to determine whether domestic and public water wells located within permit UIC setbacks (*i.e.*, Category 2 and Category 3 UICs, both non-compliant due to inadequate vertical separation distances) are protected pending the completion of required corrective actions.

Section 10: Applying the GWPD Tool. This section presents protocols designed to assist BES and DEQ in streamlining data evaluation by identifying the conditions where stormwater discharges to City-owned UICs are protective of groundwater quality based on application of the GWPD Tool or where response actions or corrective actions are needed to ensure permit compliance and long-term protection of groundwater.

Section 11: Works Cited. This section provides a listing of all references used in the preparation of this document.

Section

2

2 City of Portland's UIC Program

The City is actively implementing its UIC Program in accordance with the UICMP and the permit. This section provides a description of the City's UIC system, UIC Program and key elements of the permit. This section focuses on those areas of the permit and program related to evaluating and demonstrating that groundwater is protected as a drinking water resource in accordance with OAR 340-040.

2.1 Background

The City currently has approximately 9,000 UICs that collect stormwater from public rights-of-way and discharge it to the subsurface. UICs are most prevalent in the eastern portion of the City, where subsurface soils support greater stormwater drainage and infiltration rates. For many areas east of the Willamette River, UICs are the only form of stormwater disposal available. UICs are also an essential element of a comprehensive watershed strategy to use stormwater as a resource by infiltrating it back into the ground. UICs quickly and efficiently reintroduce stormwater into subsurface soils, which filter and cool the runoff before it finds its way to groundwater and eventually helps recharge streams. UICs are an essential element of street-side swales and "green street" (*i.e.*, vegetated stormwater management facilities) applications because they provide an infiltration point for overflow during large storm events when stormwater cannot be fully infiltrated through swales, planters, or other surface infiltration systems. UICs also preclude the need to install or increase the capacity of piped stormwater infrastructure that eventually discharges into local surface water bodies, including Johnson Creek, the Columbia Slough, and the Willamette River.

> As used in this document, **UIC** means any Class V underground injection control system owned or operated by the City of Portland.

In the Portland area, groundwater serves as a backup drinking water supply to the Bull Run reservoirs. The permit establishes the UIC construction, operation, and maintenance requirements that the City must implement to protect groundwater for use as a drinking water resource. The permit requires a comprehensive stormwater management strategy that will prevent, minimize, and control pollutants at the surface before they enter stormwater.

2.2 Overview of City Permit

In June 2005, DEQ issued the permit to the City authorizing stormwater discharges into its public UICs. DEQ (2005a) determined that the permit meets federal and state regulatory requirements to protect federally defined "underground sources of drinking water" and state defined "waters of the state."

The overarching goal of the permit is to protect the highest beneficial use of groundwater, while allowing underground injection of stormwater (DEQ, 2005a). By protecting the naturally high quality of groundwater, the public's health, safety and welfare, and the environment are protected during subsurface injection activities. The permit conditions are specifically designed to protect groundwater through managing and monitoring stormwater quality before it is discharged into the subsurface. Specifically, the permit is intended to:

- Protect groundwater as a drinking water resource while continuing to manage stormwater disposal through UICs.
- Use stormwater as a resource to maintain aquifer recharge in urbanized areas in the context of watershed health.
- Maximize economies with other City stormwater management programs.
- Emphasize stormwater management actions that prevent, minimize, and treat pollutants in stormwater before they can be discharged to a UIC.
- Encourage the use of effective best management practices (BMPs) that reduce or eliminate pollutants in stormwater before disposal into UICs.
- Demonstrate through a statistically valid discharge monitoring program and reporting requirements that the naturally high groundwater quality is maintained while meeting the goals of stormwater management and watershed health.
- Establish rigorous compliance and corrective action protocols, including time constraints, in the event that stormwater discharge quality does exceed the groundwater protection levels established in the permit.

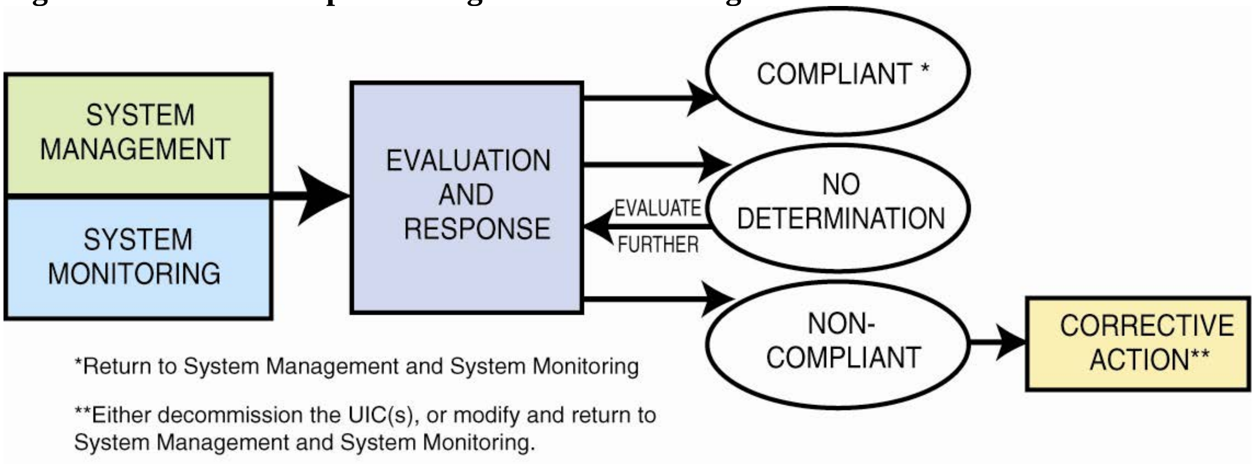
2.3 UIC Management Plan

The UICMP, submitted to DEQ in December 2006, presents the comprehensive management strategy to meet the requirements of the permit. It is the umbrella document that describes the City's overall UIC Program, which is comprised of four major program elements:

- System Management;
- System Monitoring;
- Evaluation and Response; and
- Corrective Action.

The UICMP also identifies other documents the City has prepared to address specific program activities and management practices that are part of the UIC Program The UICMP provides an overall description of the UIC Program and the program elements; program elements are summarized below. It also contains more detailed plans and guidance documents, which are the UIC Program "tools" for carrying out specific program tasks. These program tools are included as appendices to the UICMP. A diagram of the four program elements is shown in Figure 2-1.

Figure 2-1: Relationship and Integration of UIC Program Elements



2.3.1 System Management

The **System Management** program element includes ongoing, programmatic activities (BMPs) that prevent, minimize, or control pollutants before they can be discharged to a UIC. One of the activities under this element is the ongoing UIC system inventory and assessment activities, which are important to manage publicly-owned UICs and to assess the drainage to these UICs to prevent potential impacts to groundwater.

The *Systemwide Assessment* (BES, 2006g) report presents the results of the initial analyses of the City's UIC system against permit criteria including:

- UICs with inadequate separation distance;
- UICs that receive drainage from facilities that store, handle, or use hazardous or toxic materials in quantities requiring registration under the Superfund Amendment and Reauthorization Action Title III;
- UICs that receive drainage from commercial/industrial properties with site activities that may cause stormwater entering a public UIC to exceed MADLs established in the permit; and
- UICs within close proximity to domestic use wells.

The *Systemwide Assessment Follow-up Actions* work plan (BES, 2006h) presents the activities and the project timeline for further evaluating the approximately 950 UICs that were identified for follow-up as part of the *Systemwide Assessment*. The document outlines the activities and projected timeframes that will be implemented to further evaluate the identified UICs.

2.3.2 System Monitoring

The **System Monitoring** program element includes ongoing actions to demonstrate that UICs are operated in a manner that protects groundwater and meets permit conditions. The permit contains specific monitoring and reporting requirements. The City's UIC monitoring program is implemented in accordance with the SDMP (BES, 2006c).

The permit requires the City to monitor stormwater entering City-owned UIC systems throughout the life of the permit (*i.e.*, 10 years). The monitoring program is designed to be representative of the estimated 9,000 City-owned UICs using a statistically robust method to identify a subset of UICs for monitoring, and to satisfy the following specific objectives, which are described in more detail in the *SDMP*:

- Monitor the quality of stormwater discharged into public UICs and demonstrate that groundwater is protected by meeting MADLs established in the permit (DEQ, 2005a);
- Provide a high degree of confidence that the sampling design used for this program is representative of all UICs covered by the permit;
- Demonstrate through monitoring that drinking water wells are protected; and
- Provide data to inform decision making processes to identify the actions that will protect groundwater quality, improve UIC management practices, and improve overall watershed health.

Permit compliance is based on the annual mean pollutant concentration being less than the MADLs for the wet season in which the samples were collected. DEQ decided that an annual mean concentration, which is usually greater than the median, would be more protective of groundwater quality (DEQ, 2005b). In making this decision, DEQ recognizes that the annual mean may be skewed by a single storm event result or incidents beyond the City's control that may occur between sampling events and affect the sampling results. The results of the stormwater discharge monitoring program are summarized in Section 3.

2.3.3 Evaluation and Response

The **Evaluation and Response** program element describes the process and criteria used to identify, evaluate, and prioritize actions needed to protect groundwater and meet permit requirements.

The Evaluation and Response program element uses data and information generated in System Management and System Monitoring to classify individual UICs or groups of UICs as compliant, non-compliant, or no-determination. The Evaluation and Response program element consists of a variety of related strategies, procedures, criteria, and guidelines developed to evaluate UICs that may not meet permit requirements, to identify and address data gaps necessary to make sound technical compliance determinations, and to prioritize identified actions to fully evaluate UIC compliance status. The Evaluation and Response program element is designed to use available data and other information in a "weight-of-evidence"-type approach to determine compliance and to assess potential impacts to groundwater.

This document builds on the Evaluation and Response program element and is intended to provide a process to streamline the decision making as to whether UICs or groups of UICs are protective of groundwater quality. The process described in this document may be applied either during implementation of the Evaluation and Response or Corrective Action program elements, as appropriate (See Section 10).

2.3.4 Corrective Action

The **Corrective Action** program element addresses UICs that are determined to be non-compliant with permit requirements through the Evaluation and Response process. The CAP includes the process that will be used to evaluate, rank, select, and implement appropriate corrective actions. A variety of corrective actions are available, including options that do not involve construction (such as institutional controls or an assessment to demonstrate that groundwater is protected), structural/engineering controls (such as surface infiltration facilities), and UIC closure.

The permit defines four general categories of non-compliant UICs. These categories are further discussed in the following sections.

Category 1 UICs: The permit defines Category 1 UICs as those that were known to be non-compliant with permit conditions upon the date of permit issuance. Five UICs were identified as being constructed into groundwater at the time the permit was issued and therefore determined to be non-compliant. These five UICs were decommissioned in 2006, and the decommissioning was documented in the *UICMP Annual Report No. 1* (BES, 2006f).

Category 2 UICs: The permit defines Category 2 UICs as those identified as non-compliant during the *Systemwide Assessment*. Twenty-nine Category 2 UICs were identified in the *UICMP Annual Report No. 1* (BES, 2006f), due to inadequate vertical separation distances, based on the results of the *Systemwide Assessment* report (BES, 2006g). Corrective actions are currently being designed for these UICs. The recommended corrective actions were developed in accordance with the procedures described in the CAP. The permit requires Category 2 UIC corrective actions to be completed by November 1, 2010.

Category 3 UICs: The permit defines Category 3 UICs as those identified as non-compliant following completion of the *Systemwide Assessment*. The permit requires Category 3 corrective actions to be completed within three full CIP cycles following the annual report date for the reporting period in which the non-compliant public UICs are reported as discovered or in accordance with a DEQ-approved regional corrective action. The *UICMP Annual Report No. 2* (BES, 2007b) identified 338 Category 3 UICs due to inadequate vertical separation distances. Corrective actions for Category 3 UICs will be identified, evaluated, and selected in accordance with the CAP and the *Systemwide Assessment Follow-up Actions* work plan (BES, 2006h). The permit requires corrective actions for the identified Category 3 UICs to be completed by July 2011. Completion dates for Category 3 UICs are subject to change if DEQ approves a regional corrective action for addressing UICs in areas of high groundwater, as allowed by the permit. Corrective actions for the identified Category 3 UICs are expected to include a range of alternatives, including:

- Decommissioning;
- Increasing separation distance (*e.g.*, backfilling, installing shallower UIC sumps, horizontal UICs);
- Utilizing surface infiltration features (*e.g.*, swales, curb extensions) combined with overflows to new shallow UICs or an existing piped system; and
- Reducing separation distance for specific UICs or groups of UICs through a groundwater protectiveness demonstration as described in the UICMP.

Category 4 UICs: The permit defines Category 4 UICs as those that become non-compliant by failing to meet the annual mean MADL within one wet season after the initial exceedance or failing to satisfy any groundwater protection conditions of permit Schedule A. Four Category 4 UICs were identified, based on the results of the Year 2 stormwater monitoring data (see Section 3 of this document) in the *Annual Stormwater Discharge Monitoring Report –Year 2* (BES, 2007a). The permit requires corrective actions for the identified Category 4 UICs to be completed by July 2011. The recommended corrective actions for Category 4 UICs were identified and evaluated in accordance with the CAP. The recommended corrective action for these UICs was a GWPD. The site-specific GWPDs were submitted for DEQ review and approval in April 2008 (GSI, 2008a; 2008b). DEQ issued NFA determinations for these UICs in a letter dated May 30, 2008. This letter is included in Appendix A. The GWPDs for these UICs are discussed in Section 5.2.1 and Section 8.3.1 of this document.

2.4 Groundwater Protection Under the Permit

The permit requires that City-owned UICs be constructed, operated, and maintained to be protective of groundwater quality as a drinking water resource in accordance with OAR 340-040. To demonstrate groundwater is protected, DEQ included the following requirements in the permit (DEQ, 2005a):

- Utilize an aggressive statistically valid sampling design representative of the City's UICs.
- Sample a minimum of five storm events during a wet season for pollutants that commonly are detected in stormwater within urban areas.
- Sample for the presence of less common pollutants that may or may not be present in stormwater at least three times during the permit duration (*i.e.*, priority pollutant screen [PPS] analytes).

- Permit compliance is based on pollutant concentrations detected at the point stormwater enters the top of the UIC (*i.e.*, end-of pipe). MADLs do not account for the treatment and/or removal (*i.e.*, attenuation) of pollutants by physical, chemical, or biological processes in subsurface soils between the point of discharge and seasonal high groundwater.
- Utilize stormwater discharge limits (MADLs) equivalent to Oregon groundwater protection standards (typically measured in groundwater at a predetermined compliance boundary), federal drinking water standards measured in drinking water, and other health based limits.
- Vertical separation between the bottom of the UIC and shallow groundwater sufficient to allow unsaturated soil to remove or attenuate pollutants and bacteria concentrations.

DEQ established MADLs in the permit for the expected common and less common pollutants (*i.e.,* PPS analytes) in stormwater. DEQ states the MADLs are protective of groundwater quality in that they either met regulatory requirements for drinking water or DEQ demonstrated the established concentration does not pose a likely adverse impact to groundwater quality (DEQ, 2005b). "*By meeting the annual mean MADL concentration, the Permittee effectively demonstrates its discharge of stormwater to Class V UIC injections systems is protective of the groundwater in accordance with OAR 340-040-0020*" (DEQ, 2005b).

The Oregon Groundwater Quality Protection rules (OAR 340-040) do not specifically define the term "likely adverse groundwater quality impact." City-owned UICs are not designed to discharge stormwater directly into groundwater or surface water. City-owned UICs are designed to allow stormwater to infiltrate through unsaturated soils to provide treatment and reduce pollutant concentrations prior to reaching groundwater (*i.e.*, indirect discharge).

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Section

3

3 UIC Summary Data

This section summarizes the results of the City's stormwater discharge monitoring performed in Years 1 and 2 of the permit. The data is used to characterize the quality of the stormwater entering the UICs and demonstrate that discharges meet the MADLs defined by the permit, with the exception of PCP. PCP is the only pollutant that the annual mean concentration has exceeded the MADL. This section also presents a summary and discussion of vertical separation distances in the City-owned UIC system. The data presented in this section is used to develop the conceptual site model and to define input parameters for evaluating pollutant fate and transport using the GWPD Tool.

3.1 Stormwater Monitoring Result Summary

The City's UIC monitoring program is implemented in accordance with the SDMP (BES, 2006c), submitted to DEQ in August 2006. The results of the annual monitoring are presented in the *Annual Stormwater Discharge Monitoring Report* submitted to DEQ by July 15 of each permit year (BES, 2006e; BES, 2007a). The results of the Year 1 (2005-2006) and Year 2 (2006-2007) monitoring are summarized below. The results of the Year 3 (2007-2008) monitoring will be submitted to DEQ by July 15, 2008.

Compliance Monitoring

The permit identifies three pollutant categories: common, PPS analytes, and ancillary. These are defined as follows:

- **Common pollutants** are monitored during each of 5 sampling events throughout a wet season. These pollutants were identified by DEQ based on their review of multiple sources of data and literature to identify what pollutants may be contained in stormwater runoff in urban areas (DEQ, 2005a).
- **PPS analytes** are defined as less common pollutants and are monitored in permit Years 1, 4, and 9.
- **Ancillary pollutants** are defined as those analytes that are detected during the required monitoring for common pollutant or PPS analytes using EPA approved analytical methods.

MADLs are defined in Table 1 for common and PPS analytes.

3.1.1 Year 1 Results

This section summarizes the results of Year 1 (2005 – 2006) stormwater monitoring. These results are presented in the *Year 1 Annual Stormwater Discharge Monitoring Report* (BES, 2006e).

Thirty UIC locations were sampled in Year 1 including:

- Thirty UICs selected to implement the required (*i.e.*, compliance monitoring) Year 1 monitoring described in the SDMP:
  - Panel 1 (15 rotating UIC locations sampled for five storm events per year in permit Years 1 and 6); and
  - Panel 6 (15 fixed UIC locations sampled for five storm events per year in permit Years 1 through 10).

Sample locations were selected based on two traffic flow categories: <1,000 trips per day (TPD) and >1,000 TPD.

Results: Five sampling events were completed in Year 1, between October 2005 and May 2006, as required by the permit. Stormwater samples from discharges to City-owned UICs were analyzed for both common pollutant and PPS analytes (*e.g.*, metals, volatile organic compounds [VOCs], semivolatile organic compounds [SVOCs], and pesticides) as defined by the permit. Field and laboratory data collected during Year 1 met the data quality objectives defined in the SDMP.

Thirteen of the 14 common pollutants were detected in the Year 1 sampling events including: benzene, toluene, xylenes, benzo(a)pyrene, di(2-ethylhexyl)phthalate (DEHP), PCP, arsenic, cadmium, chromium, copper, lead, zinc, and total nitrogen. Seven of the 27 PPS analytes were detected during Event 1 and included: antimony, barium, beryllium, mercury, selenium, 2,4-dichlorophenoxyacetic acid (2,4-D), and dinoseb. These seven PPS analytes were monitored during Events 2 through 5 to obtain a total of five samples as required by the permit.

Thirty-five ancillary pollutants were detected at low concentrations (generally < 1 μg/L) in Year 1 sampling events. Twenty-one of these were detected at a frequency of < 9% including 16 that were detected at a frequency of < 3% during individual sampling events. The nine compounds that were detected at the highest frequencies during the individual sampling events were polycyclic aromatic hydrocarbons (PAHs). Of the PAHs, naphthalene had the highest concentration (3.61 μg/L); the maximum concentrations of the other PAHs were, in general, less than about 0.6 μg/L.

MADL Exceedances – Individual Events. Three common pollutants, PCP (nine locations), DEHP (four locations) and lead (three locations) were detected in Year 1 at concentrations above their respective MADLs during individual sampling events. Detected concentrations of all PPS analytes were below their respective MADLs.

MADL Exceedances - Annual Mean: The annual geometric mean concentrations for five UIC locations (P1_1, P6_1, P6_7, P6_8 and P6_14) exceeded the MADL for PCP. The annual geometric means for these locations range from 1.1 to 2.0 μg/L, slightly above the PCP MADL of 1.0 μg/L. The annual geometric mean values for DEHP, benzo(a)pyrene, lead, and antimony were, in general, < 50% of their respective MADLs for individual UIC locations. Annual mean concentrations were not calculated for other pollutants, because their concentrations were < 50% of the MADL and cannot theoretically exceed the MADL.

3.1.2 Year 2 Results

This section summarizes the results of Year 2 (2006 – 2007) stormwater monitoring. These results are presented in the *Year 2 Annual Stormwater Discharge Monitoring Report* (BES, 2007a).

Forty-one UIC locations were sampled during Year 2 including:

- Thirty UICs selected to implement the required (*i.e.*, compliance monitoring) Year 2 monitoring described in the SDMP:
  - Panel 2 (15 rotating UIC locations sampled for five storm events per year in permit Years 2 and 7); and
  - Panel 6 (15 fixed UIC locations sampled for five storm events per year in permit Years 1 through 10).
- One UIC location, P1_1, carried over from Year 1 monitoring due to an exceedance of the permit defined MADL for PCP.
- Ten supplemental UICs located near drinking water wells.

Sample locations were selected based on two traffic flow categories: <1,000 TPD and >1,000 TPD.

In addition to these 41 UICs, six additional UICs were sampled for specific purposes during a single event in Year 2 including: five UICs located in areas without wood treated utility poles, and one UIC sampled during Event 1 in response to a pre-sampling inspection.

Results: Five sampling events were completed, between October 2006 and May 2007, as required by the permit. Stormwater discharge samples were analyzed for common pollutants (*e.g.*, metals, VOCs, SVOCs, and pesticides) as defined by the permit. Year 2 field and laboratory data collected met the SDMP data quality objectives. Testing of PPS analytes is required in permit Years 1, 4, and 9; however, nine PPS analytes are reported in Year 2 because they were detected using EPA test methods for analysis of the common pollutants.

All common pollutants and two PPS analytes (2,4-D and chlorobenzene) were detected in Year 2 sampling events. Twenty-six ancillary pollutants (*i.e.*, analytes derived from the analytical methods for common pollutants) were detected at low concentrations (generally < 1 μg/L). The eight ancillary pollutants detected at the highest frequencies (between 51% and 98%) during the individual sampling events were PAHs. Of the PAHs detected, naphthalene had the highest concentration (1.09 μg/L).

MADL Exceedances – Individual Events: Three pollutants (PCP, DEHP and lead) were detected in Year 2 sampling events at concentrations above their respective MADLs in at least one sample. Detected concentrations of other common and PPS analytes were below their respective MADLs.

MADL Exceedances - Annual Mean: Annual geometric mean concentrations for nine UIC locations (P1_1, P6_1, P6_2, P6_7, P6_14, P2_5, P2_7, P2_13, and P2_14) exceeded the MADL for PCP (1.0 μg/L); annual geometric means for these locations range from 1.0 to 3.2 μg/L, slightly above the MADL. Annual mean concentrations for DEHP, benzo(a)pyrene, and lead were less than their respective MADLs. Annual mean concentrations were not calculated for other pollutants, because their concentrations were <50% of the MADL and cannot theoretically exceed the MADL. The annual mean concentrations for ten supplemental UIC sampling locations did not exceed MADLs.

Category 4 UICs: The annual mean concentration of PCP exceeded the MADL for a second year in four of the five UICs identified in Year 1 as exceeding the annual mean concentration. As a result, four locations (P1_1, P6_1, P6_7, and P6_14) were identified as non-compliant Category 4 UICs in accordance with the permit and reported in the *UICMP Annual Report – No. 2* (BES, 2007b).

3.2 Separation Distance Summary

This section summarizes the City's evaluation of vertical separation distance, identification of UICs with inadequate separation, and selection of corrective actions for noncompliant (Category 2 and Category 3) UICs. The information presented in this section is subsequently used in this document in the development of the conceptual site model and in defining input parameters for evaluating pollutant fate and transport using the GWPD Tool.

The *Systemwide Assessment* report (BES, 2006g) estimated separation distance for the approximately 9,000 UICs within the City's UIC system. Through a collaborative effort with DEQ and U.S. Geological Survey (USGS), the City was able to demonstrate that the vast majority of City-owned UICs have adequate separation distance between the bottom of the UIC and seasonal high groundwater. Of the initial UICs evaluated in the *Systemwide Assessment*, approximately 400 UICs were identified as potentially having inadequate separation distance. Most of these UICs are located within the Johnson Creek/Holgate Lake and Columbia Slough areas. This preliminary identification of UICs in areas of shallow groundwater was intended to focus further evaluation efforts needed to address or confirm UIC compliance status.

Of the 400 identified UICs with the potential for inadequate separation distance, 22 were determined to not pose a threat to groundwater quality because they are associated with the City's potable water supply. These locations include vault drains, aquifer storage and recovery wells, and tank overflows. Because these locations are associated with the City's potable water supply system, they pose no threat to groundwater and were previously authorized by DEQ for continued use.

Twenty-nine of the UICs were identified as Category 2 UICs, due to known inadequate vertical separation distances, based on field verification of the systemwide assessment results. The method for identification of the 29 locations is discussed in the *UICMP Annual Report No. 1* (BES, 2006f). The Category 2 UICs are currently being addressed in accordance with the process described in the CAP, as discussed in Section 2.3 of this report.

The remaining 349 UICs were identified for further evaluation in accordance with the Evaluation and Response program element described in the UICMP. Further evaluation of UICs with potentially inadequate separation distance was performed in accordance with the *Systemwide Assessment Follow-up Actions* workplan (BES, 2006h). The following activities were completed in 2007 and 2008 to evaluate the remaining UICs:

- Collected and refined information regarding the physical characteristics of the identified UICs to determine compliance status and for use in pre-design activities;
- Collected and refined information regarding soil and groundwater characteristics in the vicinity of the identified UICs;
- Updated the City of Portland's *Estimated Depth to Seasonal High Groundwater* map, based on new information received from the USGS (Snyder, in press); and
- Estimated separation distances for City-owned UICs, using the updated USGS data.

In November 2007, following completion of the further evaluation activities described above, 338 UICs were identified, in the *UICMP Annual Report No. 2* (BES, 2007b), as Category 3 UICs due to inadequate vertical separation distances. Approximately 70 of the Category 3 UICs were determined to be non-compliant, based on assumed construction depths of 30 feet. Actual depths of these UICs were obtained, where possible, in early 2008 during pre-design design activities.

Figure 3-1 is a citywide map showing the following information:

- Estimated depth to seasonal high groundwater;
- Locations of the 338 Category 3 UICs identified in November 2007 (BES, 2007b); and
- Locations of the 29 Category 2 UICs identified in December 2006 (BES, 2006f).

Category 3 UICs were defined using the best available information at the time of the compliance determination, using a weight-of-evidence approach. The determination procedure relies on the use of known and verifiable data to increase the confidence in the determination (*i.e.*, reduce the chance of the determination changing) and to allow the City to focus its efforts and resources on known high-priority issues to ensure groundwater protection and permit compliance. It is anticipated that field investigations and pre-design activities implemented to verify UIC depths and subsurface conditions will likely change the list of Category 3 UICs over time. If new data or information of known and verifiable quality becomes available over time, compliance determination(s) may be revisited and the UIC compliance status reclassified (*e.g.*, UICs determined to be non-compliant may be determined to be compliant and vice versa). Updated, prioritized lists of non-compliant UICs will be presented in each annual UICMP report.

Corrective actions for Category 3 UICs will be identified, evaluated, and selected in accordance with the CAP and the *Systemwide Assessment Follow-up Actions* workplan (BES, 2006h). Corrective actions must be completed no later than July 15, 2011 unless DEQ approves a regional corrective action plan.

Corrective action, as defined by the permit, can consist of groundwater monitoring, risk assessment using DEQ-approved protocols, or structural retrofitting of the UIC. Potential corrective actions for the Category 3 UICs were identified in the *UICMP Annual Report: Year 2* (BES, 2007b) as follows:

- **< 5 feet vertical separation distance**: Corrective actions would focus on increasing the vertical separation distance by installing new shallower UICs or horizontal UICs, or utilizing surface infiltration features (*e.g.*, swales, curb extensions) combined with overflows to new shallow UICs or an existing piped system as needed to meet the design storm. Approximately 206 of the 338 Category 3 UICs were reported to have < 5 feet of vertical separation distance.
- **≥ 5 feet and < 7 feet separation distance**: Corrective actions may include increasing the separation distance as described above or reducing the required separation distance for specific UICs or groups of UICs through a GWPD as described in the UICMP (BES, 2006a). Approximately 46 of the 338 Category UICs were reported to have ≥ 5 feet and < 7 feet of vertical separation distance.
- **≥ 7 feet separation distance**: Corrective actions would focus on reducing the required separation distance for specific UICs or groups of UICs through a GWPD as described in the UICMP (BES, 2006a). Approximately 86 of the 338 Category UICs were reported to have ≥ 7 feet of vertical separation distance.

The general distribution of vertical separation distances were evaluated for City-owned UICs. This evaluation indicated that:

- < 4 % (338) of the City-owned UICs have separation distances < 10 feet.
- < 2 % (206) of the City-owned UICs have separation distances < 5 feet.
- 94 % of the City-owned UICs have separation distances >10 feet.
- 90 % of the City-owned UICs have separation distances > 25 feet.
- 80 % of the City-owned UICs have separation distances > 40 feet.
- 70 % of the City-owned UICs have separation distances > 58 feet.
- 60 % of the City-owned UICs have separation distances > 72 feet.
- 50 % of the City-owned UICs have separation distances > 85 feet.
- 25 % of the City-owned UICs have separation distances > 110 feet.
- 10 % of the City-owned UICs have separation distances >148 feet.

Separation distance estimates are considered conservative (*i.e.*, estimated minimum distances) as used in fate and transport analyses, because the estimate of separation is made relative to the seasonal high water table. The seasonal high water level is not representative of the groundwater levels over the entire year. As shown in Figure 3-2, which presents a hydrograph for a well located near Holgate Lake over a 10-year period between 1998 and 2008, the water table fluctuates seasonally between 5 and 10 feet.

Seasonal high water levels occur for < 2 months in most years (*i.e.*, < 15% of the year). UICs receive stormwater runoff throughout the year when the separation distance would be increased. The mean water level is reported by the USGS (Snyder, in press) to be approximately 3 feet less than the seasonal high for much of the Portland area. Further, stormwater entering a UIC can infiltrate soil throughout its perforated length (*i.e.*, above the base of the UIC) providing additional travel distance (*i.e.*, separation distance) over which significant pollutant attenuation can occur.

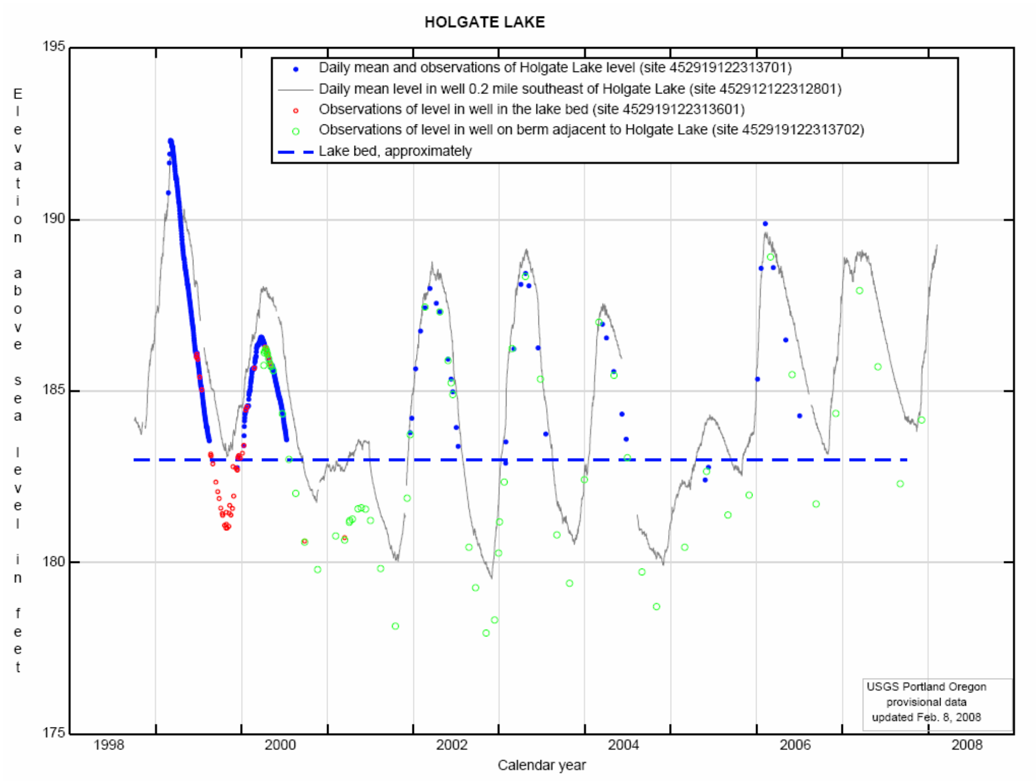

Figure 3-2: Groundwater Hydrograph from Holgate Lake Area in Portland

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Section

4

4 Pollutant Selection for Fate and Transport Analyses

Selected stormwater pollutants are identified in this section for use in the fate and transport analyses described in Sections 8 and 9. The pollutants were selected to be representative of the common pollutants, PPS analytes, and ancillary pollutants monitored under the City's permit (BES, 2006c). The results of Year 1 (2005-2006) and Year 2 (2006-2007) UIC stormwater discharge monitoring, which were summarized in Section 3, were used to inform this pollutant selection process. The selected pollutants will be used as surrogates representative of similar pollutants (*i.e.*, within the same general pollutant categories) to evaluate potential adverse impacts to groundwater associated with urban stormwater discharge to UICs using the GWPD Tool.

4.1 Pollutant Selection Process for Fate and Transport Analysis

A subset of pollutants was selected to be representative of the common pollutants, PPS analytes, and ancillary pollutants that are monitored and discharged to City-owned UICs under the City's permit. This subset of pollutants was selected, based on consideration of the following factors:

- Frequency of detection, as determined from the results of the City's Year 1 and Year 2 UIC stormwater discharge monitoring program;
- Mobility;
- Persistence in the environment; and
- Toxicity to humans (consumptive use).

Pollutants were selected to represent each of the following six broad chemical categories monitored under the permit (see the BES, 2006c):

- VOCs;
- SVOCs;
- PAHs;
- Pesticides/Herbicides;
- Metals; and
- Miscellaneous pollutants (*e.g.*, cyanide, nitrates).

The following process was used to select pollutants according to frequency of detection, mobility, persistence, and toxicity, as a basis of selection for further analysis:

1) Pollutants were evaluated with respect to frequency of detection (*i.e.*, indicator of the likelihood of presence of the pollutant in UIC stormwater discharge samples), as determined by the average frequency of detection during Years 1 and 2 of the City's stormwater discharge monitoring program (see Year 1 and Year 2 *Annual Stormwater Discharge Monitoring Reports;* BES, 2006e; BES, 2007a). Frequency of detection was ranked as follows:
   - High (75-100%);
   - Medium (21-74%); or
   - Low (<20%).

2) Pollutants were assigned a mobility category, based on their EPA groundwater mobility ranking value (for liquid, non-karst). Mobility values were obtained from EPA's *Superfund Chemical Data Matrix Methodology*, Appendix A (EPA, 2004). In the absence of an EPA mobility ranking value, mobility categories were estimated, based upon best professional judgment and knowledge of general pollutant characteristics. EPA chemical mobility was ranked on a log scale as follows:
   - High (EPA mobility ranking of 1.0);
   - Medium (EPA mobility ranking of 0.01); or
   - Low (EPA mobility ranking of <0.01).

   Pollutant solubility in water was also considered as an independent check on the EPA mobility ranking. The review of pollutant solubilities did not result in modifying pollutant selection.

3) Pollutants were evaluated based on their persistence in the environment. Persistence represents the time a pollutant may remain in the environment. This was primarily evaluated using available degradation rates. Persistence was ranked, based on the pollutants' estimated half-life (days), using information provided in *Canadian Environmental Modeling Center Report No. 200104* (Mackay et. al., 2001), as follows:
   - Infinite (does not break down);
   - High (500 and greater $days^{-1}$);
   - Medium (50-499 $days^{-1}$); or
   - Low (0-49 $days^{-1}$).

4) Pollutants were assigned a toxicity category based on a review of available regulatory screening level values (SLVs). SLVs are based upon Oregon DEQ Risk Based Concentrations (RBCs) for Groundwater Ingestion and Inhalation from Tapwater, Residential (DEQ, 2007b), EPA Region 6 Human Health Medium-Specific Screening Values (EPA, 2008b), and EPA MCLs (EPA, 2008a) for public drinking water systems, where available. In general, the lower the SLV concentration, the more toxic the pollutant is (*i.e.*, greater potential for adverse

effects on human health) and the higher the toxicity ranking. Pollutant toxicity was ranked as follows:

- High (SLV <10 µg/l);
- Medium (SLV 10-100 µg/l); or
- Low (SLV >100 µg/l).

The information used to evaluate pollutants and assign rankings for each of the pollutant categories is described above. Pollutant rankings are presented in Table 4-1. Pollutants were selected by this ranking process in a manner that ensured pollutants from each of the six broad chemical categories listed above were represented. Pollutants were selected from each pollutant category, in order to assess the variation in fate and transport characteristics of the pollutants detected by the UIC stormwater discharge monitoring program. For each of these six chemical groups, the pollutant characteristics were considered in the following order:

1) Frequency of detection (Pollutants in the low category [58 pollutants] were not considered further. Fifty-four of these pollutants were detected in < 5% of samples);
2) Mobility (Pollutants in the low category were not considered further);
3) Persistence; and
4) Toxicity.

In the event that multiple pollutants collectively scored in a similar manner, pollutants from the common pollutant and PPS analyte lists were selected before those from the ancillary pollutant list.

4.2 Pollutants Selected for Fate and Transport Analysis

Based upon the above process, the following pollutants were selected[3] for use in the analysis of vertical separation distance:

- VOCs: Toluene
- SVOCs: PCP
DEHP
- PAHs: Benzo(a)pyrene
Naphthalene
- Pesticides/Herbicides: 2,4-D
Methoxychlor
- Metals: Copper
Lead

[3] No representative pollutants were selected from the miscellaneous pollutants category, which includes nitrates and cyanide.

The objective of this selection process was to identify pollutants that are representative of:

- Pollutants most commonly detected by the City's UIC monitoring program;
- Various broad pollutant categories (VOCs, PAHs, metals, etc.) monitored under the permit; and
- Other pollutants detected in stormwater that are included within the same broad category as the selected pollutant. Pollutants were selected (e.g., toluene) to be used as conservative surrogates of other pollutants (*e.g.,* benzene, xylenes) within the same broad pollutant category (*e.g.*, VOCs).

Selection of representative pollutants for each of the pollutant categories was fairly "clear-cut", with the exception of the PAHs. Many PAHs have a high frequency of detection and high toxicity, but low mobility. Benzo(a)pyrene was selected because it is the only PAH on the common and PPS analyte lists (all other PAHs are considered ancillary pollutants). Naphthlene was also selected because it represents a "low molecular weight, noncarcinogenic PAH" and is relatively mobile compared to the other PAHs. While other PAHs exhibit similar frequencies of detection and have higher toxicity, they were not selected because they are less mobile, and because naphthalene can be used as a surrogate for these compounds (*i.e.*, if naphthalene is determined to not adversely impact groundwater quality, then it can be determined that the other PAHs are unlikely to impact groundwater quality because they are less mobile at similar concentrations).

The selected pollutants are believed to be representative of the pollutants detected by the City's UIC stormwater monitoring program and regulated by the permit. The pollutants will be used as indicators /surrogates of similar pollutants to evaluate potential adverse impacts to groundwater associated with urban stormwater discharge to UICs.

4.3 Estimated Pollutant Concentrations

4.1.1 Purpose

The results of the stormwater compliance monitoring, described in Section 3.1, were evaluated to statistically describe the concentrations of the selected pollutants identified in Section 4.2 that would subsequently be used in the fate and transport analysis described in Sections 8 and 9.

4.1.2 Background

The monitoring program sampling design (BES, 2006c) consists of selecting a generalized random-tessellation stratified (GRTS) sample from the population of UICs. The GRTS survey design is specifically designed to characterize a large system with many potential sampling locations, such as the City's UIC system. It randomly selects sampling locations form a population of potential locations whose members are distributed over a large space in a manner that produces a spatially balanced sample. The

GRTS method provides a statistically valid design that will result in unbiased estimates of population parameters and confidence intervals on the estimates that have a high probability (95%) of containing the true, unknown population parameters (BES, 2006c).

The sampling design consists of measuring mean pollutant concentrations at 30 compliance-monitoring UIC locations based on five storm events each wet season (October – May).

4.1.3 Methodology

The arithmetic average of all sampling events (*e.g.*, 5 events for rotating panels, 15 events for the fixed panel) at each UIC was used to arrive at a single measurement result (*e.g.*, average concentration) for each UIC. Thus, the indicators used in the design-based analysis are the average pollutant concentrations for all sampling events for each pollutant. The design-based analysis consists of estimating the cumulative distribution function (CDF), the mean, the 90th percentile and the 95th percentile for each pollutant specific indicator.

These concentrations were calculated using the methods described by Stevens and Olsen (2004) and the results of the UIC compliance monitoring performed in Years 1 through 3 (47 UIC locations) in accordance with the SDMP (BES, 2006c). The mean and the CDF of the proportion are calculated using the Horvitz-Thompson ratio estimator. The confidence bounds on the mean and CDF are calculated using the local mean variance estimator. The 90th and 95th percentiles and their confidence intervals are calculated using interpolation of the estimated CDF and of the confidence bounds of the estimated CDF.

4.1.4 Assumptions

Due to the high frequency of non-detected values for some of the selected pollutants, non-detects were replaced with values of 0, ½ the method reporting limit (MRL), and the MRL, and the analyses described above were performed for each data set. Use of these replacement values bracket the range of potential pollutant concentrations. DEQ risk assessment guidance (DEQ, 2000) recommends replacing non-detect values with ½ the MRL and these values are carried forward into the fate and transport analyses presented in Sections 8 and 9.

4.1.5 Results

Table 4-2 presents the following statistics for the pollutants identified in Section 4.2:

- Mean concentration;
- 95th Upper Confidence Limit (UCL) on the mean;
- 90th percentile concentration; and
- 95th percentile concentration.

Figures 4-1 through 4-9 present plots of the CDF for the selected pollutants (Note: non-detect concentrations were replaced by ½ the MRL for plotting purposes). These plots can be used to estimate the probability of a given pollutant's annual mean concentration exceeding its respective MADL.

As discussed in Section 5, DEQ and BES agreed to evaluate a range of pollutant concentration values which would represent "average" and "reasonable maximum" conditions. DEQ agreed that "average" conditions, would be used to evaluate whether stormwater discharges to UICs are protective of groundwater quality. The 95th UCL on the mean and the 95th UCL on the 95th percentile concentrations, derived using ½ the MRL, were used to estimate the average and "reasonable maximum" concentrations of pollutants selected in Section 4.2, and carried forward into the fate and transport analyses described in Sections 8 and 9. These concentrations are summarized in Table 4-2.

Comparison of Summary Statistics to MADLs

- Mean pollutant concentrations, at the end-of-pipe where stormwater enters the UIC, are significantly less (between 0.04% and 49%) than their respective MADLs or SLVs.
- 95th UCL on the mean concentrations, at the end-of-pipe where stormwater enters the UIC, are significantly less than (between 0.05% and 63%) than their respective MADLs or SLVs.
- 95th percentile concentrations (i.e., the probability of concentrations greater than these concentrations being detected is about 5%) are significantly less (between 0.05% and 49%) than MADLs with the exception of PCP and DEHP.
- PCP and DEHP are the only compounds whose 95th percentile values exceed their respective MADLs.
    - 95th percentile concentrations for PCP and DEHP are <1.75x higher than their respective MADLs.
    - 95th UCL on the 95th percentile concentrations for PCP and DEHP are both <3.4x the MADL.

These concentrations strongly indicate that groundwater quality is protected since stormwater concentrations are less than DEQ and EPA concentrations protective of drinking water (e.g., MCLs, EPA Region 6 residential water screening levels, and DEQ residential risk-based concentrations) at the point the water enters than UIC.

5 GWPD Tool Development

Section

5

This section provides a general description of the GWPD Tool and the process used to develop it.

5.1 Tool Description

As used in this document and in the UICMP (BES, 2006a), a GWPD is defined as the collective analysis performed to evaluate and document whether stormwater pollutant concentrations entering a UIC are reduced to levels protective of drinking water at the point the infiltrated stormwater reaches groundwater. Specifically, a GWPD is developed to meet the general requirements of the permit and the Groundwater Quality Protection Rules (OAR 340-040-0001 through 340-040-0210), and Oregon Environmental Hazardous Substance Remedial Action Rules (OAR 340-122-001 through 340-122-0115).

Risk Assessment /Groundwater Protection

The term "risk assessment," as referenced in the permit (Schedule B(7)) and as used in the UICMP is an evaluation and/or demonstration of whether stormwater discharges into City-owned UICs are protective of groundwater, comply with OAR 340-040, do not adversely affect the beneficial uses of groundwater, and are protective of human health and the environment. If these conditions are met, groundwater is protected in accordance with the permit.

The GWPD Tool is a solute transport spreadsheet model developed to evaluate the reduction of stormwater pollutant concentrations entering the UIC by unsaturated soil prior to the infiltrating stormwater reaching groundwater. The Tool is used to evaluate the fate and transport of pollutants in different geologic units by modifying the appropriate physical and chemical input parameters to characterize the properties of the geologic materials and pollutants.

This decision making Framework document provides streamlined and consistent protocols for applying the GWPD Tool to determine whether a particular set of UIC site conditions are protective of groundwater and where further evaluation or corrective action is required. The Framework and GWPD Tool are also intended to support NFA determinations, as appropriate. The appropriate uses of the Framework and GWPD Tool are discussed in Section 10.

5.2 Tool Development

The GWPD Tool was developed using a phased approach; two work phases were completed under DEQ oversight as the foundation of the Tool. The purpose of the phased approach was to allow the Tool to be developed in a methodical manner. Phase 1 focused on the development of the methodology and assumptions to be used in evaluating a limited number of UICs with a single issue (MADL exceedance) and a single pollutant (PCP). Phase 2 built on the results of the Phase 1 and incorporated DEQ's comments on the Phase 1 results. Phase 2 expanded the Phase 1 methodology to evaluate two issues (vertical separation distance and potential MADL exceedance) and multiple pollutants representative of stormwater entering the City's UIC system.

Phase 1 and Phase 2 were developed with active DEQ oversight achieved in part through scheduled bimonthly meetings. BES and their consultant GSI Water Solutions (GSI) met with DEQ and incorporated DEQ comments and suggestion into the analyses throughout the Tool development process. The primary purpose of these ongoing meetings was to develop the approach and specific methodologies to be used to evaluate pollutant fate and transport through unsaturated soil in order to determine if stormwater discharges to City-owned UICs were reasonably likely to result in adverse impacts to groundwater quality. During these meetings DEQ and BES agreed on the following fundamental principals which served as a basis for GWPD Tool development:

- Unsaturated subsurface soils are part of the treatment prior to the stormwater reaching groundwater. Permit compliance is based on concentrations detected at the point stormwater enters the top of the UIC (*i.e.*, end-of pipe) and does not account for the treatment/removal (*i.e.*, attenuation) of pollutants by subsurface soils between the point of discharge and seasonal high groundwater.
- Regarding the general hydrogeological CSM for evaluating pollutant fate and transport, it is recognized that the system is complex due to pulsed stormwater inputs, soil wetting and drying cycles, variability in soil type and texture with depth, etc.
- Fate and transport analysis is an appropriate method to evaluate and document groundwater protection.
- The fate and transport analysis should include consideration of chemical, physical, and biological processes occurring in unsaturated subsurface soils between the point of stormwater discharge and seasonal high groundwater.
- The use of a one-dimensional, constant source advection dispersion equation that incorporates sorption and degradation (biotic and abiotic) is appropriate to assess pollutant fate and transport.
- Because of the complexities in the hydrogeologic system and variability in stormwater concentrations, it is appropriate to evaluate "average" conditions for representing soil characteristics, degradation rates, etc. and determining potential groundwater impacts. The "reasonable maximum" scenario, as defined by DEQ and EPA guidance, would be used to provide an evaluation of uncertainties in the fate and transport calculations.
- Based on an initial review of pollutant sorption capacities that Portland area soils have a significant ability to bind pollutants (*i.e.*, high pollutant sorption capacity) and that with the very low pollutant concentrations observed in the UIC stormwater discharge monitoring data, the sorption capacity is not likely to be reached.

- A range of parameter values would be used to represent "average" and "reasonable maximum" scenarios (pollutant source terms and model input parameters for the protectiveness demonstrations).
- The fate and transport of PCP is pH dependent (*i.e.*, higher sorption occurs at lower pH). BES and DEQ agreed to use Portland-specific groundwater pH data to define the "average" and "reasonable maximum" sorption values.
- Biodegradation of PCP would be evaluated using aerobic conditions, based on Portland-specific groundwater dissolved oxygen data. Dissolved oxygen in the unsaturated zone is expected to be as great or greater than that observed in local groundwater.
- The list of representative pollutants to evaluate decreases in separation distance and to evaluate generic stormwater discharges, would be based on pollutant:
  - Frequency of detection in UIC monitoring data;
  - Mobility;
  - Persistence; and
  - Toxicity.

In addition, DEQ acknowledged that their review of historical groundwater data indicated that "After more than 60 years of stormwater injection in the Portland area, stormwater and groundwater data do not indicate adverse impacts to groundwater quality resulting from subsurface stormwater disposal" (DEQ, 2005b).

5.2.1 Phase 1: Category 4 UIC Groundwater Protectiveness Demonstrations

The first phase of Tool development evaluated four non-compliant UICs, identified following the second year (2006-2007) of stormwater discharge monitoring. These UICs were identified as Category 4 because annual mean PCP concentrations in stormwater exceeded the MADL for two consecutive years. A one-dimensional mathematical fate and transport equation and site-specific parameter values (*e.g.*, soil type, contaminant concentration) were used to evaluate and document whether stormwater pollutant concentrations entering the UIC are reduced to levels protective of drinking water at the point the infiltrated stormwater reaches groundwater. The results of these analyses are presented in Section 8. BES submitted the following documents to DEQ for review and approval, demonstrating groundwater quality is protected and supporting NFA determinations as the recommended corrective action for the four identified Category 4 UICs:

1. *Category 4 UIC Corrective Actions - Groundwater Protectiveness Demonstrations* prepared by GSI and EnviroIssues under the direction of the BES UIC Program staff. This technical memorandum is dated April 7, 2008.
2. *Peer Review of UIC Category 4 Groundwater Protectiveness Demonstration – Draft dated March 3, 2008* prepared by S.S. Papadopulos & Associates (SSP&A). BES retained SSP&A to perform an independent review of the draft GSI technical memorandum. SSP&A's memorandum is dated April 6, 2008.

3. *Category 4 – UICs Corrective Action.* Letter from Rod Struck, BES to Rodney Weick, DEQ informing DEQ that BES had identified the GWPD (*e.g.*, risk assessment) as the selected corrective action for the four Category 4 UICs. This letter requested DEQ approval of the selected corrective action and NFA determinations.
4. *Category 4 UICs – Corrective Actions.* This April 15, 2008 letter (Rod Struck, BES to Rodney Weick, DEQ) provides a table showing how key comments made by SSP&A (April 6, 2008) were incorporated into the final GSI technical memorandum dated April 7, 2008.

The documents, listed above, regarding the Category 4 Corrective Actions were developed with DEQ input and the final documents were reviewed by DEQ. DEQ's comments on these documents were provided in an April 29, 2008 electronic mail (Rodney Weick, DEQ to Rod Struck, BES). In addition to their provided comments, DEQ concluded that the methodology and assumptions used in the analyses presented in these documents provide a good analytical tool for evaluating pollutant transport in unsaturated zone soil beneath City-owned UICs.

DEQ issued an NFA determination for the four Category 4 UICs on May 30, 2008. A copy of this letter is included in Appendix A.

5.2.2 Phase 2: Evaluation of Vertical Separation Distance

The second phase of Tool development included building on the methodology and assumptions developed in Phase 1 to evaluate whether a vertical separation distance (*i.e.*, the distance between the bottom of a UIC and seasonal high groundwater) of < 10 feet is protective of groundwater. Phase 2 was developed with DEQ participation and input, similar to their involvement in Phase 1, described in Section 5.2.1. Phase 2 expanded the analyses performed in Phase 1 from a single issue (MADL exceedance) and single pollutant (PCP) to multiple issues (MADL exceedance, separation distance) and multiple pollutants. Phase 2 included incorporation of DEQ's April 29, 2008 comments on the Phase 1 technical memorandum and SSP&A recommendations (SSP&A, 2008). In this phase, a range of site parameters specific to the Portland area, and the pollutants identified in Section 4.2 of this document, were evaluated and incorporated into the analyses. The results of this evaluation were used to identify site-specific conditions and pollutant concentrations that would be protective of groundwater for separation distances of 5 and 7 feet. The results of Phase 2 are presented in Section 8. A copy of the technical memorandum, *Evaluation of Vertical Separation Distance - Groundwater Protectiveness Demonstration* is included in Appendix B. This memorandum was prepared under BES oversight by GSI, SSP&A, and EnviroIssues and is dated May 27, 2008.

DEQ approved this technical memorandum on June 5, 2008. A copy of this letter is included in Appendix C.

5.2.3 Phase 3: Development of GWPD Framework

The last phase of work involved developing the generic GWPD Framework, based upon the methodology, assumptions, and results of the Phase 2 analyses (see Sections 8 and 9). Phase 3 included applying the results of Phase 2 to a wider range of UIC issues and conditions that might be expected to exist in Portland. In addition, a groundwater fate and transport analysis was performed to demonstrate that identified domestic and public water wells located within permit UIC setbacks (*i.e.*, Category 2 and Category 3 UICs, both non-compliant due to inadequate vertical separation distances) are protected pending the completion of corrective actions; this evaluation is presented in Section 9. Section 10 presents the steps or protocols for applying the GWPD Tool to UICs that fall within four specific categories identified during permit negotiations and permit implementation including:

- UICs with inadequate separation distance;
- UICs located within permit specified setbacks from drinking water wells (private or public);
- UICs with stormwater concentrations exceeding permit specified MADLs at end-of-pipe where stormwater enters the UIC; and
- UICs that have ubiquitous stormwater pollutants (*e.g.*, PCP in stormwater).

5.3 Tool Limitations

In preparing this document, the City identifies assumptions and exposure parameters that are conservative enough to cover typical City-owned UICs (*i.e.*, located in rights-of-way). The assumptions and parameters are not intended to be applied to UICs that have been subject to spills of hazardous substances, may receive large volumes of petroleum product (*i.e.*, non-aqueous phase liquid), or may receive stormwater runoff from heavily industrialized properties. Spills will be managed in accordance with the *Spill Prevention and Pollution Control Plan* included in the UICMP.

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Section

6

6 Environmental Setting

This section presents a summary of the environmental setting used in developing the conceptual site model and selecting input parameters for the GWPD Tool. The Tool uses available regional and/or site-specific geologic and hydrogeologic information, where readily available. Physical and chemical properties of unsaturated zone soils and the selected representative pollutants are obtained from selected references and available regulatory guidance, as described in the following sections.

6.1 Regional Geologic Overview

Most of Portland lies within the Portland Basin, a northwest-trending, down dropped structural basin, bounded by the Portland Hills to the west and the Cascades to the east. The basin is approximately 20 miles wide and 45 miles long and is filled with up to 1,600 feet of sedimentary deposits (Golder, 1993).

Geologic units in the Portland Basin are shown in Figure 6-1. The sedimentary and volcanic deposits in the Portland Basin range in age from upper Eocene to Holocene. As described in the UIC Report (BES, 2002), the oldest rocks (Eocene to middle Oligocene) sedimentary rocks and Skamania Volcanics generally are not exposed in the Portland Metropolitan area. The oldest rocks are overlain by basalts of the Columbia River Basalt Group (middle Miocene), Rhododendron Formation (middle to late Miocene), the Sandy River Mudstone and Troutdale Formations (late Miocene to late Pliocene). Overlying these deposits are the Boring Lava and Volcanic Rocks of the High Cascade Range (late Pliocene to Pleistocene), and catastrophic flood deposits and recent alluvium (Late Pleistocene and Holocene).

Figure 6-2 shows the surficial geology in the Portland Basin. Because of the high permeability of gravels, UICs in the City of Portland tend to be located in late Pleistocene catastrophic flood deposits or the Pleistocene upper Troutdale Formation. The Troutdale Formation is denoted QTg, and the catastrophic flood deposits are denoted either Qff (fine-grained facies) or Qfc (coarse-grained facies). These formations are described in Madin (1990):

- **Coarse-Grained Facies (Qfc).** Gravel with silt and coarse sand matrix. Gravel size ranges from pebbles to boulders.
- **Fine-Grained Facies (Qff).** Coarse sand and silt.
- **Upper Troutdale Gravels (QTg).** Cemented gravel with sand and silt matrix. Gravel size ranges from pebbles to boulders.

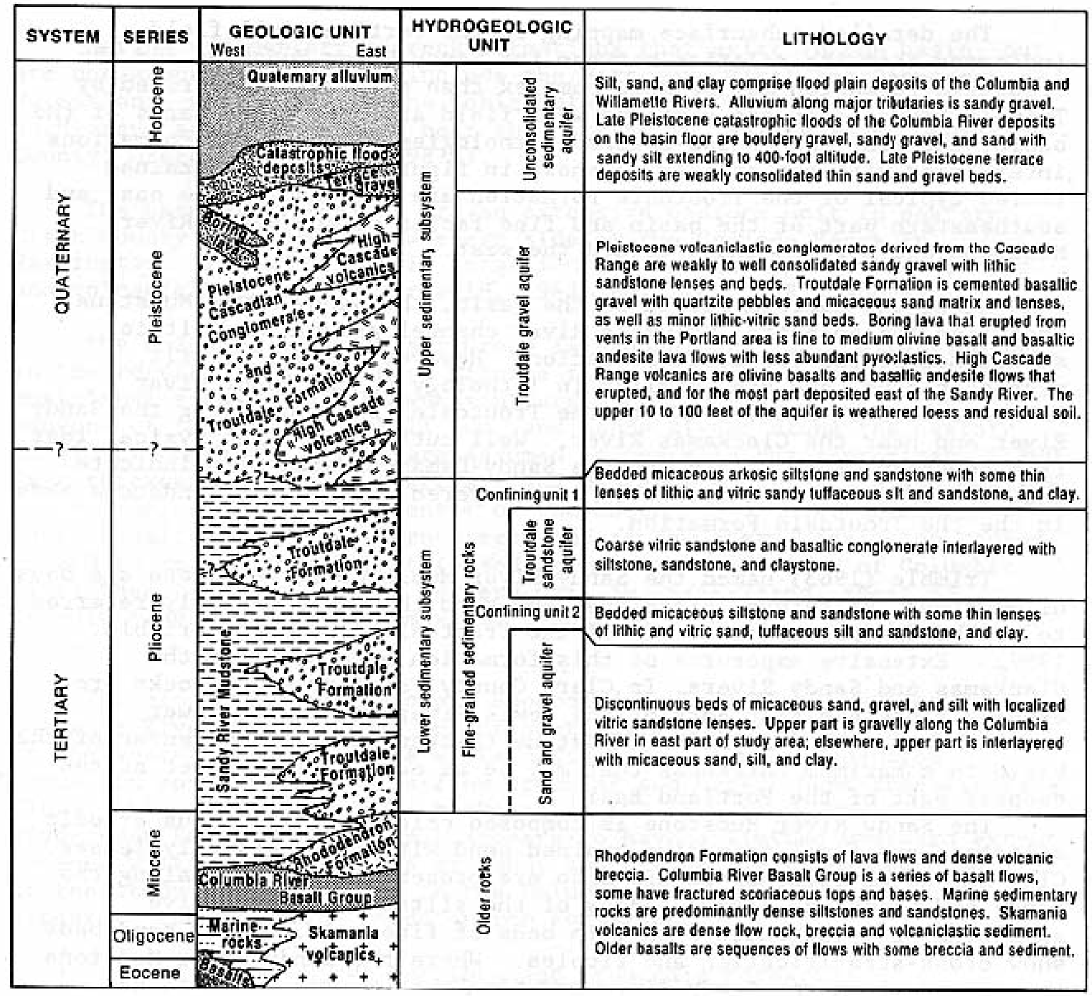

Figure 6-1 - Stratigraphic Representation of Geologic and Hydrogeologic Units in the Portland Basin, Oregon (Swanson, et. al., 1993, Figure 3)

6.2 Regional Hydrogeologic Overview

The hydrogeology of the Portland basin has been described by several authors (Trimble, 1963; Willis, 1977 and 1978; Hoffsetter, 1984; Hartford and McFarland, 1989; Swanson, et. al, 1993; Snyder, in press). In general, six regionally-significant hydrogeologic units are recognized in the Portland Basin. As described by Harford and McFarland (1989) and Swanson et al. (1993), the regionally-significant hydrogeologic units are from oldest to youngest:

1) Sand and Gravel Aquifer;
2) Confining Unit 2;
3) Troutdale Sandstone Aquifer (TSA);
4) Confining Unit 1;

5) Troutdale Gravel Aquifer (TGA); and

6) Unconsolidated Gravel Aquifer (UG).

UICs in the City of Portland primarily discharge into the TGA and the UG; therefore, the following sections focus on the TGA and UG.

6.2.1 Aquifers

UICs discharge into either the UG or the TGA aquifers. The UG consists of the coarse-grained and fine-grained facies discussed in Section 6.1, and consists of catastrophic flood deposits. The UG grain size distribution ranges from pebble to boulders (for the Qfc) to a fine sand (for the Qff). The TGA consists of the Troutdale Gravel geologic unit - cemented gravel with sand and silt matrix. According to USGS (1996a; 1996b), permeability of the UG is much higher than the TGA, and the UG produces more water. However, the TGA is capable of producing several hundred gallons per minute in some locations.

Trimble (1963) describes the unconsolidated sedimentary aquifer of Swanson (1993) as lacustrine deposits that include the Bretz flood deposits (catastrophic flood deposits in Figure 3) and upper Troutdale gravels, with clasts that range in size from pebbles to large boulders. These clasts commonly are clay coated. Hartford and McFarland (1989) and Swanson, et. al. (1993) identify these deposits as consolidated to weakly consolidated intercalated beds and lenses of bouldery gravel, sandy gravel, and sandy silt with a matrix of generally fine to coarse sand with silt.

6.2.2 Depth to Groundwater

Figure 3-1 shows that the depth shallow groundwater is encountered in the Portland area ranges from over 200 feet below ground surface (bgs) in the eastern portion of the City of Portland to under two feet bgs near the Columbia River. The depth to groundwater for individual UICs or groups of UICs is estimated using the City's *Estimated Depth to Seasonal High Groundwater* map, based on new information received from the USGS (Snyder, in press). It should be noted that the USGS information is draft and subject to change after USGS publication of the document.

6.2.3 Groundwater Geochemistry

Groundwater geochemistry data collected from 12 USGS wells, screened at or near the water table on the east side of the Willamette River, were used to assess pH levels and dissolved oxygen concentrations for use in evaluating the fate and transport of stormwater pollutants in the subsurface. Groundwater data was initially collected by the USGS and DEQ. Measurements for pH and dissolved oxygen (parameters important to the fate and transport analysis) are available in selected wells from 1997 to 2007. According to these measurements, groundwater is aerobic, and groundwater pH is near neutral. Portland area groundwater pH levels and dissolved oxygen concentrations are discussed in the *Category 4 UIC Corrective Actions Groundwater Protectiveness*

Demonstrations Technical Memorandum (GSI, 2008a) and the *Updated Groundwater Protectiveness Demonstrations Technical Memorandum* (GSI, 2008b).

6.2.4 Unsaturated Zone Soil Geochemistry

As was discussed earlier, the UG and TGA consist of gravel and sand. Gravel and sand are moderately porous, have moderate bulk densities, and allow for relatively rapid movement of water. In addition, the gravel and sand in the Portland Basin contain relatively low concentrations of organic carbon (however, total organic carbon in stormwater is expected to accumulate in the soil adjacent to and below the UICs, resulting in locally high concentrations of organic carbon). Organic carbon levels are further discussed in the *Evaluation of Vertical Separation Distance Technical Memorandum* (Appendix B).

Section 7

7 Conceptual Site Model

This section discusses the CSM that is the basis for development of the GWPD Tool. At its most basic level, the CSM can be thought of as a "picture" of an UIC system that shows the relationships between potential pollutant sources, exposure pathways, and receptors.

> **Risk**
> In order for risk to exist there must be a complete pathway from the pollutant source to the receptor.

Risk-based decision making involves evaluating current and reasonably likely future risks to human health associated with the presence of pollutants (*i.e.*, contaminants) at a given site and using that information to develop appropriate actions to manage or reduce risks to acceptable levels. To assess risk, the following information is needed:

- Types of pollutants present;
- Type of potential receptors (humans, ecological);
- Identification of the ways pollutant exposure may occur (inhalation, ingestion, etc.);
- Pollutant concentrations;
- Nature of pollution (media impacted, size/area, location); and
- Toxicity and persistence of identified pollutants.

The information listed above is used to develop the CSM for City-owned UICs that describes the known or suspected sources of contamination; considers how and where the pollutants are likely to move (migration pathways) in Section 7.1; describes known or suspected sources of pollutants in Section 7.2; and identifies who is likely to be affected by the pollutants (receptors) in Section 7.3. Toxicity and persistence of the pollutants selected for analyses by the GWPD are discussed in Section 4.

7.1 Migration Pathways

This subsection describes the typical UIC configuration and the general fate and transport of a stormwater pollutant discharged to a UIC. The primary purpose of this section is to identify the potential pathways in which a human or ecological receptor may be exposed to stormwater pollutants so that these migration pathways can be evaluated by the GWPD Tool and receptors can be considered in the GWPD Framework.

7.1.1 Typical UIC Configuration

Figure 7-1 shows a schematic of a City-owned UIC system. A typical City-owned UIC system consists of a stormwater inlet (*e.g.*, catch basin), sedimentation manhole, and the UIC (*i.e.*, sump, drywell). The stormwater inlet collects stormwater for discharge into the sedimentation manhole, which is a solid concrete cylinder generally three to four feet in diameter and 10 feet deep, located upstream of the UIC. The sedimentation manhole provides pretreatment prior to stormwater discharging to the UIC and is designed to remain full of stormwater. Water leaves the sedimentation manhole though a "bent elbow" drainpipe that extends below the water surface. Sedimentation manholes provide pretreatment by allowing sediment in stormwater to settle before entering the UIC and by preventing floatables (*e.g.*, debris, oil and grease) from flowing into the UIC.

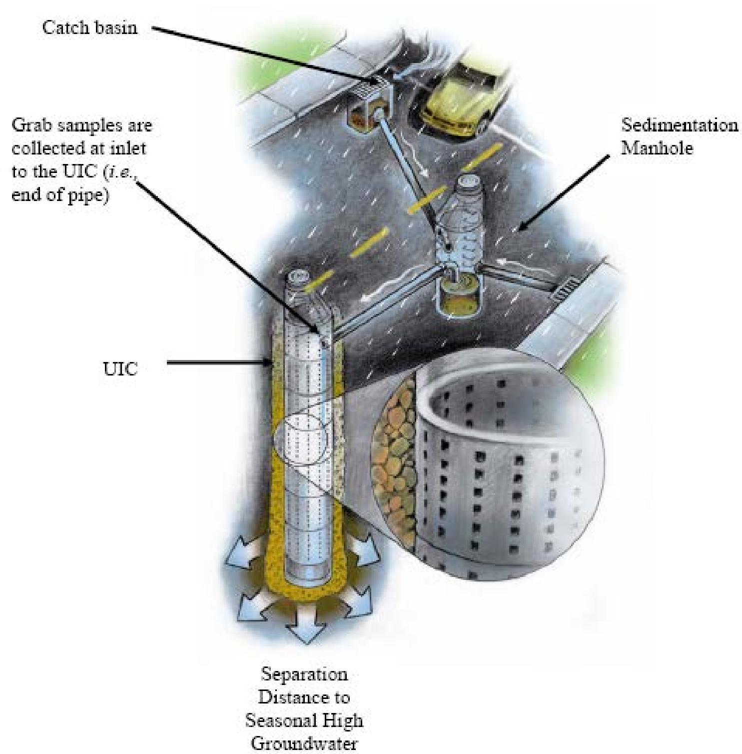

Figure 7-1: Schematic of Typical City UIC System

UICs are generally four feet in diameter and range in depth from about 2 feet up to 40 feet. Most of the City-owned UICs are approximately 30 feet deep. In accordance with the permit, the compliance point for pollutants in stormwater is the end of pipe where stormwater is discharged into the UIC downstream of any pretreatment device (*e.g.*, sediment manhole) and does not account for the treatment/removal (*i.e.*, attenuation) of pollutants by subsurface soils between the point of discharge and seasonal high groundwater.

7.1.2 Pollutant Fate and Transport in Unsaturated Soil

Stormwater from the UIC is discharged into the subsurface soil, infiltrates through the soil (*i.e.*, unsaturated zone), and eventually recharges groundwater. In reality, stormwater discharges occur during storm events of sufficient intensity to generate runoff (DEQ, 2005a). Storm events are of limited frequency and duration. The total days of storm events of sufficient intensity (> 0.08 inches of rainfall) to generate runoff to a drywell occur, on average, between 60 and 80 days during the wet season (October through May). Ninety percent of precipitation in the Portland Basin occurs during the wet season. Prior to entering the unsaturated zone, large-size particulate matter (which pollutants may be sorbed to) falls out of suspension into a sump (*e.g.*, sediment trap ring) at the bottom of the UIC. During transport through the unsaturated zone, pollutant concentrations are attenuated by:

- **Volatilization.** Volatilization is pollutant attenuation due to 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 volatilization is not significant at depths below most UIC bottoms (*i.e.*, 30 feet), volatilization is not included in this GWPD (EPA, 2001).

- **Adsorption.** Adsorption is pollutant attenuation due to 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 contaminant molecule and the ions of the soil molecule's surface.

- **Degradation.** Degradation is pollutant attenuation due to biotic and abiotic processes. Abiotic degradation includes hydrolysis, oxidation-reduction and photolysis. Biotic degradation involves microorganisms metabolizing contaminants through biochemical reactions. Degradation is described by a first-order decay constant.

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

As a result of adsorption, degradation, and dispersion, pollutant concentrations in unsaturated soil beneath the UIC are lower than pollutant concentrations measured at the stormwater inlet. The permit allows for unsaturated zone soils to function as part of the water quality treatment system (DEQ, 2005b). To assure that the unsaturated zone functions as intended as part of the treatment system, a vertical separation distance sufficient to reduce pollutant concentrations in infiltrating stormwater to levels protective of drinking water quality, must be maintained (See Section 3.2).

To determine the pathways that might allow pollutants detected in stormwater discharges to UICs to reach potential receptors, consideration was given to how someone might be exposed to the pollutants within the UIC and how the pollutants might move resulting in future exposures. Generally, human exposure to pollutants may result from inhalation, ingestion, or dermal contact. For exposure to occur a receptor needs both an exposure point of contact with a contaminated environmental medium (*e.g.*, stormwater, stormwater solids, groundwater) and an exposure route (*e.g.*, ingestion of groundwater). Table 7-1 describes potential pollutant exposure pathways and their applicability to UICs. This list of potential exposure pathways is based on the transport properties of pollutants commonly detected in stormwater and the conservative assumption that soil, stormwater, and groundwater are contaminated.

Table 7-1: Potential Exposure Pathway Applicability

(Note: bolded pathways retained for further evaluation)

Medium	Exposure Pathway	Applicability
Air	Inhalation of volatiles	Not applicable. Stormwater is either at ground surface or discharged to a typical UIC completed at a depth of 30 feet bgs.
Stormwater Solids / Impacted Soil	Ingestion of stormwater pollutants, Inhalation of particulates or vapors, and Dermal absorption	Not applicable. Stormwater solids are contained in the sedimentation manhole or accumulate at depth of approximately 30 feet bgs in the UIC. Solids are periodically cleaned out and disposed of in accordance with appropriate regulations Potentially impacted soils, if present, would be located at a depth >8 feet bgs (*i.e.*, top UIC perforation).
	Volatilization to outdoor air	Not applicable. Volatile compounds are not expected in stormwater discharges. Volatilization would most likely occur from stormwater prior to entering the UIC.
	Volatilization to indoor air	Not applicable. Volatile compounds are not expected in stormwater discharges. UICs are constructed in City streets or open City rights-of-way.
	Leaching of stormwater pollutants from soil/sediments to groundwater	**Applicable**. Selected stormwater pollutants may leach from solids accumulated in the UIC or potentially impacted soils adjacent to the UIC.
Stormwater / Sump Water/ Groundwater	**Ingestion of stormwater pollutants** and Inhalation of volatiles	**Applicable (ingestion only)**. Stormwater pollutants can theoretically migrate through unsaturated soil (vertical separation distance) to groundwater and then subsequently migrate with groundwater to a potential receptor (drinking water well user). Inhalation of volatile compounds is not applicable. Volatile compounds are not expected in stormwater discharges.
	Volatilization to outdoor air	Not applicable. Volatile compounds are not expected in stormwater discharges.
	Volatilization to indoor air	Not applicable. Volatile compounds are not expected in stormwater discharges. UICs are constructed in open space within City right-of-way.
	Dermal absorption of stormwater pollutants and Inhalation of volatiles	Not applicable. This pathway would be applicable to construction or excavation workers that come into contact with contaminated sump water or groundwater in a semi-enclosed space. If present contaminated media would be present at depths > 8 feet bgs.

Based on the analyses presented in Table 7-1, the only exposure pathways of concern are:

- Leaching of stormwater pollutants from solids accumulated in the UIC or potentially impacted soils adjacent to the UIC; and
- Ingestion of pollutants in groundwater.

The GWPD Tool and this Framework were developed to address these exposure pathways of concern by evaluating pollutant fate and transport (*e.g.*, treatment, attenuation) in unsaturated soil. It should be noted that evaluation of these pathways is conservative because:

- Stormwater solids are accumulated in solid sedimentation manholes prior to stormwater discharging to a UIC.
- Stormwater solids accumulated in the sedimentation manhole and UICs are periodically removed during routine operations and maintenance activities.
- Stormwater concentrations entering the UICs are generally significantly less than drinking water standards at the point stormwater discharges into the UIC. Observed individual sampling event MADL exceedances are typically < 3x the MADL for a very limited number of pollutants (lead, PCP, DEHP). Observed annual mean concentrations for PCP are typically < 2x the MADL; PCP is the only pollutant that the mean annual concentration has exceeded its MADL.

7.2 Potential Stormwater Pollutant Sources

This subsection describes the types and sources of potential urban stormwater pollutants. The primary purpose of this section is to identify the potential sources of the stormwater pollutants that will be evaluated by the GWPD Tool and the GWPD Framework.

City-owned UICs receive stormwater runoff primarily from city streets and rights-of-way in non-industrial areas. Impervious source areas (*e.g.*, streets, parking lots, driveways, roofs, sidewalks) likely contribute the most stormwater runoff to UIC discharges during small storm events. Runoff from pervious areas (*e.g.*, lawns, unpaved parking lots, open space, undeveloped areas) likely increases during larger storm events. Discharges to City-owned UICs include both rainwater (*i.e.*, dissolved fraction) and particulate matter (*i.e.*, solids) picked up by stormwater flow.

Sources of pollutants on paved areas include particulates that have not been removed by wind or street cleaning activities. Atmospheric deposition (*e.g.*, auto exhaust, wood stoves), deposition from activities on the impervious surfaces (*e.g.*, pavement wear, auto braking, auto accidents, auto drippage [brake fluid, fuels, antifreeze, transmission oil, oils, grease], spills, material storage), and resuspension and redeposition of particulates from nearby areas are likely sources of stormwater pollutants. Particulates from pervious or impervious areas may be transported via stormwater flow to catch basins, sedimentation manholes, or UIC sumps. Particulate transport is largely dependent on stormwater flow velocities, particulate sizes, and settling rates.

Potential UICs pollutants and their potential sources are summarized in the Table 7-2.

Table 7-2: Potential UIC Pollutants and Sources

Pollutant Category	Potential Sources
Petroleum Hydrocarbons	Automobile drippage (fuel, oil, grease), asphalt wear, tires
PAHs and SVOCs	Fuels, automobile exhaust (fuel combustion), air deposition, asphalt, tires, wood preservatives
PCP[4]	Treated wood, wood preservatives
Phthalates[5]	Used automotive oil, automotive belts, brake pads, packing peanuts, tires, etc.
Metals	Automobiles, roof runoff, native soil, pesticides, etc.
Pesticides/Herbicides	Insecticides and herbicides applied in or near rights-of-way
Nutrients (Nitrates, phosphorous)	Fertilizers, landscaped areas
Bacteria (*e.g.*, *e. coli*, fecal coliform)	Animal waste (*e.g.*, avian, dog, cat, raccoon, rodent)

Many of these pollutants have low solubilities and are strongly associated with particulates suspended in the stormwater (*e.g.*, suspended solids).

Section 3 provides a summary of the UIC monitoring program required by the permit. Only three pollutants (PCP, lead, and DEHP) have exceeded permit-specific MADLs at the point of discharge into the UIC. Each of these stormwater pollutants is commonly detected at low concentrations in stormwater discharges to the UICs and is considered to be ubiquitous. A ubiquitous pollutant is one that does not have a discrete point source. An example of a ubiquitous pollutant is PCP that leaches from wood-treated utility poles. Utility poles are present throughout the City. A non-ubiquitous, or point-source, pollutant has a discrete source, such as a spill or a pollutant that migrates from a known industrial site and can be reasonably addressed through source control actions. Ubiquitous sources are addressed through actions such as street cleaning and public education.

Stormwater monitoring data collected during the Year 1 and Year 2 stormwater discharge monitoring events (BES, 2006e; BES, 2007a) suggest that only a few pollutants associated with stormwater (PCP, DEHP, and lead), are detected at concentrations exceeding MADLs. A number of other pollutants are detected in stormwater at concentrations significantly less than their respective MADLs or SLVs (*e.g.*, EPA Region 6). Since few pollutants are detected at compliance-defined limits, an evaluation of cumulative risk was considered unnecessary, consistent with the approach in DEQ's

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4 See *Technical Memorandum Chemical Profile: Pentachlorophenol* (BES, 2005b) for additional Pentachlorophenol sources.

5 See *Technical Memorandum Chemical Profile: Phthalates* (BES, 2005c) for additional phthalate sources.

guidance for *Risk-Based Decision Making for the Remediation of Petroleum-Contaminated Sites* (DEQ, 2003; revised DEQ 2007b).

Section 4 describes the pollutants selected for analyses by the GWPD Tool and this Framework. These pollutants were selected based on consideration of the following factors: frequency of detection by the UIC stormwater monitoring program, mobility, persistence, and toxicity. The selected pollutants are representative of the pollutant categories identified in Table 7-2.

7.3 Potential Receptors

This subsection describes potential human or ecological receptors that may be exposed to stormwater pollutants by the migration pathways identified in Section 7.1. Protection of the identified receptors is considered in the GWPD Framework.

7.3.1 Human Receptors

The permit is based on the protection of groundwater and identifies drinking water as the highest beneficial use of groundwater. It is conservatively assumed that groundwater is used as a drinking water resource and that the potential groundwater receptors (*i.e.*, consumers) are adults and children in a residential scenario (single-family home). This is a conservative assumption, since it assumes that polluted groundwater is the primary source of drinking water for the identified receptors. This assumption is protective of both current and potential future uses of groundwater.

The current (*i.e.*, actual) use of groundwater and potential current receptors can be identified by performing a survey of drinking water wells within a set radius of a given UIC. The purpose of the well search is to identify the nearest potential groundwater user (*i.e.*, receptors) that theoretically could be exposed to pollutants discharged into the subject UIC. The results of the groundwater well survey can be used in part to qualitatively or quantitatively assess the theoretical risk that a pollutant(s) may pose to that potential receptor (*i.e.*, well user) under current and/or future conditions.

In addition, a well search identifies the nearest potential groundwater well. This information can be used to conservatively estimate the shortest theoretical pollutant migration distance (*i.e.*, the horizontal distance between the surface locations of the UIC and the water well) in order to qualitatively assess risk to well users. Use of this distance is conservative in that it assumes:

- The nearest well is hydraulically downgradient of the UIC (*i.e.*, groundwater and pollutant(s) migrate in a straight line from the point of injection to the well).
- No pollutant attenuation occurs.
- Groundwater flow is horizontal (*i.e.*, vertical flow in the aquifer is not considered and the tortuous pathway a pollutant particle would take around individual soil/aquifer particles is not considered).

The permit requires the City to identify UICs near domestic or public wells (*i.e.*, within specified horizontal separation distances or setbacks), demonstrate that these UICs comply with the stormwater discharge quality limits established in the permit, and take appropriate corrective action if they do not meet the water quality limits established in the permit. The *Systemwide Assessment* (BES, 2006g) identifies domestic and public water wells located within 500 feet of a UIC or within a two-year time-of-travel (TOT) of a public water well. These results are used to evaluate whether potential groundwater users (receptors) may be impacted by stormwater discharges to City-owned UICs and to assess conditions needed to ensure protection of human health. Locations where receptors (drinking water wells) are within 500 feet or a 2-year TOT, are considered in the GWPD Framework in Sections 8 and 9.

Based on USGS, DEQ, and City groundwater monitoring data, there is no indication that elevated levels of stormwater pollutants discharged to UICs have adversely impacted groundwater quality (DEQ, 2005b). DEQ reviewed stormwater quality data from multiple sources and reviewed literature on the physical and geologic characteristics of sediments underlying the Portland Basin to ascertain the general ability of the unsaturated sediments to naturally attenuate and filter pollutants in storm water. Groundwater quality underlying the Portland Basin has been monitored since the mid-1970’s. DEQ maintained a monitoring network of private domestic water wells until the mid-1990’s and the USGS monitored groundwater quality in the mid- and late-1990’s (DEQ, 2005b). The City has sampled selected USGS wells since 2003.

7.3.2 Ecological Receptors

Evaluation of potential ecological receptors or ecological risk is not considered necessary for the following reasons:

- Most City-owned UICs are constructed in public rights-of-way (*i.e.*, roads), which are obviously devoid of ecologically important species and habitat.
- UICs are constructed below ground. Stormwater pollutants are typically discharged to a depth > 3 feet bgs, and are therefore unlikely to come into contact with biota in native soil or ecological receptors.
- City-owned UICs are not located in immediate proximity to surface water bodies. Therefore, stormwater discharges are not reasonably likely to discharge to surface waters or otherwise affect surface water quality.
- Stormwater pollutants are not expected to reach the land surface in a manner that would result in contact with ecological receptors.

7.4 Summary of CSM

Some stormwater pollutants can theoretically reach groundwater by migrating through unsaturated soil or by leaching from stormwater solids captured in the UIC system (*e.g.*, sedimentation manholes, UIC sumps) or from contaminated soil adjacent to the UIC. Pollutant concentrations at the point stormwater enters groundwater are expected to be significantly lower than the input concentration. Pollutant concentrations would be reduced as the pollutant travels from the UIC vertically downward though unsaturated soil into groundwater by various physical processes (advection, dispersion, dilution, diffusion, volatilization, sorption / desorption), chemical reactions (ion exchange, complexation, abiotic transformation), and biological activity (aerobic and anaerobic biodegradation). If a stormwater pollutant reached groundwater, the concentration would continue to be reduced prior to human contact or consumption by these processes as the pollutant is transported with groundwater though saturated soil toward the nearest drinking water well intake.

As described in Section 7.2, potential UIC pollutants are believed to be associated with the release of pollutants from motor vehicles (*e.g.*, fuels, oils, brakes, tires, belts) and motor vehicle exhaust. These pollutants are generally hydrophobic, as discussed in Section 4, and therefore, they would tend to sorb to stormwater solids and settle out in catch basins, the sedimentation manhole, or the UIC, or be filtered out by native materials. Pollutants discharged to UICs are assumed to have a limited extent outside the UIC, based on their hydrophobic nature and ability to degrade. "*Unsaturated sediments in the vadose (unsaturated) zone function as part of the water quality treatment system. These unsaturated sediments attenuate pollutants*…" (DEQ, 2005b). This is consistent with EPA's statement (EPA, 1996) that contaminants at sites with shallow sources, thick unsaturated zones, and/or degradable contaminants may attenuate and/or degrade before reaching the groundwater.

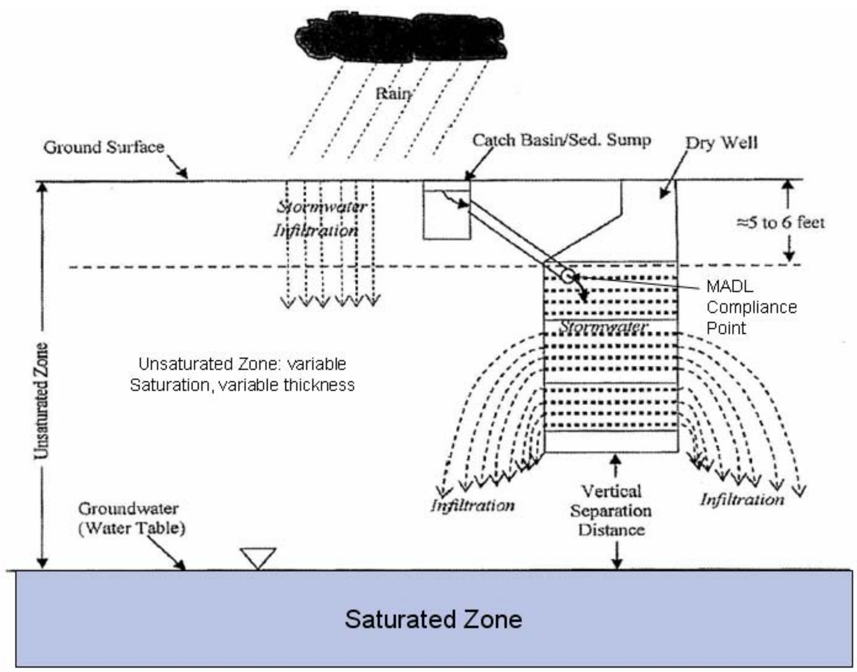
Figure 7-2 provides a schematic of the CSM described in the previous sections. The CSM shows that UICs discharge stormwater into unsaturated soil adjacent to and below the UIC structure. Stormwater pollutants are attenuated in the soil (*e.g.*, sand, gravel) by sorption, degradation, dispersion, and mechanical filtration. This implies that a greater unsaturated zone thickness provides greater protection of the underlying shallow groundwater.

For a complete pollutant migration pathway to exist from the UIC (*e.g.*, point of stormwater discharge) to a drinking water well, pollutants would need adequate volume and concentration to overcome applicable physical, chemical, and biological processes along the flow path and adequate travel time to reach the potential receptor (*i.e.*, groundwater consumer). The likelihood that groundwater quality (or a given drinking water well) may be impacted at a concentration above background (*i.e.*, antidegradation) or above concentrations protective of drinking water is dependent on numerous variables in addition to the physical, chemical, and biologic pollutant attenuation processes listed above including, but not limited to:

- Variability in pollutant discharge rate and volume;
- Variability in pollutant discharge concentration;
- Pollutant characteristics (solubility, octanol-water coefficients, etc.);
- Separation distance between base of UIC and shallow groundwater;
- Groundwater oxidation/reduction potential; and

- Variability in UIC site stratigraphy/lithology:
  - Consideration of the effect of variation in the percent fine or organic content between soil particles (grains) to affect pollutant sorption, dispersion, etc. due to variations in lithology or microstratigraphy; and
  - Consideration of the effect of variation in local soil/aquifer permeability on groundwater flow velocity, pollutant retardation, etc. due to variations in lithology or microstratigraphy.

Figure 7-2: UIC Conceptual Site Model



(After DEQ, 2005b)

The GWPD Tool presented in this document, to evaluate whether groundwater is adversely impacted by stormwater pollutants discharged to UICs, is based on the CSM (pathways, pollutants, receptors), UIC stormwater discharge concentrations (Section 3), Portland area geology and hydrogeology (Section 6) and other Portland specific information (Section 5). Section 8 presents the methodology as applied to analyze the fate and transport of pollutants in unsaturated soil for UICs with ≥5 feet of separation distance. Section 9 presents "worst case" analyses of the potential fate and transport of pollutants in groundwater for UICs with <5 feet of separation distance. The purpose of these analyses is to determine whether domestic and public water wells located within permit UIC setbacks (*i.e.*, Category 2 and Category 3 UICs, both non-compliant due to inadequate vertical separation distances) are protected pending the completion of required corrective actions.

Section

8

8 GWPD Technical Methodology and Results: ≥ 5 Feet of Separation Distance

This section describes the GWPD Tool developed for assessing the potential "risk" to groundwater posed by the discharge of urban stormwater runoff into City-owned UICs. The Tool described in this section applies to UICs with a vertical separation distance of ≥ 5 feet. The permit and the DEQ's "*Fact Sheet and Class V Underground Injection Control (UIC) Permit Evaluation*" report (DEQ, 2005b) identify pollutant fate and transport analyses as a method that the City may use to evaluate and/or demonstrate groundwater is protected in accordance with OAR 340-040. Specifically, the GWPD Tool consists of a DEQ-approved, Portland specific, analytical methodology to evaluate the reduction of stormwater pollutant concentrations, entering UICs, by unsaturated soil prior to the infiltrating stormwater reaching groundwater.

Results of the GWPD Tool as applied in this section were used to develop a Look-Up Table (Look-Up Table) of stormwater discharge concentrations that are protective of groundwater quality for UICs with ≥ 5 feet of vertical separation distance (see Section 8.8.4). UICs with <5 feet of vertical separation are discussed in Section 9.

8.1 Purpose of the GWPD Tool

The purpose of the GWPD Tool is to have a simple streamlined approach to assess whether stormwater discharges to City-owned UICs are protective of groundwater. The Tool can be used to evaluate decisions regarding the need for further evaluation, corrective action, or to support a NFA decision. Appropriate uses of the Framework and GWPD Tool are discussed in Section 10.

The results of the GWPD, based on the DEQ-approved *Evaluation of Vertical Separation Distance – Groundwater Protectiveness Demonstration Technical Memorandum* (Appendix B), indicate stormwater discharges entering City-owned UICs are protective of groundwater for UICs with ≥5 feet of vertical separation distance (See Section 8.8.3). The approved GWPD Tool was used to define UIC site conditions that are protective of groundwater. A generic groundwater protectiveness Look-Up Table presented as Table 8-1 was generated using the GWPD Tool. The uses of the GWPD Tool are described in Section 8.2. In general, the results presented in this generic Look-Up Table can be applied to any UICs with a vertical separation distance of ≥5 feet. The GWPD Tool

Groundwater Protection

"Groundwater protection," as used in this document and in OAR 340-040 means:

- Existing or potential beneficial uses for which natural groundwater quality allows are protected (i.e., beneficial uses are not adversely impacted).
- The highest potential beneficial use of groundwater is as a drinking water resource.
- MADLS and OAR numerical groundwater quality reference levels are not exceeded in groundwater. These levels are: obtained from the SDWA; protective of drinking water; and typically measured in groundwater.
- Present and future public health, safety, and welfare and the environment are protected.

(analytical approach) can be used with UIC specific data for individual UICs or groups of UICs, if appropriate, to evaluate groundwater protectiveness for separation distances of <5 feet, on a case-by-case basis, if appropriate (e.g., shallow Park Bureau UICs).

8.2 GWPD Tool Description

This section describes the basis of the GWDP Tool, assumptions, uncertainties, and the resulting generic Look-Up Table (Table 8-1). The process used to develop the technical approach and methodology used in the GWPD Tool is discussed in Section 5. The CSM developed in Section 7 was used to formulate the approach and to select an appropriate equation to evaluate the fate and transport of stormwater pollutants. Portland-specific soil characteristics and pollutant properties used to define parameter inputs are discussed in Sections 4 and 6. Specific application instructions for applying the Tool and Look-Up Table are provided in Section 10.

The solute transport equation, a detailed description of the parameters, and methods for estimating site-specific parameter values, are provided in *Evaluation of Vertical Separation Distance – Groundwater Protectiveness Demonstration Technical Memorandum* (Appendix B). This section summarizes the key information from the technical memorandum.

8.2.1 Description of the Solute Transport Equation Used in the GWPD Tool

The GWPD Tool consists of a one-dimensional mathematical fate and transport equation using site-specific parameter values (*e.g.*, soil type, contaminant concentration). The Tool evaluates whether stormwater pollutant concentrations entering the UIC are reduced to levels that meet OAR 340-040 at the point the infiltrated stormwater reaches groundwater. The solute transport equation incorporates the attenuating mechanisms discussed in Section 4.1, including sorption, degradation (biotic and abiotic) and dispersion to estimate pollutant concentration at the water table (*e.g.*, Watts, 1998). Volatilization is not included as it is expected to be a small to insignificant attenuation factor at the depths in the vadose zone into which the UICs discharge.

8.2.2 Key Assumptions in GWPD Tool

The key assumptions in applying the unsaturated solute transport equation included in the GWPD Tool are:

- Transport is one dimensional vertically downward from the bottom of the UIC to the water table.
- 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, of short duration, and result in varying water levels within the UIC dependent on the infiltration capacity of the formation).
- Pollutant concentrations in stormwater are constant.

- Pollutant concentrations in water discharging into the UIC are uniform and constant throughout the period of infiltration.
- 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.
- There is no partitioning of the pollutant to the gas phase in the vadose 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:

- UICs are typically constructed with a solid concrete bottom and approximate 2-foot deep sediment sump, so stormwater is initially discharged horizontally through the sides of the UIC. Vertically downward migration of stormwater does not begin until the stormwater has traveled some distance from the UIC. Therefore, the assumption that stormwater flows directly downward from the base of the UIC underestimates the travel distance of stormwater in the vadose zone.
- Stormwater flow from the UIC is assumed to be constant with a uniform flow through the vadose zone. In reality, stormwater flows are highly variable and short in duration resulting in varying water levels within the UIC depending on the infiltration capacity of the surrounding formation. Thus, the UIC will periodically 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 over the duration of the period over which the UIC contains water.
- Pollutant concentrations are assumed to be constant. In reality, they are variable throughout storm events. This is very conservative for a few reasons. The 95% UCL on the mean is used for the reasonable maximum scenario, which likely over predicts the concentration throughout the duration of a storm event. In addition, the GWPD does not take into account pollutant attenuation that occurs while in the UIC prior to entering the formation.

8.2.3 GWPD Input Parameter Selection

Input parameters used in the solute transport equation (*i.e.*, GWPD Tool) include pore water velocity, porosity, soil moisture content, fraction organic carbon, organic carbon partitioning coefficient, and degradation rate. Of these six parameters, the solute transport equation is most sensitive to pore water velocity. A site-specific pore water velocity was calculated based on the results of over 100 UIC sump capacity tests conducted on City UICs. The fraction organic carbon in the vadose zone in the vicinity of the UICs was estimated based on the total organic carbon concentrations found in stormwater entering the UICs. Organic carbon will filter out and sorb to the sands surrounding the UICs increasing the fraction of organic carbon relative to that naturally occurring in the formation or sand and gravel in which the UICs are completed. The porosity, soil moisture content, bulk density, and organic carbon partitioning coefficients were estimated based on the geochemistry (*e.g.*, redox conditions) of the vadose zone in the Unconsolidated Sands and Gravels and Upper Troutdale Gravels. Degradation rates were estimated based on a literature review looking specifically at conditions similar to: 1) the formation in which the UICs are completed, 2) the geochemistry of the formation, and 3) the concentration ranges found in stormwater entering the UICs as measured in Years 1 and 2.

As described in Section 5, GWPD Tool development and parameter selection was conducted under DEQ oversight. DEQ approved methodology and the input parameters used in the *Evaluation of Vertical Separation Distance – Groundwater Protectiveness Demonstration Technical Memorandum* (Appendix B) on June 5, 2008 (See Appendix C).

8.2.4 GWPD Tool Scenarios

Two scenarios were evaluated using the GWPD for each selected pollutant (See Section 4) including:

- Average (*i.e.*, the central tendency or expected mean value of the parameter); and
- Reasonable maximum (*i.e.*, the plausible upper bound or highest value reasonably expected to occur).

Given the compounded conservatism in parameter values used for the reasonable maximum scenario, DEQ concurred that the average scenarios are considered the most realistic and that the average scenario will be used to make NFA determinations. The reasonable maximum parameter value is the highest concentration that is reasonably expected to occur (EPA, 1989; DEQ, 2000), and this scenario would be used to evaluate the potential uncertainty inherent in the average scenario outcome.

8.2.5 GWPD Tool Approvals

Development of the GWPD Tool (described in Section 5), was completed by BES and their consultant, GSI, with significant input from DEQ. After initial development of the GWPD Tool, BES retained the services of SSP&A to conduct an independent technical review of the Tool. SSP&A has significant experience and training relevant to unsaturated zone pollutant fate and transport analyses, geochemistry, and senior-peer review. SSP&A (2008) concluded in their technical memorandum - *Peer Review of UIC Category 4 Groundwater Protectiveness Demonstration* that the GWPD Tool is appropriate, defensible, and consistent with current state-of-the-practice. DEQ approved this memorandum on May 30, 2008 (Appendix A).

DEQ approved the *Evaluation of Vertical Separation Distance, Groundwater Protectiveness Demonstration* model on June 5, 2008. A copy of DEQ's approval letter is provided in Appendix C.

8.3 GWDP Tool Results

The GWPD Tool was used to estimate pollutant attenuation in unsaturated soil between the point of discharge into the UIC and shallow groundwater for two scenarios:

- Annual mean PCP concentration exceedences at four Category 4 UICs (See Section 5.2.1); and
- Vertical separation distances < 10 feet (See Section 5.2.2).

The following sections summarize the results of using the GWPD Tool to evaluate the two scenarios described above. In-depth descriptions of GWPD Tool application are provided in the *Category 4 UIC Corrective Actions – Groundwater Protectiveness Demonstrations Technical Memorandum* (GSI, 2008a) and *Evaluation of Vertical Separation Distance – Groundwater Protectiveness Demonstration Technical Memorandum* (Appendix B).

8.3.1 Category 4 UICs

The preliminary version of the GWPD Tool was applied to four non-compliant UICs identified following the second year of stormwater discharge monitoring (GSI, 2008a). These UICs (*i.e.*, P1_1, P6_1, P6_7 and P6_14) were identified as Category 4 because annual mean PCP concentrations in stormwater exceeded the MADL [PCP MADL is 1 micrograms per liter (µg/L)] for two consecutive years. The UICs were characterized by a large separation distances (*i.e.*, ranging from approximately 60 to 150 feet) and relatively low mean annual PCP concentrations [*i.e.*, ranging from 1.15 (P1_1) to 1.9 (P6_7) µg/L]. The recommended corrective action for each of the Category 4 UICs was a GWPD.

Application of the GWPD Tool to Category 4 UICs demonstrated that PCP concentrations infiltrating into unsaturated soil from these UICs will not reach shallow groundwater. It was concluded that unsaturated subsurface soil attenuates (*i.e.*, treats /removes) PCP in stormwater discharges to the subject UICs (*i.e.*, under both average and reasonable maximum conditions) to levels protective of beneficial uses of groundwater and public health and the environment as required by OAR 340-040. Therefore, an NFA determination was recommended for these UICs.

DEQ approved the NFA determination in writing for the four Category 4 UICs evaluate, and issued a NFA letter, dated April 30, 2008 (See Appendix A).

8.3.2 Evaluation of Inadequate Vertical Separation Distance

The second application of the GWPD Tool evaluated whether vertical separation distances < 10 feet are protective of groundwater quality for a range of representative stormwater pollutants. The City's UICs are completed in the three upper hydrogeologic units present in the Portland Basin (see Section 6). Because input parameters (*e.g.*, pore water velocity, porosity, etc.) and assumptions used in the GWPD Tool are dependent on geology, separation distance was evaluated for three scenarios: UICs completed in Qff, UICs completed in Qfc, and UICs completed in QTg. Separation distances of ≥5 feet and ≥7 feet were evaluated for each geologic unit. The results of this evaluation were submitted to DEQ in an *Evaluation of Vertical Separation Distance – Groundwater Protectiveness Demonstration Technical Memorandum*, dated May 2008. DEQ approved the model that was presented in this technical memorandum on June 5, 2008. A copy of DEQ's approval letter and the memorandum are provided in Appendices B and C. A summary of the evaluation results is presented below.

The vertical separation distance evaluation estimated attenuation of representative organic pollutants (*i.e.*, benzo(a)pyrene, naphthalene, PCP, DEHP, 2,4-D, methoxychlor, and toluene), metals (copper and lead), and bacteria. The average scenario results for the three hydrogeologic units indicate that the representative pollutants are attenuated within 5 feet of the base of the UIC even when stormwater concentrations exceed 10x the MADL.

The analysis concluded that with a ≥5 foot distance in the most permeable geologic unit (*i.e.*, Qfc of the UG), UICs with a separation distance of 5 feet are protective of the beneficial uses of groundwater, public health, and the environment in accordance with OAR 340-040 even if pollutant concentrations entering the UICs are at concentrations of >10 x the MADL for organic pollutants.

For metals, the analysis concluded that it would take over 600,000 days (>1,600 years) for copper and over 7,900,000 day (>2,150 years) for lead at average concentrations detected in Years 1 and 2 data to infiltrate to the water table. Even when metals eventually reach the water table, the concentrations are protective of groundwater (*i.e.*, below the MADL).

Bacteria was evaluated based on a literature review coupled with using EPA's *Virulo* reduction probability analysis for transport of viruses through the vadose zone. The literature review of similar geologic material supports a five-foot separation distance as adequate for most septic systems which have considerably higher concentrations of bacteria than are present in stormwater. EPA's *Virulo* model was adapted to estimate the probability that bacteria would be significantly attenuated (*i.e.*, meet a 99.9% reduction in concentration) in a 5 foot thickness of unsaturated sandy loam. The model indicated that there was a zero probability of failure for the modeled 5 foot separation distance. Based on this analysis, it was concluded that groundwater is protected from bacteria with a vertical separation distance of 5 feet.

8.4 GWPD Tool: Generic Look-Up Table

The GWDP Tool was applied to develop a range of generic stormwater pollutant concentrations and environmental conditions protective of groundwater for City-owned UICs with separation distances ≥5 feet. A generic Look-Up Table (Table 8-1) was generated using the GWPD Tool using input parameters from the most permeable geologic unit (*i.e.*, Qfc of the UG). The selection of a 5 foot separation distance[6] and the most permeable geologic unit was based on the results presented in the *Evaluation of Vertical Separation Distance – Groundwater Protectiveness Demonstration Technical Memorandum* (Appendix B) which indicates that concentrations significantly above the MADLs will not result in stormwater pollutants reaching the groundwater or reaching it at concentrations above the risk-based MADL.

It is assumed that the Look-Up Table can be applied to City-owned UICs with vertical separation distances ≥ 5 feet. For example, if a UIC or group of UICs meets the conditions (*i.e.* ≥ 5 feet vertical separation distance and stormwater concentrations are within the range of stormwater input concentrations identified in the table), then the UIC is protective of groundwater. Section 10 presents the steps for applying the generic GWPD Tool. Although the Look-Up Table is specifically for UICs with separation distances ≥ 5 feet, the GWPD Tool could be used at an individual or group of UICs with similar attributes where the separation distance is < 5 feet in very specific cases such as Park Bureau UICs that drain large landscaped or grassy areas where there is not a potential risk to drinking water wells.

Table 8-1 presents the Look-Up Table which is a summary of stormwater discharge concentrations for the selected representative pollutant list (see Section 4.2) determined to be protective of groundwater quality for UICs with a separation distance of ≥5 feet. Again, these values are based on the fate and transport analyses of UICs located in the more permeable geologic unit. Concentrations protective of groundwater for stormwater entering UICs completed in less permeable geologic units would be higher due to increased attenuation capacity of the finer-grained units.

The Look-Up Table presents a range of potential stormwater concentrations. The following concentrations (see Section 4.3) were evaluated using the GWPD Tool to demonstrate groundwater quality is protected in accordance with OAR 340-040:

- Input concentration equal to the 95% UCL on the mean;
- Input concentration equal to the MADL; and
- Input concentration equal to 10x the MADL.

The upper limit of input concentrations included in the analyses was selected as 10x the MADL. Concentrations in stormwater entering a UIC have not and are not expected to

[6] Separation distances < 5 feet were not evaluated and are likely protective for some pollutants. Corrective actions for UICs with separation distances < 5 feet will be selected in accordance with the CAP.

exceed concentrations > 10x the MADL, based on the results of Years 1 through 3 UIC stormwater discharge monitoring (*i.e.*, concentrations >10x the MADL are outside the range of expected concentrations in stormwater as discussed in Section 4.3). In the event concentrations >10x the MADL are detected; BES will initiate appropriate further evaluation, response actions, or corrective actions, as described in Section 10, and the UICMP.

The output concentrations presented in Table 8-1 represent the concentration below the UIC immediately above the water table (*i.e.*, at 5 feet below the UIC). Stormwater concentrations entering the UIC are reduced by >99% prior to reaching groundwater. The analysis indicates that the range of input concentrations for the representative pollutants (benzo(a)pyrene, naphthalene, PCP, DEHP, 2,4-D, methoxychlor, and toluene) are protective of groundwater quality as a drinking water resource, even at concentrations 10x the MADL. Table 8-1 shows the results of this analysis.

Table 8-1: Generic Groundwater Protectiveness Demonstration Tool – Look-Up Table (UICs $\geq$ 5 Feet of Vertical Separation)

Pollutant	MADL [1] (µg/L)		95% UCL [2] on the Mean (µg /L)		10x MADL (µg /L)		Percent Reduction[5]
	Input Concentration [3]	Output Concentration [4]	Input Concentration	Output Concentration [4]	Input Concentration	Output Concentration [4]	
Benzo(a)pyrene	0.2	0	0.02	0	2	0	100%
Naphthalene	6.2 [6]	0	0.05	0	62	0	100%
PCP	1	0	0.60	0	10	0	100%
DEHP	6	0	3.80	0	60	0	100%
2,4-D	70	0.25	0.68	0.003 [7]	700	2.5	99.6%
Methoxychlor	40 [6]	0	0.1	0	400	0	100%
Toluene	1,000	8	2.05	0.02 [7]	10,000	76.7	99.2%

NOTES:

[1]MADL = Maximum Allowable Discharge Limit

[2]UCL = Upper Confidence Limit (See Section 4.3)

[3]Input concentration is the concentration of the pollutant entering the UIC (MADL, 95% UCL on the Mean, or 10x MADL as described in header)

[4]Output concentration is the concentration below the UIC and immediately above the water table

[5]Percent Reduction = Input Concentration/Output Concentration; applies to MADL, 95% UCL, and 10x MADL evaluations.

[6]Concentrations are EPA Region 6 Human Health Medium-Specific SLVs (EPA, 2008)

[7]Output concentration is less than the analytical laboratory MRL of 0.1 µg /L for 2,4-D and 0.5 µg /L for toluene.

Section 9

9 Protectiveness Evaluation for UICs with < 5 Feet of Separation Distance

This section presents "worst case" analyses of the potential fate and transport of pollutants in groundwater for UICs with < 5 feet of separation distance. The purpose of these analyses is to determine whether domestic and public water wells located within permit UIC setbacks (*i.e.*, Category 2 and Category 3 UICs, both non-compliant due to inadequate vertical separation distances) are protected pending the completion of required corrective actions. City-owned UICs with vertical separation distances of < 5 feet are not compliant with permit conditions and corrective action is required (see Section 2).

Two methods are presented in this section to evaluate potential impacts including:

- Pollutant dilution at the point it enters groundwater (Section 9.3); and
- Fate and transport of the pollutant in groundwater (Section 9.4).

The analyses presented in this section are "worst case" in that it is assumed that stormwater pollutants are discharged directly into groundwater; this is not the case. These UICs have < 5 feet of vertical separation to seasonal high groundwater. The permit does not allow direct discharge of stormwater into groundwater.

The results of these analyses are intended to demonstrate protection of potential groundwater users pending completion of the required corrective actions and to assist BES in prioritizing corrective actions.

"Worst case", as used in this document, means a hypothetical scenario developed to analyze potential risks to groundwater. The assumptions used in this scenario include:

- UICs with < 5 feet of vertical separation distance are considered to discharge directly to groundwater. (This is conservative because separation distances are estimated based on seasonal high groundwater levels, and UICs have up to 3 feet of additional separation distance for most of the year.)
- Stormwater pollutant concentrations are discharged at concentrations up to the 95th UCL on the 95th percentile value for the reasonable maximum scenario.

The conservatism in these "worse case" conditions is compounded by the use of conservative assumptions in input parameter values for the reasonable maximum scenario (as described in Sections 9 and 10). The combination of the conservative assumptions in the analysis becomes an unlikely scenario. "Worst case" as used in this document does not include consideration of spills to UICs.

9.1 Background

UICs with separation distances of < 10 feet are non-compliant with the permit as discussed in Section 2 and were identified as either Category 2 or 3 UICs. Corrective actions for these UICs are being selected in accordance with the CAP and are required to be completed by July 2011 unless DEQ approves a Regional Corrective Action Plan as allowed for by the permit (See *Annual UICMP Report No. 2* for additional information). Corrective actions for Category 2 or 3 UICs may include UIC decommissioning, horizontal or shallower UICs, or the use of surface infiltration facilities (swales, curb extensions, planters) to physically increase the vertical separation distances. Twenty-nine Category 2 UICs were identified in the *Annual UICMP Report No. 1* (BES, 2006f); 25 of these have separation distances of < 5 feet. Approximately 200 Category 3 UICs were identified in the *Annual UICMP Report No. 2* (BES, 2007a) with estimated separation distances of < 5 feet. About 35 of the Category 2 and 3 UICs are located within 500 feet of a domestic or public drinking water well or within the 2-year TOT of a public water supply well.

9.2 Protectiveness Evaluation Approach

In order to ensure the potential well users located near Category 2 and Category 3 UICs are protected, a screening level risk assessment was performed. This evaluation assessed if drinking water wells near UICs with separation distances of < 5 feet could be adversely impacted due to ongoing stormwater discharges. The evaluation (*i.e.*, screening level risk assessment) conservatively assumes a worse case scenario that UICs with a separation distance of < 5 feet discharge directly into groundwater. Two methods were employed independently to evaluate whether groundwater is protected under this scenario, including a simple groundwater dilution model and a fate and transport spreadsheet model. The spreadsheet model was used to evaluate the pollutants (PCP, toluene, and 2,4-D) determined to be most mobile, based on the pollutant selection criteria (see Section 4) and the results of GWPD Tool applications (see Section 8).

The conceptual model for UICs with < 5 feet of separation distance is very conservative (i.e., "worst case" in that it assumes that stormwater pollutants are discharged directly into groundwater. In this case, pollutants hypothetically discharged directly to groundwater immediately mix with groundwater (i.e., concentrations are diluted) and pollutants are transported and attenuated in the saturated sands and gravels by sorption, degradation, dispersion, and mechanical filtration. Although dilution and fate and transport in groundwater occur simultaneously, in this section each process is conservatively considered independently of the other. Each process (dilution and fate and transport) is capable of significantly reducing pollutant concentrations and potential adverse affects to domestic well users well before reaching public or private potable wells.

9.3 Simple Dilution Model

BES used a worst case simple dilution analysis, the same analysis DEQ used in the permit (DEQ, 2005a) to establish a MADL for lead that is less conservative than the EPA action level for tap water. The MADL is measured at the point stormwater is discharged into the UIC. The dilution analysis determined no adverse impact to groundwater quality from lead for its beneficial uses and meets the groundwater compliance limits established in the permit. DEQ supported the lead MADL (50 μg/L) based on consideration of the following factors:

- Portland's existing stormwater BMP controls and stormwater management programs;

- Existing groundwater quality data from USGS monitoring wells in areas that receive injected stormwater;
- Attenuation and filtration of pollutants in soils within the unsaturated zone; and
- Dilution effects in groundwater.

DEQ's simple dilution analysis was performed to estimate the concentration of lead in groundwater based on the concentrations of lead discharged to a UIC. This is a conservative analysis as it assumes no natural attenuation and a constant pollutant loading at the MADL concentration into the UIC.

9.3.1 Assumptions

DEQ Assumptions:

1. Stormwater discharge occurs at water table (*i.e.*, no separation distance, no unsaturated zone attenuation)
2. Hydraulic Conductivity (K) = 200 ft/day for the unconfined recent alluvial aquifer (McFarland and Morgan, 1996)
3. Aquifer thickness = 10 feet Aquifer thickness was assumed to equal a typical domestic or monitoring well screen interval of 10 feet with mixing across the entire screen interval
4. Unit aquifer = width of drywell x aquifer thickness = 4 feet x 10 feet = 40 ft^2
5. *i* = hydraulic gradient, estimated about 0.0002 – 0.00002 foot per foot (McFarland and Morgan, 1996)
6. Pollutant input concentration: Lead = 50 µg/L (note: EPA Action Level is 15 µg/Lat the tap)

9.3.2 Methodology

DEQ used Darcy's Law to estimate dilution as described below:

Darcy's Law: Q = KiA

Q = Rate of Flow

K = 200 feet/day

A = aquifer unit area

i = unit hydraulic gradient (dimensionless)

$$Q = (200 \text{ ft/day})(0.00002)(40 \text{ ft}^2) = 0.16 \text{ ft}^3\text{/day}$$

$$\text{Liter conversion: } (0.16 \text{ ft}^3\text{/day})(28.32 \text{ L/ft}^3) = 4.5 \text{ L/day}$$

$$\text{Dilution effect per day} = \frac{\text{UIC discharge concentration}}{\text{unit aquifer volume}}$$

$$= \frac{0.050 \text{ mg}}{4.53 \text{ L}} = 0.011 \text{ mg/l}$$

For the simple analysis presented above, a reduction of up to 78 percent of the input concentration for lead would be expected as a result of groundwater dilution only. If a gradient of 0.0002 is used in the above analyses, a reduction up to 98 percent in lead concentration would be expected.

9.3.3 Results

This analysis indicates that measured stormwater discharge concentrations can be divided by a dilution factor of between 4.5 and 45 (obtained if a gradient of 0.0002 is used) to estimate groundwater concentrations. Conversely MADL concentrations can be multiplied by this factor to estimate a stormwater concentration that would exceed a protective standard (*e.g.*, MCL, MADL) which is considered protective of groundwater. For example, if the EPA action level for lead at the tap was used, stormwater concentrations with a range between 68 µg/L (15 µg/L x 4.5) and 680 µg/L (15 µg/L x 45) could be considered protective of groundwater.

Using a dilution factor of 4.5, Table 9-1 presents the estimated stormwater discharge concentrations that would be protective of groundwater (or after minimal "worse case" dilution, be equal to the MADL in groundwater) for the list of selected pollutants (see Section 4). The 95th UCL on the mean pollutant concentrations for permit Years 1 through 3 are also presented to show that even without dilution, generally concentrations in stormwater are below concentrations considered protective of human health (*e.g.*, MADLs, EPA screening values), demonstrating that groundwater is not adversely impacted by stormwater discharges to the City's UICs and nearby wells are protected.

This evaluation is conservative because it does not account for any attenuation of pollutants and assumes stormwater is directly discharged to groundwater. When natural attenuation processes and filtration in the unsaturated zone are considered in conjunction with aquifer dilution, it becomes apparent why lead and other pollutants are not detected in area groundwater (DEQ, 2005b).

Table 9-1: Protective Groundwater Concentrations by Simple Dilution

Pollutant	95th UCL on the Mean Concentration (µg/L)[a]	MADL (µg/L)	Estimated Stormwater Concentration Protective of Groundwater[b] (µg/L)
Lead	9.5	50	68[c]
Copper	9.9	1,300	5,850
Zinc	53.6	5,000	22,500
Benzo(a)pyrene	0.02	0.2	0.9
Naphthalene	0.05	6.2[d]	28
PCP	0.6	1.0	4.5
DEHP	3.8	6.0	27
2,4-D	0.68	70	315
Methoxychlor	0.1	40[d]	180
Toluene	2.1	1,000	4,500

(Table notes continued on next page)

Table 9-1 Notes:

[a] 95th UCL on the mean was estimated for each pollutant using the results of Year 1-3 UIC compliance monitoring data. See Section 4.3.

[b] Estimated Stormwater Concentration Protective of Groundwater estimated by multiplying the MADL by a dilution factor of 4.5. This assumes stormwater is directly injected into groundwater and does not account for natural attenuation of pollutants by physical, chemical, or biological process during migration through unsaturated soils or groundwater.

[c] This estimate is based on the EPA tap water action level for lead of 15 μg/l.

[d] Concentrations are EPA Region 6 Human Health Medium-Specific SLVs (EPA, 2008).

Based on the simple worse case dilution analyses presented above, groundwater quality is protective of human health in accordance with OAR 340-040 since the estimated 95th UCL on the mean concentrations entering the UICs are significantly less than the MADL and that the estimated dilution upon the pollutant entering groundwater will further reduce the concentrations by a minimum of 4.5.

9.4 Fate and Transport of Pollutants in Groundwater

The GWPD Tool evaluated the fate and transport of pollutants in the vadose zone and indicated that subsurface soils in the Portland area are highly effective in reducing pollutant concentrations between the point of discharge and the point stormwater infiltrates into groundwater. In this section, the theoretical fate and transport of pollutants in groundwater are evaluated for UICs with < 5 feet of vertical separation distance. The evaluation assesses the distance that a pollutant that is directly discharged into groundwater (*i.e.*, "worst case") will travel prior to being attenuated to concentrations below analytical laboratory MRLs, or to zero.

9.4.1 Assumptions

The following are assumptions used in considering the fate and transport of pollutants in groundwater:

- Stormwater discharges directly into groundwater, even though many of the UICs with < 5 feet of separation distance may have 5 or more feet of separation for much of the year.
- Pollutant attenuation in the unsaturated zone is not considered. Separation distances are based on seasonal high groundwater levels. As previously discussed in this document, seasonal high groundwater levels are expected to occur < 15 % of the year.
- Stormwater pollutant concentrations are conservatively assumed to continuously discharge to UICs at 95^{th} UCL on the mean and 95^{th} UCL on the 95^{th} percentile concentrations.
- An average scenario and reasonable maximum scenario were simulated to assess a conservative range of pollutant fate and transport distances in groundwater. The stormwater discharge input concentration used for the average scenario was 95% UCL on the mean, while the 95% UCL on the 95 percentile value was used for the reasonable maximum scenario (see Section 4.3).

- No dilution is considered.
- The aquifer is homogeneous and isotropic, no pumping is occurring, and vertical gradients are insignificant.
- Adsorption follows a linear isotherm and is a reversible processes.
- Groundwater velocity is sufficiently fast so that molecular diffusion can be ignored.

9.4.2 Methodology

BIOSCREEN (EPA, 1996), a saturated flow solute transport model, was selected to estimate the attenuation distances for selected pollutants: PCP, 2,4-D, and toluene. These pollutants were chosen based on previous applications of the GWPD Tool to the following nine pollutants:

- Copper
- Lead
- Benzo(a)pyrene
- Naphthalene
- PCP
- DEHP
- 2,4-D
- Methoxychlor, and
- Toluene.

These nine pollutants were chosen, based on the pollutant selection criteria presented in Section 4. Of these nine pollutants, PCP, 2,4-D, and toluene exhibited the least amount of attenuation during pollutant fate and transport (i.e., were the most mobile) due to the lower retardation and biodegradation rates associated with these three pollutants. Therefore, BIOSCREEN was applied only to PCP, 2,4-D, and toluene.

The software, which is programmed in a Microsoft Excel spreadsheet environment and based on the Domenico analytical solute transport model, has the ability to simulate advection, dispersion, adsorption, and aerobic decay (EPA, 1996). In general, BIOSCREEN input parameter values are similar to those used in the GWPD Tool; however, a few values were revised to address saturated and horizontal flow conditions. Parameter value selection is presented in Appendix B for the GWPD Tool and Appendix D for BIOSCREEN; Appendix D also presents the BIOSCREEN results.

9.4.3 Results

This section summarizes the results of the BIOSCREEN analyses presented in Appendix D.

The results for PCP indicate that:

- PCP concentrations are below the MADL or EPA MCL at the point stormwater enters the UIC under the average scenario.
- PCP will be attenuated to an estimated concentration of 0 at a distance between 1 foot from the UIC (average scenario) and 6 feet from the UIC (reasonable maximum scenario).
- Exceedance of the PCP MADL or EPA MCL is restricted to within 1 foot of the UIC for the reasonable maximum scenario.

The results for toluene indicate that:

- Toluene concentrations are well below (*i.e.*, at least 100x < the MCL) the MADL and EPA MCL at the point stormwater enters the UIC under the average and reasonable maximum scenarios.
- Toluene will be attenuated to the laboratory MRL of 0.5 µg/L at a distance of < 1 foot from the UIC for the average scenario and within 22 feet from the UIC for the reasonable maximum scenario. The MRL for toluene in water using EPA Method 8260B was specified in the SDMP (BES, 2006c).
- The toluene MADL and EPA MCL are not exceeded in groundwater.

The results for 2,4-D indicate that:

- 2,4-D concentrations are well below (*i.e.*, are less 100x < the MADL) the MADL and EPA MCL at the point stormwater enters the UIC under the average and reasonable maximum scenarios.
- 2,4-D will be attenuated to the laboratory MRL of 0.1 µg/L in a distance of about 4 feet from the UIC for the average scenario and about 75 feet from the UIC for the reasonable maximum scenario. The MRL for 2,4-D was specified in the SDMP (BES, 2006c).
- The 2,4-D MADL and EPA MCL are not exceeded in groundwater.

Key Points of Analysis:

- PCP is the only pollutant detected with an annual geometric mean concentration above the MADL. For the reasonable maximum scenario, where the 95%UCL on the 95% percentile is conservatively used as the stormwater input concentration into City-owned UICs, the estimated PCP concentration is predicted to be below the MADL within 1 foot of the UIC.

- 2,4-D and toluene are well below the MADL/screening level concentration at the point of stormwater discharge into City-owned UICs. The 95% UCL on the mean for 2,4-D, based on Year's 1-3 data, is 0.68 µg/L; this is 2 orders of magnitude below the MADL of 70 µg/L. The 95% UCL on the mean for toluene, based on Year's 1-3 data, is 2.05 µg/L; this is 3 orders of magnitude below the MADL of 1000 µg/L. No individual MADL exceedences have occurred for either toluene or 2,4-D.

Table 9-2 summarizes the maximum distances that PCP, toluene, and 2,4-D are expected to travel in groundwater if directly discharged to groundwater prior to reaching either a zero concentration or the analytical laboratory MRL. These estimates are conservative in that they assume direct discharge into groundwater and do not account for dilution at the point stormwater enters groundwater or for attenuation in unsaturated soil (*e.g.*, vertical separation distance) prior to stormwater reaching groundwater. Because of the complexities in the hydrogeologic system and variability in stormwater concentrations, both "average" and "reasonable maximum" scenarios, as defined by DEQ and EPA guidance, are provided to assess the uncertainties in the fate and transport calculations (see Section 5).

Table 9-2: Estimated Pollutant Travel Distances in Groundwater

Scenario		PCP	Toluene	2,4-D
MADL (µg/L)		1	1,000	70
Average [a]	Est. Stormwater Input Conc. (µg/L)	0.6	2.05	0.68
	Travel Distance (feet)	1	<1	4
Reasonable Maximum [b]	Est. Stormwater Input Conc. (µg/L)	2.62	8.08	6.58
	Travel Distance (feet)	6	10	75
Concentration at Specified Travel Distance		**0** µg/L	**0.5** µg/L (MRL)	**0.1** µg/L (MRL)

NOTES:
PCP = pentachlorophenol
2,4-D = 2,4-dichlorophenoxyacetic acid
MRL = Method Reporting Limit specified in the SDMP (BES, 2006c)
[a] Stormwater input concentration based on 95th UCL on the mean (see Section 4.3)
[b] Stormwater input concentration based on 95th UCL on the 95th percentile value (see Section 4.3)

The nearest domestic well to a UIC with vertical separation distance of < 5 feet is approximately 220 feet (BES, 2007b). The groundwater fate and transport analysis indicates pollutants in stormwater are protective of groundwater. Average pollutant concentrations in stormwater are less than their respective MADLs prior to entering City-owned UICs. Under the reasonable maximum scenario, PCP is less than the MADL within about a foot of the UIC. Therefore, it can be concluded that potential groundwater wells located within permit UIC setbacks defined by the permit and potential groundwater receptors (well users) are protected prior to corrective actions being completed on Category 2 and 3 UICs.

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Section

10

10 Applying the GWPD Tool

This section is designed to assist BES and DEQ in streamlining data evaluation by identifying the conditions where stormwater discharges to City-owned UICs are protective of groundwater quality or where response actions or corrective actions are needed to ensure permit compliance and long-term protection of groundwater. These results of the GWPD Tool applications (presented in Sections 8 and 9) and the CSM are used to develop protocols for evaluating whether groundwater is protected. Protocols are included in this section for evaluating the UIC issues identified during permit development (see Section 1.1) including:

- Pollutant MADL Exceedances (Section 10.2);
- Vertical Separation Distance of < 10 feet (Section 10.3);
- UICs within Permit Specified Well Setbacks (Section 10.4); and
- Ubiquitous Pollutants (Section 10.5).

The permit states that an NFA may be an appropriate corrective action for a non-compliant condition. The GWPD is also designed to document the conditions used to show groundwater quality is protected in accordance with OAR 340-040 and that "no further action" is warranted, as allowed under the permit.

10.1 Tool Application

The permit and associated implementation documents require the City to identify response actions and/or corrective actions for UICs that do not meet stormwater discharge limits, requirements for separation distance, or other permit requirements. This document was developed to address several issues identified during permit development to ensure that:

- UICs have adequate separation distance to protect groundwater quality.
- Public and private drinking water wells are protected.
- Groundwater is protected as a drinking water resource.

This section is based on the CSM (described in Section 7), and the GWPD Tool and the pollutant fate and transport assumptions (described in Sections 8 and 9). In developing and applying the GWPD Tool, average and reasonable maximum exposure parameters were used to conservatively evaluate City-owned UICs. The parameters used in this Tool are based on Portland specific conditions (*e.g.*, geology, hydrogeology, stormwater discharge quality) to the extent data are available and practicable. These parameters are discussed in Sections 8 and 9 and Appendices B and D. Decisions made using this document should demonstrate that the key assumptions used in developing the GWPD Tool are appropriate for the specific application of the results represented in Sections 8 and 9.

The GWPD Tool and the protocols described in this section may be applied to individual City-owned UICs or groups of UICs where:

- The UIC system is managed in accordance with the permit and UICMP.
- The quality of stormwater discharged under the permit is representative and statistically valid.
- The City's SWMM and the *Portland Watershed Management Plan* provide an overall framework for protection of human health and the environment.

Prior to applying the GWPD Tool and/or the results of the GWPD Tool application presented in Section 8, it is assumed that the activities, described in the *UICMP - Evaluation and Response* program element have been implemented including:

- A Compliance Determination has been completed, if appropriate (Appendix F of the UICMP).
- Appropriate UIC Evaluation and Response Guidelines (Appendix H of the UICMP) were implemented to identify the source or cause of the non-compliant condition.
- Pollutant sources have been identified and controlled, if possible (Appendix H of the UICMP).
- Data of known and sufficient quality are available to evaluate potential impacts to groundwater.

The GWPD Tool should not be applied prior to appropriate Evaluation and Response activities being performed. The GWPD Tool is generally used to:

1) Evaluate UIC stormwater discharge monitoring results in order to determine if groundwater is protected.
2) Determine if vertical separation distances less than the permit specified distances are protective of groundwater quality.
3) Identify the need for further evaluation or corrective action.
4) Define generic conditions (*e.g.*, pollutant concentrations, soil characteristics, separation distance) under which groundwater is protected for ubiquitous pollutants.
5) Determine if stormwater discharges to UICs within permit specified setbacks from domestic or public water wells are protective of groundwater as a drinking water resource.
6) Evaluate and/or address regional UIC issues.
7) Support GWPD and NFA decisions as appropriate corrective actions for selected non-compliant UICs.

10.2 Tool Application to Pollutant MADL Exceedances

This section describes the protocol BES will implement to evaluate whether specific MADL exceedances measured during individual storm event(s) or annual average mean concentration(s) are protective of groundwater quality in accordance with OAR 340-040.

10.2.1 Purpose

The purpose of this section is to assist BES and DEQ in making the following decisions:

1. For individual stormwater discharge sample results (*e.g.*, single storm event, response samples) that exceed permit MADLs, determine if further evaluation or response actions are needed.
2. For annual mean stormwater discharge concentrations that exceed the MADL in the first year of monitoring, determine if response actions are needed.
3. For annual mean stormwater discharge concentrations that exceed the MADL in the second consecutive year of monitoring (*i.e.*, future Category 4 UICs), demonstrate as appropriate that groundwater quality is not reasonably likely to be adversely impacted and that "no further action" is an appropriate corrective action.

10.2.2 Basis of MADL Protectiveness Evaluation

The discussion and decision making Framework presented in this section are based on the results of the fate and transport analyses (see Section 8) performed to evaluate and document whether stormwater pollutant concentrations entering a UIC are reduced to levels that meet the groundwater protection requirements of OAR 340-040 at the point the infiltrated stormwater reaches groundwater. Using the fate and transport methodology and the soil and chemical input parameters that were summarized in Section 8, and approved by DEQ to evaluate Category 4 UICs (Appendix A), and vertical separation distance (Appendix C), it was determined:

- Representative pollutants measured in stormwater discharges (see Table 8-1) to City-owned UICs would be attenuated during unsaturated zone transport with vertical separation distances of ≥ 5 feet in the three geologic units in which City-owned UICs are completed.
- Pollutant MADL exceedences (*i.e.*, Year 1 and Year 2 MADL exceedances) measured at the end of pipe (*i.e.*, compliance point) are protective of groundwater as a drinking water resource under either the average or reasonable maximum scenario conditions if a separation distance of 5 feet is present (Note: separation distances of < 5 feet may also be protective of groundwater for some pollutants; however, distances < 5 feet were not specifically evaluated).
- The results of the analyses presented in this document are consistent with DEQ's review of regional groundwater quality data that indicate stormwater discharges to UICs are protective of groundwater quality (DEQ, 2005b).

- The results of the pollutant fate and transport evaluation demonstrate that the overarching goal of the permit to protect the highest beneficial use of groundwater, while allowing underground injection of urban stormwater from City rights-of-way, is attained even in the event of reduced separation distances and/or low level exceedences of the permit MADLs.
- Application of the GWPD Tool indicates groundwater quality is protected as a drinking water resource when stormwater discharge concentrations are 10x the MADL (Note: stormwater concentrations for all pollutants with the exception of DEHP have been significantly < 10x the MADL).

10.2.3 Tool Application Protocol

Prerequisites for GWPD Tool Application to UICs with MADL Exceedances:

- Analytical data are of known and verifiable quality.
- UIC has $\geq$5 feet of vertical separation distance.
- Pollutant exceedance is < 10x the MADL.
- Assumptions used in fate and transport analyses are representative and appropriate.
- UIC is located > 50 feet from a private water supply well (domestic, irrigation).
- Pollutants are not due to a spill.

The steps described in this section are intended to demonstrate when groundwater quality is adequately protected from discharge of stormwater containing pollutants at concentrations greater than permit specified MADLs (*i.e.*, observed or predicted low-level exceedances of permit MADLs) or to determine when further evaluation and/or corrective action is required. Prior to applying the GWPD Tool, key elements of *UICER Guideline No. 2: MADL Exceedances* should be applied and used to:

1. Meet the notification and reporting requirements of the permit.
2. Review available analytical data to:
    a. Determine if the observed concentration is within the defined concentration range for the pollutant of interest (see *Annual SDM Reports* and Table 4-2).
    b. Identify whether the concentration is an outlier.
3. Assess potential pollutant sources or causes of the MADL exceedance.

Results of the above evaluation can then be used to determine whether stormwater pollutant discharges to an individual UIC or group of UICs are protective of groundwater quality in accordance with OAR 340-040 or if further action is warranted (see *UICER Guideline No. 6: Groundwater Protectiveness Demonstration* and *UICER Guideline 6a: Fate and Transport Analyses*).

The steps described below provide the decision making Framework to determine whether discharge limits of pollutants to an individual UIC or group of UICs are protective of groundwater. These steps apply to UICs where stormwater monitoring data have been detected at a concentration(s) exceeding a permit defined MADL during at least one sampling event.

Step 1: Identify UIC(s) of Interest and Summarize UIC Characteristics

When a pollutant is detected at a concentration exceeding permit defined MADLs through stormwater discharge monitoring at an individual UIC location or group of UICs, the following information regarding the UIC should be compiled and tabulated for evaluation:

- UIC completion depth;
- Separation distance;
- Site geology;
- Predominant land use in area of UIC;
- Traffic category;
- Proximity to nearest drinking water well[7]; and
- Potential pollutant source.

Step 2: Identify Pollutant of Interest

Identify the pollutant of interest from the results of the stormwater discharge monitoring program. A pollutant of interest is an analyte which exceeds its applicable MADL or screening level concentration (*e.g.*, EPA Region 6 Media Specific Screening Levels). A pollutant of interest may be identified during stormwater compliance monitoring (*e.g.*, individual storm event sampling, calculation of annual mean concentrations, response action sampling, etc.).

Step 3: Estimate Representative Discharge Concentration for Pollutants of Interest

Estimate the following representative concentrations of the pollutant entering an individual UIC or group of UICs:

- Use the measured individual UIC stormwater discharge concentration to evaluate potential adverse groundwater impacts for one time exceedances of the MADL (e.g., compliance storm event sampling, response action sampling).
- Use the calculated annual mean concentration to evaluate potential adverse groundwater impacts where the annual mean concentration has exceeded the MADL.
- Use the 95th UCL concentration on the mean estimated from the results of the UIC stormwater compliance monitoring program (See Table 4-2 or equivalent) to evaluate potential adverse groundwater impacts where the annual mean concentration has exceeded the MADL.

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[7] The 50-foot distance is intended to assist in prioritizing and screening UICs for further evaluation and/or corrective action. In the event UIC(s) are identified within 50 feet of a drinking water well (e.g., irrigation, domestic) further evaluation and/or corrective action will be initiated. This distance is 10% of the permit defined UIC setback from drinking water wells, and the analyses in Sections 8 and 9 show that groundwater is protected in accordance with OAR 340-04, well within this distance for the representative pollutants and concentrations evaluated.

Step 4: Determine if Groundwater is Protected

Step 4a: Verify that the UIC of interest has >10 feet of vertical separation distance.[8] If not, the UIC is not compliant with the permit and should be identified as a Category 3 UIC, if not previously identified as such (see *Section 10.3 - Tool Application to Vertical Separation Distance*).

Step 4b: UICs with Vertical Separation Distances < 5 feet. If the UIC of interest has < 5 feet of vertical separation distance, the Look-Up Table (Table 8-1) developed using the GWPD Tool is not applicable, and appropriate further evaluation, response, or corrective action should be determined in accordance with the UICMP (BES, 2006a).

Step 4c: UICs with Vertical Separation Distances > 5 feet. For UICs with ≥ 5 feet of vertical separation, compare the representative pollutant concentration determined in Step 3 to the concentrations presented in the Look-Up Table (Table 8-1).

Step 4d: Determine the appropriate action - if the representative concentration for the subject pollutant or an appropriate surrogate pollutant is:

- < 95th UCL concentration on the mean – groundwater quality is protected and an NFA is warranted.
- > 95th UCL concentration on the mean and < 10x the MADL – groundwater quality is protected and an NFA is warranted.
- > 10x the MADL – such high concentrations are not expected to typically be present in stormwater, based on the results of the UIC monitoring discharge monitoring program. Such concentrations indicate a pollutant source is likely present within the UIC catchment basin. Source identification, source-specific

Conservatism Inherent in Protectiveness Decisions:

The decisions made regarding MADL exceedances are based on Portland specific data (to the extent possible) and a series of assumptions. Several key assumptions are conservative and provide an additional, qualitative level of protection to the decisions made in this section. Key conservative assumptions include:

- Vertical separation distances are based on seasonal high groundwater levels. These levels occur < 1 or 2 months of the year. Separation distances may be up to 3 feet greater during the year.
- Vertical separation distances of < 5 feet are protective for many pollutants. The 5-foot separation distance was selected to ensure stormwater treatment by unsaturated soils.
- Pollutant concentrations > 10x the MADL may occur but are considered unlikely. Available stormwater data do not suggest this is likely for pollutants. DEHP is the only pollutant which has exceeded the MADL concentration by 10x. However, many DEHP concentrations are estimated due to laboratory QA/QC issues. Observed DEHP concentrations are likely associated with laboratory issues or stormwater solids.
- Pollutant concentrations > 100x the MADL are protective of groundwater quality for some pollutants where separation distances are > 5 feet.
- 5-foot separation distance is based on the results of the fate and transport analyses in Qfc. Many UICs are located in less permeable geologic formations that have a significantly higher capacity to attenuate pollutant concentrations.
- Approximately 95% of City-owned UICs have vertical separation distances of > 10 feet; 90% have separation distances of > 20 feet.

[8] For UICs with a total depth of ≤ 5 feet from ground surface to the bottom of the UIC, the permit required vertical separation distance is 5 feet from groundwater.

monitoring, or corrective action will be initiated, as appropriate, in accordance with the applicable *UICER Guidelines* or CAP.

Step 5: Decision Documentation and Verification

Step 5a: Documentation. GWPDs made using the above steps for individual UICs or group of UICs will be documented in the permit required annual UICMP report submitted to DEQ in November of each year. This report will include a table that summarizes the following information:

- BES UIC node number;
- Street address;
- UIC depth;
- Land use;
- Traffic category;
- Presence of sedimentation manhole;
- Vertical separation distance;
- Distance to nearest drinking water well;
- Geologic unit;
- Pollutant(s) of interest;
- Representative pollutant concentration(s) (See Table 4-2);
- Estimated pollutant reduction in unsaturated soil (See Table 8-1) for the 95th UCL on the mean concentration, and 10x MADL;
- BES GWPD results, including:
    - Corrective action needed - UICs determined to require corrective action will be identified and prioritized in accordance with the permit.
    - Groundwater protected - UICs determined to be protective of groundwater quality will be identified.
    - Further evaluation – UICs where further evaluation is needed will be identified along with anticipated tasks (e.g., *UICER Guidelines*) to be implemented.

Step 5b: Decision Verification. For those UICs determined to be protective of groundwater quality, the following key assumptions of the GWPD will be reviewed on an annual basis as part of the annual UICMP report to verify previous decisions are protective of groundwater or to identify if new information indicates additional analyses should be performed:

- Vertical Separation Distance. Currently separation distances are calculated using total UIC depth and April 2008 USGS generated depth to groundwater estimates for the Portland Area. In the event the depth to groundwater estimates are revised or modified, separation distances will be recalculated and the minimum 5-foot separation distance will be verified.

- Results of the stormwater discharge monitoring program. Data will be reviewed to ensure:
    - Pollutants detected are similar in concentration and frequency of detection to those identified in Year 1 and Year 2 monitoring.
    - New pollutants of interest are not identified.
    - Significant increases in pollutant concentrations or pollutant concentration trends are not identified.

10.3 Tool Application to Vertical Separation Distance

This section describes the protocol BES will implement to evaluate and/or demonstrate that a City-owned UIC with a vertical separation distance less than the permit requirement of 10 feet[9] is protective of groundwater quality in accordance with OAR 340-040.

10.3.1 Purpose

The purpose of this section is to assist BES and DEQ in making the following decisions:

1. For individual City-owned UICs or groups of UICs with vertical separation distances < 10 feet, determine if response actions or corrective actions are needed.
2. For City-owned UICs with vertical separation distances ≥ 5 feet[10] (e.g., current and future Category 3 UICs), demonstrate as appropriate that groundwater quality is protected and that “no further action” is an appropriate corrective action.

10.3.2 Basis of Vertical Separation Distance Evaluation

The discussion and decision making Framework presented in this section is based on the results of the fate and transport analyses (see Sections 8 and 9) performed to evaluate and document whether stormwater pollutant concentrations entering a UIC are reduced to levels that meet the groundwater protection requirements of OAR 340-040 at the point the infiltrated stormwater reaches groundwater. Using the fate and transport methodology and the soil and chemical input parameters that were summarized in Section 8, and approved by DEQ to evaluate Category 4 UICs (Appendix A), and vertical separation distance (Appendix C), it was determined:

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[9] The permit requires 10 feet of vertical separation distance for UICs with total depths > 5 feet. Schedule F, Section 5(tt) of the Permit states: “. . . Under no circumstance shall a separation distance between groundwater and the bottom of the public UIC be less than 5 feet, unless specifically authorized in writing by the Department, that protects groundwater to primary drinking water regulations under the federal SDWA, or complies with the groundwater protection requirements specified in Oregon Administrative Rules (OAR) 340-40. . . ”

[10] For City-owned UICs with vertical separation distances < 5 feet (e.g., current and future Category 3 UICs) appropriate response and/or corrective actions will be completed in accordance with the permit compliance schedule, the Corrective Action Plan (BES, 2006b) and the UICMP (BES, 2006a).

- Representative pollutants measured in stormwater discharges (see Table 8-1) to City-owned UICs would be attenuated during unsaturated zone transport with vertical separation distances of $\geq$ 5 feet in the three geologic units in which City-owned UICs are completed.
- Pollutant MADL exceedences (*i.e.*, Year 1 and Year 2 MADL exceedances) measured at the end of pipe (*i.e.*, compliance point) are protective of groundwater as a drinking water resource under either the average or reasonable maximum scenario conditions if a separation distance of $\geq$ 5 feet is present (Note: separation distances of < 5 feet may also be protective of groundwater for some pollutants; however, distances of < 5 feet were not specifically evaluated).
- Unsaturated soils have the capacity to treat the types of pollutants and the low concentrations of pollutants that enter the UICs via urban stormwater. Pollutants are treated in the unsaturated zone by filtration, sorption, and biodegradation processes. In addition, it is likely that the treatment capacity of the unsaturated zone around the UICs is enhanced by the organic carbon found in stormwater which continues to be added to the unsaturated zone.
- The results of the analyses presented in this document are consistent with DEQ's review of regional groundwater quality data that indicate stormwater discharges to UICs are protective of groundwater quality (DEQ, 2005b).
- The results of the fate and transport evaluation (see Section 8 and Appendix B) demonstrate that the overarching goal of the permit to protect the highest beneficial use of groundwater, while allowing underground injection of urban stormwater from City rights-of-way, is attained even in the event of reduced separation distances and/or low level exceedences of the permit MADLs.
- Application of the GWPD Tool indicates groundwater quality is protected as a drinking water resource when stormwater discharge concentrations are 10x the MADL and City-owned UICs have $\geq$ 5 feet of vertical separation distance. (Note: stormwater concentrations for all pollutants with the exception of DEHP have been significantly < 10x the MADL).

Prerequisites for GWPD Tool Application to UICs with less than Permit-required Separation Distance:

- Estimated vertical separation distance is based on latest versions of USGS estimates.
- UIC has $\geq$5 feet of vertical separation distance.
- Pollutant exceedance is < 10x the MADL.
- Assumptions used in GWPD Tool (see Section 8 and Appendix B) are representative and appropriate.
- UIC is located > 50 feet from a private water supply well (domestic, irrigation).

10.3.3 Tool Application Protocol

The steps described in this section are intended to demonstrate when groundwater is adequately protected from stormwater discharges to City-owned UICs or to determine when further evaluation and/or corrective action is required. Prior to applying the GWPD Tool, key elements of *UICER Guideline No. 1: Separation Distance* (BES, 2006a) should be applied and used to:

1. Meet the notification and reporting requirements of the permit.
2. Estimate separation distance.
3. Compile and review available UIC data.
4. Determine UIC compliance.

Results of the above evaluation can then be used to determine whether stormwater pollutant discharges to an individual UIC or group of UICs with vertical separation distances < 10 feet are protective of groundwater quality or if further response action or corrective action is warranted (see *UICER Guideline No. 6: Groundwater Protectiveness Demonstration* and *UICER Guideline No. 6a: Fate and Transport Analyses*).

The steps described below provide the decision making Framework to determine whether vertical separation distances of < 10 feet at an individual UIC or group of UICs are protective of groundwater quality as defined in OAR 340-040. These steps apply to UICs that have been identified as having vertical separation distances less than those required by the permit (*i.e.*, Category 3 UICs).

Step 1: Identify UIC(s) of Interest and Summarize UIC Characteristics

Compile and tabulate the following information for evaluation for individual UIC locations or group of UICs, that have been identified to have vertical separation distances < 10 feet:

- UIC completion depth;
- Vertical separation distance;
- Predominant land use in area of UIC; and
- Traffic category.

Step 2: Determine if Groundwater is Protected

Step 2a: Determine if UIC of interest (UIC with < 10 feet of vertical separation distance[11]) has been identified and reported as a Category 3 UIC in accordance with the permit. If not previously identified as a Category 3 UIC, refer back to *UICER Guideline No. 1: Separation Distance* (BES, 2006a) and the *UIC Compliance Determination Procedure* (BES, 2006a).

Step 2b: UICs with Vertical Separation Distances < 5 feet. If UIC of interest has < 5 feet of vertical separation distance, this Tool is not applicable, and appropriate further

[11] For UICs with a total depth of ≤ 5 feet from ground surface to the bottom of the UIC, the permit required vertical separation distance is 5 feet from groundwater.

evaluation, response, and/or corrective action should be determined in accordance with the UICMP (BES, 2006a).

Step 2c: UICs with Vertical Separation Distances > 5 feet. If the UIC of interest has ≥ 5 feet of vertical separation, confirm that the following assumptions used in the analyses of vertical separation distance apply:

i. UIC is managed (*i.e.*, operated and maintained) under the City of Portland's permit.

ii. UIC receives urban right-of-way runoff.

iii. UIC construction is similar to that described in the CSM (see Section 7).

iv. Stormwater pollutant types and concentrations entering the UIC are represented by the pollutants identified in Table 4-2.

Step 2d: Determine the appropriate action; for the subject UIC(s):

- If the assumptions listed in Step 2c are not true - further evaluation is needed (See *UICER Guidelines*) or this section is not applicable (see Section 10.1).
- If the assumptions listed in Step 2c are true – groundwater quality is protected if the vertical separation distance is ≥ 5 feet and; therefore, and an NFA is warranted.

Conservatism Inherent in Protectiveness Decisions:

The decisions made regarding the protectiveness of vertical separation distances of >5 feet are based on Portland specific data to the extent possible and a series of assumptions. Several key assumptions are conservative and provide an additional, qualitative level of protection to the decisions made in this section. Key conservative assumptions include:

- Vertical separation distances are based on seasonal high groundwater levels. These levels occur < 1 or 2 months of the year. Separation distances may be up to 3 feet greater during part of the year.
- Vertical separation distances of <5 feet are protective for many pollutants. The 5-foot separation distance was selected to ensure stormwater treatment by unsaturated soils.
- The protectiveness evaluation assumed pollutants are present in stormwater at significant concentrations (95th UCL on the mean, > MADL). Available UIC stormwater monitoring data indicate most concentrations are much lower.
- 5-foot separation distance is based on the results of the fate and transport analyses inQfc. Many UICs are located in less permeable geologic formations that have a significantly higher capacity to attenuate pollutant concentrations.
- Approximately 94% of City-owned UICs have vertical separation distances > 10 feet; 90% have separation distances > 25 feet (Section 3.2).

Step 3: Decision Documentation and Verification

Step 3a: Documentation. GWPDs made using the above steps for individual UICs or group of UICs will be documented in the permit required annual UICMP report submitted to DEQ in November of each year. This report will include a table that summarizes the following information:

- BES UIC node number;
- Street address;
- UIC depth;
- Land use;
- Traffic category;

- Presence of sedimentation manhole;
- Vertical separation distance;
- Distance to nearest drinking water well;
- Geologic unit;
- Pollutant(s) of interest;
- Representative pollutant concentrations (see Table 4-2);
- Estimated pollutant reduction in unsaturated soil (see Table 8-1);
- BES GWPD results, including:
    - Corrective action needed - UICs determined to require corrective action will be identified and prioritized in accordance with the permit.
    - Groundwater protected - UICs determined to be protective of groundwater quality will be identified.
    - Further evaluation – UICs where further evaluation is needed will be identified along with anticipated tasks (e.g., *UICER Guidelines*) to be implemented.

Step 3b: Decision Verification. For those UICs determined to be protective of groundwater quality, the following key assumptions of the GWPD will be reviewed on an annual basis as part of the annual UICMP report to verify previous decisions are protective of groundwater or to identify if new information indicate additional analyses should be performed:

- Vertical Separation Distance. Currently separation distances are calculated using total UIC depth and April 2008 USGS generated depth to groundwater estimates for the Portland Area. In the event the depth to groundwater estimates are revised or modified, separation distances will be recalculated and the minimum 5-foot separation distance will be verified.
- Results of the stormwater discharge monitoring program. Results will be reviewed to ensure:
    - Pollutants detected are similar in concentration and frequency of detection to those identified in Year 1 and Year 2 monitoring.
    - New pollutants of interest are not identified.
    - Significant increases in pollutant concentrations or pollutant concentration trends are not identified.

10.4 Tool Application to UICs within Permit Specified Well Setbacks

This section describes the protocol BES will implement to evaluate whether City-owned UICs located < 500 feet from a domestic well (e.g., drinking water, irrigation, household), within a two-year TOT of a public water well, or located < 500 feet from a public water well without a delineated TOT, are protective of groundwater quality in accordance with OAR 340-040.

10.4.1 Purpose

The purpose of this section is to assist BES and DEQ in making the following decisions:

1. For individual City-owned UICs located within permit specified setbacks from drinking water wells, determine the conditions under which stormwater discharges to the UIC are protective of groundwater quality and potential groundwater users.
2. For individual City-owned UICs located within permit specified setbacks from drinking water wells, determine the conditions under which response actions or corrective actions are needed.

10.4.2 Basis of Drinking Water Well Protectiveness Evaluation

The discussion and decision making Framework presented in this section is based on the results of the groundwater fate and transport analyses (see Sections 8 and 9) performed to evaluate and document whether stormwater pollutant concentrations entering a UIC are reduced to levels that meet the groundwater protection requirements of OAR 340-040 at the point the infiltrated stormwater reaches groundwater. Using the fate and transport methodology and the aquifer and chemical input parameters that were summarized in Section 8, and approved by DEQ to evaluate Category 4 UICs (Appendix A), and vertical separation distance (Appendix C), it was determined:

- Representative pollutants measured in stormwater discharges (see Table 8-1) to City-owned UICs would be attenuated during unsaturated zone transport with vertical separation distances of ≥ 5 feet in the three geologic units in which City-owned UICs are completed.
- Pollutant MADL exceedences (*i.e.*, Year 1 and Year 2 MADL exceedances) measured at the end of pipe (*i.e.*, compliance point) are protective of groundwater as a drinking water resource under the either average or reasonable maximum scenario conditions if a separation distance of ≥ 5 feet is present (Note: separation distances of < 5 feet may also be protective of groundwater for some pollutants; however, distances of < 5 feet were not specifically evaluated).
- The results of the analyses presented in this document are consistent with DEQ's review of regional groundwater quality data that indicate stormwater discharges to UICs are protective of groundwater quality (DEQ, 2005b).

- The results of the fate and transport evaluation demonstrate that the overarching goal of the permit to protect the highest beneficial use of groundwater, while allowing underground injection of urban stormwater from city rights-of-way, is attained even in the event of reduced separation distances and/or low-level exceedences of the permit MADLs.
- Application of the GWPD Tool indicates groundwater quality is protected as a drinking water resource when stormwater discharge concentrations are 10x the MADL (Note: stormwater concentrations for all pollutants with the exception of DEHP have been significantly < 10x the MADL).

10.4.3 Tool Application Protocol

The steps described in this section are intended to demonstrate when discharge of stormwater into City-owned UICs located within permit specified setbacks from drinking water wells is protective of groundwater quality or when further evaluation and/or corrective action is required. Prior to applying the GWPD Tool, key elements of *UICER Guideline No. 3: Proximity to Drinking Water Wells* should be applied and used to:

1. Meet the notification and reporting requirements of the permit.
2. Estimate horizontal distance between City-owned UIC and the nearest drinking water well.
3. Compile and review available UIC data.
4. Evaluate quality of stormwater discharges to UICs located near drinking water wells (see *Annual SDM Report*).
5. Determine UIC compliance.

Prerequisites for GWPD Tool Application to UICs within Permit-specified Well Setbacks:

- Analytical data are of known and verifiable quality.
- UIC has $\geq$5 feet of vertical separation distance.
- Pollutant exceedance is < 10x the MADL.
- Assumptions used in fate and transport analyses are representative and appropriate.
- UIC is located > 50 feet from a private water supply well (domestic, irrigation).

Results of the above evaluation can then be used to determine whether stormwater pollutant discharges to an individual UIC are protective of groundwater quality in accordance with OAR 340-040 or if further action is warranted (see *UICER Guideline No. 6: Groundwater Protectiveness Demonstration* and *UICER Guideline No. 6a: Fate and Transport Analyses*).

The steps described below provide the decision making Framework to determine whether discharge limits of pollutants to an individual UIC or group of UICs are protective of groundwater quality as defined in OAR 340-040.

Step 1: Identify UIC(s) of Interest and Summarize UIC Characteristics

Compile and tabulate the following information for evaluation for individual UIC locations that have been identified within permit specified setbacks from domestic or public water wells:

- UIC location;
- UIC completion depth;
- Vertical separation distance;
- Distance to nearest drinking water well (see Footnote 7);
- Predominant land use in area of UIC;
- Traffic category;
- Presence of pretreatment (e.g., sedimentation manhole, surface infiltration facility); and
- Sample identification number (if applicable).[12]

Step 2: Identify Well(s) of Interest and Summarize Characteristics

Compile and tabulate the following information to evaluate individual domestic (drinking water or irrigation), or public water well locations that have been identified within permit specified setbacks from a UIC:

- Well location;
- Well total completion depth;
- Well screened internal;
- Well use (if known);
- Potential pollutant sources on well property (if known).

Step 3: Estimate Representative Stormwater Discharge Concentrations

Step 3a: Compile UIC Compliance Stormwater Monitoring Data. Table 4-2 presents the estimated mean, 95th UCL on the mean, and the 95th percentile concentrations of the representative stormwater pollutants discussed in Section 4.2 and evaluated using the GWPD Tool (see Sections 8 and 9). Additional stormwater discharge data should be compiled, as necessary and appropriate.

Step 3b: Analyze UIC Supplemental Stormwater Monitoring Data. Supplemental UIC monitoring was conducted in permit Year 2 (2006-2007) and Year 3 (2007-2008). Ten UICs located within 500 feet of a domestic well or with a 2-year TOT were sampled in each year. Ten additional UICs will be sampled in Year 4 (2008-2009).

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[12] Check UIC location to determine if it has been sampled as part of the UIC compliance monitoring program or supplemental sampling program. If so, identify sample identification number (e.g., location code), approximate address, and year(s) sampled.

This data will be analyzed following completion of Year 3 and Year 4 monitoring to determine the following:

- Pollutant frequency of detection. The frequency of detection values for the supplemental UICs will be compared to the frequency of detections estimated for the compliance monitoring data. This comparison will be used to determine if the suite of pollutants (see Section 4) used in the fate and transport analyses is representative of the supplemental UICs.
- Estimated mean concentration for representative pollutants;
- Estimated 95th UCL on the mean concentration for representative pollutants;
- Estimated 95th percentile concentrations of representative stormwater pollutants; and
- If the compliance monitoring data is adequately representative of the UICs located near drinking water wells or with a 2-year TOT.

<u>Step 3c</u>: <u>Identify Representative Stormwater Concentrations</u>. Using the results of Steps 3a and 3b, identify representative stormwater concentrations to be used in Step 4 to evaluate potential impacts to groundwater. Only those pollutants with an estimated mean, 95th UCL on the mean, or 95th percentile concentrations greater than or equal to the MADL will be carried forward into Step 4. Estimate the following concentrations to describe the range of pollutant concentrations that may enter an individual UIC or group of UICs as follows:

- Use measured UIC stormwater discharge concentration data (e.g., compliance sampling, supplemental sampling), if available, to evaluate whether groundwater is protected.
- Use the estimated mean pollutant concentration to evaluate if groundwater is protected.
- Use the 95th UCL on the mean concentration to evaluate whether the upper bound or "reasonable maximum" scenario is protective of groundwater.

Step 4: Determine if Groundwater is Protected

<u>Step 4a</u>: <u>UICs with Vertical Separation < 5 Feet.</u> If the UIC of interest has < 5 feet of vertical separation distance, this Tool is <u>not</u> applicable, and appropriate further evaluation, response, and/or corrective action should be determined in accordance with the CAP (BES, 2006b) and UICMP (BES, 2006a). However, the likelihood of stormwater pollutants impacting nearby groundwater wells (domestic or public) at concentrations greater than or equal to MADLs should be evaluated (see Section 9) to determine if groundwater users are protected and to prioritize corrective actions. Potential impacts should be evaluated by:

- Estimating the concentration of the pollutant at the point it enters groundwater using simple dilution. If the estimated pollutant concentration is less than its corresponding value in Table 9-1, it can be determined, that groundwater users are protected pending completion of a corrective action.

- Evaluating the fate and transport of the pollutant in groundwater as described in Section 9.
    1. If the pollutant concentration is expected to attenuate to the pollutants MADL or an appropriate risk-based SLV (DEQ RBC or EPA Region 6) concentration within 15 feet of the UIC (*i.e.*, within approximately ½ the width of a typical City right-of-way) it can be determined that groundwater users are protected pending completion of a corrective action.
    2. If the pollutant concentration attenuates to the MADL or SLV concentration within 50 feet of the UIC, the subject domestic or public water well will be considered protected prior to completion of the corrective action.[13]

Step 4b: UICs with Vertical Separation < 5 Feet. If the UIC of interest has ≥ 5 feet of vertical separation, confirm that the following assumptions, used in the analyses of vertical separation distance, apply:

- The UIC is managed (*i.e.*, operated and maintained) under the City of Portland's permit.
- The UIC receives urban right-of-way runoff.
- UIC construction is similar to that described in the CSM (see

Conservatism Inherent in Protectiveness Decisions for UICs Near Drinking Water Wells:

Decisions made regarding the protection of groundwater quality are based on Portland specific data to the extent possible and a series of assumptions. Several key assumptions are conservative and provide an additional, qualitative level of protection to the decisions made in this section. Key conservative assumptions include:

- Vertical separation distances are based on seasonal high groundwater levels. These levels occur <1 or 2 months of the year. Separation distances may be up to 3 feet greater during the year.
- Vertical separation distances <5 feet are protective for many pollutants. The 5-foot separation distance was selected to ensure stormwater treatment by unsaturated soils.
- The protectiveness evaluation assumed pollutants are present in stormwater at significant concentrations (95th UCL on the mean, > MADL). Available UIC stormwater monitoring data indicate most concentrations are much lower.
- 5-foot separation distance is based on the results of the fate and transport analyses in Qfc. Many UICs are located in less permeable geologic formations that have a significantly higher capacity to attenuate pollutant concentrations.
- Approximately 94% of City-owned UICs have vertical separation distances > 10 feet; 90% have separation distances > 25 feet (Section 3.2).
- Major conservative assumption is that stormwater flows directly from the UIC to the drinking water well (i.e., shortest horizontal distance). This assumption is overly conservative in that it does not consider groundwater flow directions, vertical groundwater gradients, well intake depth, etc.
- It is conservatively assumed that shallow groundwater within the City of Portland is reasonably likely to be used as a sole source drinking water resource and identified wells are actively used for primary drinking water purposes. Some wells are reported to be used only for irrigation purposes.

[13] DEQ's 2007 Internal Management Directive (IMD) states that DEQ "*…can find that there will be no lasting effects on groundwater …quality, and that groundwater could potentially be used as a water supply if the disposal system were to be decommissioned*" and that the groundwater inside this area could be considered part of the treatment system and exceed background groundwater quality while still satisfying the requirements of OAR 340-040. For example, technical reasons why a system may not have a lasting effect on groundwater quality could be that the system will be sited in an area with higher-than-average aquifer permeabilities and so would "flush" quickly following system decommissioning; the typical treatment system as outlined in the IMD.

Section 7).

- The pollutants identified in Table 4-2 represent stormwater pollutant types and concentrations anticipated to be entering the UIC.

Step 4c: Determine the appropriate action for the subject UIC(s):

- If the assumptions listed in Step 4b, are not true - further evaluation or corrective action is needed (See *UICER Guidelines*) or this section is not applicable (see Section 10.1).
- If the assumptions listed in Step 4b, are true – groundwater quality is protected if the vertical separation distance is $\geq$ 5 feet and; therefore, an NFA is warranted.

Step 5: Decision Documentation and Verification

Step 5a: Documentation. GWPDs made using the above steps for individual UICs or groups of UICs will be documented in the permit required annual UICMP report submitted to DEQ in November of each year. This report will include a table that summarizes the following information:

- BES UIC node number;
- Street address;
- UIC depth;
- Land use;
- Traffic category;
- Presence of sedimentation manhole;
- Vertical separation distance;
- Distance to nearest drinking water well;
- Geologic unit;
- Pollutant(s) of interest;
- Representative pollutant concentration(s) (See Table 4-2); and
- BES GWPD results, including:
  - Corrective action needed - UICs determined to require corrective action will be identified and prioritized in accordance with the permit.
  - Groundwater protected - UICs determined to be protective of groundwater quality will be identified.
  - Further evaluation – UICs where further evaluation is needed will be identified along with anticipated tasks (e.g., *UICER Guidelines*) to be implemented.

Step 5b: Decision Verification. For those UICs determined to be protective of groundwater quality, the following key assumptions of the GWPD will be reviewed on an annual basis as part of the annual UICMP report to verify that previous decisions are protective of groundwater or to identify if new information indicate additional analyses should be performed:

- Vertical Separation Distance. Currently separation distances are calculated using total UIC depth and April 2008 USGS generated depth to groundwater estimates for the Portland Area. In the event the depth to groundwater estimates are revised or modified, separation distances will be recalculated and the minimum 5-foot separation distance will be verified.
- Results of the stormwater discharge monitoring program. Results will be reviewed to ensure:
  - Pollutants detected are similar in concentration and frequency of detection to those identified in Year 1 and Year 2 monitoring.
  - New pollutants of interest are not identified.
  - Significant increases in pollutant concentrations or pollutant concentration trends are not identified.

10.5 Tool Application to Ubiquitous Pollutants

This section describes the protocol BES will implement to evaluate whether ubiquitous pollutants detected in stormwater discharges to City-owned UICs are protective of groundwater quality in accordance with OAR 340-040.

10.5.1 Purpose

The purpose of this section is to assist BES and DEQ in making the following decisions:

1. Determine the conditions under which stormwater discharges of ubiquitous pollutants to City-owned UICs are protective of groundwater quality.
2. Determine the conditions under which further evaluation, response actions, or corrective actions are needed due to stormwater discharges of ubiquitous pollutants to City-owned UICs.

Ubiquitous Pollutant

Ubiquitous pollutants are specifically defined for the purposes of this document as those pollutants detected by the Year 1 and Year 2 Stormwater Discharge Monitoring Program at a frequency $\geq$75% and with a concentration $\geq$50% of the MADL. The following contaminants are considered ubiquitous:

1. PCP
2. DEHP
3. Lead

10.5.2 Basis of Ubiquitous Pollutant Protectiveness Evaluation

The discussion and decision making Framework presented in this section is based on the results of the fate and transport analyses (see Sections 8 and 9) performed to evaluate and document whether stormwater pollutant concentrations entering a UIC are reduced to levels that meet the groundwater protection requirements of OAR 340-040 at the point the infiltrated stormwater reaches groundwater. Using the fate and transport methodology and the soil and chemical input parameters that were summarized in Section

8, and approved by DEQ to evaluate Category 4 UICs (Appendix A), and vertical separation distance (Appendix C), it was determined:

- Representative pollutants measured in stormwater discharges (see Table 8-1) to City-owned UICs would be attenuated during unsaturated zone transport with vertical separation distances of $\geq$ 5 feet in the three geologic units in which City-owned UICs are completed.
- Pollutant MADL exceedences (*i.e.*, Year 1 and Year 2 MADL exceedances) measured at the end of pipe (*i.e.*, compliance point) are protective of groundwater as a drinking water resource under either average or reasonable maximum scenario conditions if a separation distance of $\geq$ 5 feet is present (Note: separation distances of < 5 feet may also be protective of groundwater for some pollutants; however, distances of < 5 were not specifically evaluated).
- The results of the analyses presented in this document are consistent with DEQ's review of regional groundwater quality data that indicate stormwater discharges to UICs are protective of groundwater quality (DEQ, 2005b).
- The results of the fate and transport evaluation demonstrate that the overarching goal of the permit to protect the highest beneficial use of groundwater, while allowing underground injection of urban stormwater from city rights-of-way, is attained even in the event of reduced separation distances and/or low level exceedences of the permit MADLs.
- Application of the GWPD Tool indicates groundwater quality is protected as a drinking water resource when stormwater discharge concentrations are 10x the MADL (Note: stormwater concentrations for all pollutants with the exception of DEHP have been significantly < 10x the MADL).

10.5.3 Tool Application Protocol

The steps described in this section are intended to demonstrate when groundwater quality is adequately protected from discharges of stormwater containing ubiquitous pollutants or to determine when further evaluation and/or corrective action is required. Prior to applying the GWPD Tool, key elements of *UICER Guideline No. 7: Regional Assessment of Problem* should be considered and used to:

1. Identify the potential regional issue.
2. Refine the CSM.
3. Evaluate stormwater quality discharge to City-owned UICs.

Prerequisites for GWPD Tool Application to UICs that Receive Ubiquitous Pollutants:

- Analytical data are of known and verifiable quality.
- UICs have $\geq$5 feet of vertical separation distance.
- Pollutant exceedance < 10x the MADL.
- Assumptions used in fate and transport analyses are representative and appropriate.
- UIC are located > 50 feet from a private water supply well (domestic, irrigation).

The steps described below provide the decision making framework to determine whether discharge of ubiquitous pollutants to City-owned UICs are protective of groundwater quality as defined in OAR 340-040.

Conservatism Inherent in Protectiveness Decisions for UICs Near Drinking Water Wells:

Decisions made regarding the protection of groundwater quality are based on Portland specific data to the extent possible and a series of assumptions. Several key assumptions are conservative and provide an additional, qualitative level of protection to the decisions made in this section. Key conservative assumptions include:

- Vertical separation distances are based on seasonal high groundwater levels. These levels occur < 1 or 2 months of the year. Separation distances may be up to 3 feet greater during the year.
- Vertical separation distances <5 feet are protective for many pollutants. The 5-foot separation distance was selected to ensure stormwater treatment by unsaturated soils.
- The protectiveness evaluation assumed pollutants are present in stormwater at significant concentrations (95^{th} UCL on the mean, > MADL). Available UIC stormwater monitoring data indicate most concentrations are much lower.
- 5-foot separation distance is based on the results of the fate and transport analyses in Qfc. Many UICs are located in less permeable geologic formations that have a significantly higher capacity to attenuate pollutant concentrations.
- Approximately 94% of City-owned UICs have vertical separation distances > 10 feet; 90% have separation distances > 25 feet.
- A significant assumption is that stormwater flows directly from the UIC to the drinking water well (i.e., shortest horizontal distance). This assumption is overly conservative in that it does not consider groundwater flow directions (vertical groundwater gradients, well intake depth, etc.).
- It is conservatively assumed that shallow groundwater within the City of Portland is reasonably likely to be used as a sole source drinking water resource and that identified wells are actively used for primary drinking water purposes. Some wells are reported to be used only for irrigation purposes.

Step 1: Extrapolate Stormwater Discharge Monitoring Results to City-owned UICs

Step 1a: Compile UIC Compliance Stormwater Monitoring Data. Table 4-2 presents the estimated mean, 95^{th} UCL on the mean, and the 95^{th} percentile concentrations of the representative stormwater pollutants discussed in Section 4.2 and evaluated using the GWPD Tool (see Sections 8 and 9). Additional stormwater discharge data should be compiled, as necessary and appropriate.

Step 1b: Identify Representative Stormwater Concentrations. Using the results of Step 1a, identify representative stormwater concentrations to be used in Step 2 to evaluate potential impacts to groundwater. Only those pollutants with an estimated mean, 95^{th} UCL on the mean, or 95^{th} percentile concentrations greater than or equal to the MADL will be carried forward into Step 2. Estimate the representative concentration of the pollutant entering an individual UIC or group of UICs as follows:

- Use the estimated mean pollutant concentration to evaluate whether groundwater is protected.
- Use the 95th UCL on the mean concentration to evaluate whether the upper bound or “reasonable maximum” scenario is protective of groundwater.

Step 2: Determine if Groundwater is Protected

Step 2a: If the UICs of interest have < 5 feet of vertical separation distance, this Tool is not applicable, and appropriate further evaluation, response, and/or corrective action should be determined in accordance with the CAP (BES, 2006b) and UICMP (BES, 2006a). However, the likelihood of stormwater pollutants impacting nearby groundwater wells (domestic or public) at concentrations greater than or equal to MADLs should be evaluated (see Section 9). Potential impacts should be evaluated by:

- Estimating the concentration of the pollutant at the point it enters groundwater using simple dilution. If the estimated pollutant concentration is less than its corresponding value in Table 9-1, it can be determined, that groundwater users are protected pending completion of a corrective action.
- Evaluating the fate and transport of the pollutant in groundwater as described in Section 9:
    1. If the pollutant concentration is expected to attenuate to the pollutants MADL or an appropriate SLV (*e.g.*, DEQ RBC, EPA Region 6 SLV, MRL) concentration within 15 feet of the UIC (*i.e.*, within approximately ½ the width of a typical city right-of-way) it can be determined that groundwater uses are protected pending completion of a corrective action.
    2. If the pollutant concentration attenuates to the MADL concentration within 50 feet of the UIC (see Footnote 7), the type of use (*e.g.*, irrigation, domestic) and frequency of use (e.g., daily, seasonal) of the subject domestic or public water well will be considered in order to determine if potential well users are protected prior to completion of the corrective action and for prioritizing corrective actions.[14]

Step 2b: If the UIC of interest has ≥ 5 feet of vertical separation, confirm that the following assumptions, used in the analyses of vertical separation distance apply:

- The UIC is managed (*i.e.*, operated and maintained) under the City of Portland's permit.
- The UIC receives urban right-of-way runoff.
- UIC construction is similar to that described in the CSM (see Section 7).
- Stormwater pollutants and extrapolated pollutant concentrations entering the UIC are < the values (see Table 8-1) determined to be protective of groundwater quality based on the fate and transport analyses presented in Section 8.

Step 2c: Determine the appropriate action for the subject UIC(s):

[14] DEQ's 2007 IMD states that DEQ "*…can find that there will be no lasting effects on groundwater …quality, and that groundwater could potentially be used as a water supply if the disposal system were to be decommissioned*" and that the groundwater inside this area could be considered part of the treatment system and exceed background groundwater quality while still satisfying the requirements of OAR 340-040. For example, technical reasons why a system may not have a lasting effect on groundwater quality could be that the system will be sited in an area with higher-than-average aquifer permeabilities and so would "flush" quickly following system decommissioning; the typical treatment system as outlined in the directive.

- If the assumptions listed in Step 2b, are not true - further evaluation or corrective action is needed (See *UICER Guidelines*) or this section is not applicable (see Section 10.1).
- If the assumptions listed in Step 4b, are true – groundwater quality is protected if the vertical separation distance is $\geq$ 5 feet and therefore an NFA is warranted.

Step 3: Decision Documentation and Verification

Step 3a: Documentation. GWPDs made using the above steps for regional City-owned UICs will be documented in the permit required annual UICMP report submitted to DEQ in November of each year. This report will include a discussion of the following:

- Pollutant(s) of interest;
- Representative pollutant concentration(s) (See Table 4-2); and
- BES GWPD results, including:
    - Corrective action needed - UICs determined to require corrective action will be identified and prioritized in accordance with the permit.
    - Groundwater protected - UICs determined to be protective of groundwater quality will be identified.
    - Further evaluation – UICs where further evaluation is needed will be identified along with anticipated tasks (*e.g.*, *UICER Guidelines*) to be implemented.

Step 3b: Decision Verification. For those UICs determined to be protective of groundwater quality, the following key assumptions of the GWPD will be reviewed on an annual basis as part of the annual UICMP report to verify that previous decisions are protective of groundwater or to identify if new information indicates additional analyses should be performed:

- Vertical Separation Distance. Currently separation distances are calculated using total UIC depth and April 2008 USGS generated depth to groundwater estimates for the Portland Area. In the event the depth to groundwater estimates are revised or modified, separation distances will be recalculated and the minimum 5-foot separation distance will be verified.
- Results of the stormwater discharge monitoring program. Results will be reviewed to ensure:
    - Pollutants detected are similar in concentration and frequency of detection to those identified in Table 1.
    - New pollutants of interest are not identified or are shown to be protective using the methodologies described in Section 8 and the supporting appendices.
    - Significant increases in pollutant concentrations or pollutant concentration trends are not identified.

10.6 DEQ Review and Approval

Application of the GWPD Tool to individual or groups of UICs will result in one of the following determinations:

- Corrective action is warranted in accordance with the CAP (BES, 2006b).
- Further evaluation or response actions are needed to determine if groundwater is protected in accordance with the UICMP (BES, 2006a).
- Groundwater is protected and the UIC meets the conditions for a NFA determination.

GWPD decisions will be documented in the annual UICMP report submitted to DEQ by November 1 of each permit year.

Upon DEQ's approval of this document, the CAP, and the UICMP, GWPDs and NFAs determination will be considered appropriate corrective actions for selected non-compliant City-owned UICs. Future GWPD and NFA determinations, performed by the City in accordance with the protocols defined the CAP and Section 10 of this report will be considered appropriate corrective actions as allowed by the permit [Schedule C(11)(a)], approved by DEQ, and not require individual written approval from DEQ. Decisions will be documented in the annual UICMP report as discussed in Section 10.6.2. In the event the GWPD Tool is applied to new issues or regional concerns, BES will prepare a document for DEQ review and approval requesting a NFA determination on a case-by-case basis. DEQ's review may result in one of the following actions:

- Approve the document and issue a NFA letter.
- Request that additional information be submitted or work be performed in support of the proposed NFA.
- Determine that the site does not meet the conditions for an NFA and require that addition corrective actions be taken.

10.6.1 Issue Specific Technical Memoranda

Technical memoranda will be prepared to document the application of this document to three specific UIC issues identified during permit negotiation and subsequently captured in the permit, the UICMP (BES, 2006a), and the *Annual UICMP Reports* (BES, 2006f; BES, 2007b). These technical memoranda include:

1. **Category 3 UICs**. The GWPD Tool described in this document and the results of *Evaluation of Vertical Separation Distance Technical Memorandum* (Appendix B) will be applied to the Category 3 UICs, identified in the 2006-2007 *Annual UICMP Report* (BES, 2007b). UICs with vertical separation distances $\geq$ 5 feet and < 10 feet will be evaluated individually. These analyses will be used to demonstrate that groundwater quality is protected and an NFA (*i.e.*, risk assessment) is an appropriate corrective action.

2. **UICs Near Drinking Water Wells.** The GWPD Tool described in this document and the results of *Evaluation of Vertical Separation Distance Technical Memorandum* (Appendix B) will be applied to UICs within permit-defined setbacks from drinking water wells. These analyses will be used to estimate "anticipated" stormwater discharge concentrations. Mean and 95th UCL on the mean stormwater discharge concentrations will be estimated from the UIC compliance (Years 1, 2, and 3) and supplemental monitoring (Years 2 and 3) for representative pollutants. The results of the compliance and supplemental monitoring will be used to extrapolate from the available data the number of UICs that may exceed the MADL in at least one sampling event and the number of UICs where the mean annual pollutant concentration may exceed its respective MADL for two consecutive years (*i.e.*, potentially non-compliant Category 4 UICs). The estimated pollutant concentrations will also be evaluated to demonstrate that groundwater quality is protected City-wide in accordance with OAR 340-040 and an NFA (*i.e.*, risk assessment) would be an appropriate corrective action for these potentially non-compliant UICs. This technical memorandum will be submitted to DEQ following the *Year 3 Annual Stormwater Discharge Monitoring Report*. The results of these analyses will be confirmed following completion of the third year (*i.e.*, Year 4 2007-2008) supplemental monitoring program.

3. **Ubiquitous Pollutant Concentrations.** The GWPD Tool described in this document and the results of *Evaluation of Vertical Separation Distance Technical Memorandum* (Appendix B) will be applied to ubiquitous PCP and DEHP concentrations detected in Years 1, 2, and 3 UIC compliance monitoring. Analytical data for these compounds will be extrapolated from the compliance monitoring locations citywide. The extrapolated data will be used to estimate the number of UICs that may exceed the MADL in one sampling event and the number of UICs where the mean annual pollutant concentration may exceed its respective MADL for two consecutive years (*i.e.*, potentially non-compliant UICs). The extrapolated pollutant concentrations will also be evaluated to demonstrate that groundwater quality is protected City-wide in accordance with OAR 340-040 and an NFA (*i.e.*, risk assessment) would be an appropriate corrective action for these potentially non-compliant UICs. This technical memorandum will be submitted to DEQ following the *Year 3 Annual Stormwater Discharge Monitoring Report* to allow incorporation of Year 3 data.

These technical memoranda will be provided to DEQ for review and approval. If appropriate, BES will request that DEQ provide written approval that the GWPDs are appropriate corrective actions and groundwater quality is protected in accordance with OAR 340-040.

10.6.2 Future Tool Application

The GWPD Tool and Framework are intended to provide the City and DEQ with a process for making decisions regarding the need for further evaluation or corrective action. The procedures and guidelines presented in the UICMP will be implemented prior to performing GWPDs for the issues identified in this section or similar issues that are discovered based on ongoing permit implementation activities including:

- Stormwater discharge compliance monitoring;
- Evaluation and response program elements; and
- Systemwide assessment activities.

Future Tool applications will follow the protocols in this section and use the Look-Up Tables presented in Sections 8 and 9, as appropriate. The results of the GWPD Tool application will be documented in the annual UICMP report submitted to DEQ by November 1 of each year, as discussed in Sections 9.2 through 9.5.

The GWPDs support the findings presented in DEQ's Permit Evaluation Report and in a DEQ Internal Management Directive that, under appropriate circumstances:

- Stormwater discharges as described in this GWPD meet the intent of Oregon's groundwater quality protection rules.
- Disposal of right-of-way stormwater runoff into UICs (*i.e.*, indirect discharge to groundwater) is often a more desirable method of disposal than direct discharge to surface water because natural physical, chemical, and biological processes may enhance stormwater quality (*i.e.*, reduce pollutant concentrations) prior to discharge to surface water.
- Disposal of municipal stormwater by discharge to subsurface soil (*i.e.*, indirect discharge to groundwater) may be environmentally beneficial if planned, installed, and operated correctly, and if located under the right geographic, hydrogeologic, and environmental conditions. The type of indirect discharge system should be matched to the specific conditions of the site. The following are potential benefits of using indirect discharge:
    - Stormwater is a resource to recharge underlying aquifers by mimicking the natural hydrologic cycle.
    - Stormwater temperatures may reduce and assist in meeting in-stream temperature standards.
    - UICs may help maintain beneficial stream flow volumes (*e.g.*, cool summer baseflow), and reduce stormwater inputs during peak flow conditions (flood conditions).
    - Subsurface soils provide mechanical filtration of stormwater solids.
    - Natural geochemical, physical, and biologic processes within the soil and aquifer reduce stormwater pollutant concentrations.

Section 11

11 WORKS CITED

BES (2002). Underground Injection Control Report. Prepared by: City of Portland Bureau of Environmental Services, March 15, 2002. 57 pp.

BES (2004). Stormwater Management Manual. Prepared by: City of Portland Bureau of Environmental Services.

BES (2005a). Portland Watershed Management Plan. Prepared by: City of Portland Bureau of Environmental Services.

BES (2005b). Fact Sheet on Pentachlorophenol. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2005c). Fact Sheet on Phthalates. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2006a). Underground Injection Control Management Plan. Prepared by: City of Portland Bureau of Environmental Services, December.

BES (2006b). Corrective Action Plan. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2006c). Stormwater Discharge Monitoring Plan. Prepared by: City of Portland Bureau of Environmental Services, August.

BES (2006d). UIC Decommissioning Procedure. Prepared by: City of Portland Bureau of Environmental Services, December.

BES (2006e). Annual Stormwater Discharge Monitoring Report: Year 1 – October 2005 to May 2006. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2006f). UICMP Annual Report No. 1. Prepared by: City of Portland Bureau of Environmental Services, December.

BES (2006g). Systemwide Assessment. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2006h). Systemwide Assessment Follow-Up Actions. Prepared by: City of Portland Bureau of Environmental Services, December.

BES (2007a). Annual Stormwater Discharge Monitoring Report: Year 2 – October 2006 to May 2007. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2007b). UICMP Annual Report No. 2. Prepared by: City of Portland Bureau of Environmental Services, December.

DEQ (1998). Guidance for Ecological Risk Assessment, Level 1 – Scoping, November. Available online at: http://www.deq.state.or.us/lq/pubs/docs/cu/GuidanceEcologicalRisk.pdf

DEQ (2000). Guidance for Conduct of Deterministic Human Health Risk Assessments - revised May 2000. Available online at: http://www.deq.state.or.us/lq/pubs/docs/cu/GuidanceConductHumanHealth.pdf

DEQ (2001). DEQ Report to the Legislature – Implementation of Oregon's Groundwater Protection Act, January. Available online at: http://www.deq.state.or.us/wq/pubs/reports/2001gwreport.pdf

DEQ (2003). Risk-Based Concentrations for Individual Chemicals Spreadsheet. (Revised in July 2007.)

DEQ (2005a). Water Pollution Control Facilities Permit for Class V Stormwater Underground Injection Control Systems, Permit No. 102830. June 1, 2005.

DEQ (2005b). Fact Sheet and Class V Underground Injection Control (UIC) Permit Evaluation, Permit Number 102830.

DEQ (2007a). Disposal of Municipal Wastewater Treatment Plant Effluent by Indirect Discharge to Surface Water via Groundwater or Hyporheic Water. Internal Management Directive. Water Quality Division. September 2007. Available online at: http://www.deq.state.or.us/wq/pubs/imds/indirectdischarge.pdf

DEQ (2007b). Risk-Based Concentrations for Individual Chemicals Spreadsheet – revised July 4, 2007. Available online at: http://www.deq.state.or.us/lq/pubs/docs/RBDM03F.xls

EPA (1989). Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual (Part A, Baseline Risk Assessment). Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002. December. Available online at: http://www.epa.gov/oswer/riskassessment/ragsa/pdf/rags-vol1-pta_complete.pdf

EPA (1991). Risk Assessment Guidance for Superfund: Volume 1 – Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals). Interim. Office of Emergency and Remedial Response. EPA/540/R-

92/003. December. Available online at: http://rais.ornl.gov/homepage/HHEMB.pdf

EPA (1996). Soil Screening Guidance: Technical Background Document. Office of Solid Waste and Emergency Response, Washington, DC. May. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/index.htm

EPA (2001). Fact Sheet: Correcting the Henry's Law Constant for Soil Temperature.

EPA (2002). Protecting Drinking Water through Underground Injection Control - Drinking Water Pocket Guide # 2. Office of Ground Water and Drinking Water. EPA 816-K-02-001. January 2002. Available online at: http://www.epa.gov/OGWDW/uic/pdfs/pocketguide_uic_protectng_dw_thru_uic.pdf

EPA (2004). U.S. EPA's Superfund Chemical Data Matrix Methodology Report, Appendix A. Available online at: http://www.epa.gov/superfund/sites/npl/hrsres/tools/app_a_1.pdf

EPA (2008a). Region 6 Human Health Medium Specific Screening Levels 2008 - revised March 8, 2008. Available online at: http://www.epa.gov/Region6/6pd/rcra_c/pd-n/screenvalues.xls.

EPA (2008b). National Primary Drinking Water Standards. Available online at: http://www.epa.gov/safewater/contaminants/index.html.

Golder (1993). Drainage Sump Study. Prepared for: City of Portland Bureau of Environmental Services, June.

GSI (2008a). Category 4 UIC Corrective Actions- Groundwater Protectiveness Demonstrations (GWPD). Prepared for: City of Portland Bureau of Environmental Services UIC Program, April.

GSI (2008b). Category 4 UIC Corrective Actions- Updated Groundwater Protectiveness Demonstrations (GWPD). Prepared for: City of Portland Bureau of Environmental Services UIC Program, April.

GSI (2008c). Evaluation of Vertical Separation Distance, Groundwater Protectiveness Demonstration. Prepared for: City of Portland Bureau of Environmental Services UIC Program, May.

Hartford, S.V., and McFarland, W.D. (1989). Lithology, Thickness, and Extent of the Hydrogeologic Units Underlying the East Portland Basin Area, Oregon, U.S. Geological Survey Water-Resources Investigation Report 88-4110, 23p.

Hoffsetter, W.H. (1984). Geology of the Portland well field. *Oregon Geology,* 46: 6, 63-67.

Kincaid, T., and Olsen, T. (with contributions from Stevens, D., Platt, C., White, D., and Remington, R.) (2007). Spsurvey: Spatial Survey Design and Analysis. R package version 1.6.2. Available online at: http://www.epa.gov/nheerl/arm/.

Mackay, D., Sharpe, S., Cahill, T., Gouin, T., Cousins, I., and Toose, L. (2001). Assessing the Environmental Persistence of a Variety of Chemical Substances Including Metals. CEMC Report No. 200104. Trent University, Peterborough, Ontario.

Madin, I. (1990). Earthquake Hazard Geology Maps of the Portland Metropolitan Area, Oregon. Open File Report: 0-90-2.

McFarland, W.D., and Morgan, D. S. (1996). Description of the ground-water flow system in the Portland Basin, Oregon and Washington, U. S. Geological Survey Water-Supply Paper 2470-A, 58 p.

R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Snyder, D.T., in press. Estimated Depth to Groundwater and Configuration of the Water Table in the Portland, Oregon Area: U.S. Geological Survey Scientific Investigations Report 2008-5059.

SSP&A (2008). Peer Review of UIC Category 4 Groundwater Protectiveness Demonstration. Prepared for: City of Portland Bureau of Environmental Services, April.

Stevens, D. L., Jr. and Olsen, A. R. (2004). Spatially balanced sampling of natural resources. *Journal of the American Statistical Association*, 99: 262-278.

Swanson. R.D., McFarland, W.D., Gonthier, J. B., and Wilkinson, J. M., (1993). A description of the hydrogeologic units in the Portland Basin, Oregon and Washington, U. S. Geological Survey Water - Resources Investigations Report 90-4196, 56 p.

Trimble, D.E. (1963). Geology of Portland Oregon and adjacent areas, U.S. Geological Survey Bulletin 1119. 119 p.

USGS (1996a). Description of the Groundwater Flow System in the Portland Basin, Oregon and Washington. USGS Water Supply Paper 2470-A. United States Government Printing Office, Washington, 56 p.

USGS (1996b). Simulation Analysis of the Groundwater Flow System in the Portland Basin, Oregon and Washington. USGS Water Supply Paper 2470-B. United States Government Printing Office, Washington.

Willis, R.F. (1977). Groundwater exploratory program: Bureau of Water Works, Portland, Oregon, 284 p., 17 plates.

Willis, R.F. (1978). Pilot well study: Bureau of Water Works, Portland, Oregon 150p., 23 plates.

Watts, R.J. (1998). Hazardous Wastes: Sources, Pathways, Receptors. John Wiley and Sons, New York: New York.

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Tables

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Table 4-1: Properties of WPCF Permit Pollutants Used in Selection of Representative Indicator Pollutants -

	MADL	MCL[1]	DEQ RBCs for Ground-water[2]	Region 6 Residential Water Screening Value	ca/nc[4]	VOC (yes/no)[5]	Solubility (mg/L)[6]	EPA Mobility Ranking[7]	Mobility of Pollutant	Mobility of Pollutant (assumed)	Persistence (half-life [days])[8]	Persistence Ranking	Frequency of Detection (Years 1 and 2) (%)[9]	Pollutant Category[10]
	µg/L	µg/L	µg/L											
Common Pollutants														
Benzene	5	5	0.35	0.35	ca	y	1800	1	High		10	Low	1	V
Toluene	**1000**	**1000**	**2300**	**2300**	**nc**	**y**	**530**	**1**	**High**		**0.5**	**Low**	**37**	**V**
Ethylbenzene	700	700	1300	1300	nc	y	170	1	High		0.3	Low	1	V
Xylenes	10,000	10,000	210	200	nc	y	180	1	High		17.5	Low	1	V
Pentachlorophenol	**1**	**1**	**0.47**	**0.56**	**ca**	**n**	**2000**	**1**	**High**		**100**	**Medium**	**82**	**SV**
Di(2-ethylhexyl)phthalate	**6**	**6**	**4.1**	**4.8**	**ca**	**n**	**0.34**	**0.0001**	**Low**		**14**	**Low**	**62**	**SV**
Benzo(a)pyrene	**0.2**	**0.2**	**0.0029**	**0.0029**	**ca**	**n**	**0.0016**	**0.0001**	**Low**		**300**	**Medium**	**24**	**PAH**
Arsenic (Total)	10	10	0.038	0.045	ca	n	120000	0.01	Medium		infinite	infinite	100	M
Cadmium (Total)	5	5	18	18	nc	n	1700	0.01	Medium		infinite	infinite	41	M
Chromium VI	100	100	110	110	nc	n	600000	0.01	Medium		infinite	infinite	80	M
Copper (Total)	**1300**	**1300**	**1400**	**1400**	**nc**	**n**	**570**	**0.01**	**Medium**		**infinite**	**infinite**	**100**	**M**
Lead (Total)	**50**	**15**	**15**	**15**			**870**	**0.01**	**Medium**		**infinite**	**infinite**	**100**	**M**
Zinc (Total)	5000	NR	NR	11,000	nc	n	1400	0.01	Medium		infinite	infinite	100	M
Nitrate-nitrogen	10,000	10,000	NR	NR			High in soil & water	NR	High		infinite	infinite	30	O
Priority Pollutant Screen														
Antimony (Total)	6	6	NR	15	nc	n	170,000	0.01	Medium		infinite	infinite	97	M
Barium (Total)	2000	2000	7300	7300	nc	n	2,800	0.01	Medium		infinite	infinite	100	M
Beryllium (Total)	4	4	73	73	nc	n	84,000	0.01	Medium		infinite	infinite	12	M
Selenium (Total)	50	50	NR	180	nc	n	2.60E+06	1.0	High		infinite	infinite	3	M
Thallium (Total)	2	2	NR	2.6	nc	n	8600	0.01	Medium		infinite	infinite	0	M
Mercury (Total, inorganic)	2	2	11	3.7	nc	n	450	0.01	Medium		infinite	infinite	50	M
Cyanide (Total)	200	200	730	730	nc	n	NR	1.0	High		infinite	infinite	0	O
Alachlor	2	2	NR	0.84	ca	n	240	0.01	Medium		14	Low	0	P/H
Atrazine	3	3	NR	0.3	ca	n	70	0.01	Medium		100	Medium	0	P/H
Bis(2-chloroisopropyl)ether	0.8	NR	NR	NR	ca	y	1,700	NR	Medium		100	Medium	0	SV
Bis(2-chloroethyl)ether	0.3	NR	NR	0.0098	ca	y	17,200	NR	Medium		100	Medium	0	SV
Carbofuran	40	40	NR	180	nc	n	351	NR	Medium		110	Medium	0	P/H
Carbon Tetrachloride	5	5	0.17	0.17	ca*	y	790	1.0	High		265	Medium	0	V
Chlorobenzene	100	100	90	91	nc	y	470	1.0	High		110	Medium	<1	V
o-Dichlorobenzene	600	600	50	49	nc	y	4000	1.0	High		slow	High	0	V
p-Dichlorobenzene	75	75	0.48	0.47	ca	y	79	1.0	High		104	Medium	0	V
1,3-Dichlorobenzene	5.5	NR	15	14	nc	y	125	NR	High		42	Low	0	V
1,2,4-Trichlorobenzene	70	70	12	8.2	nc	y	35	1.0	High		104	Medium	0	V
Chlordane	2	2	0.16	0.19	ca*	n	0.056	0.01	Medium		812	High	0	P/H
Lindane[HCH(gamma)]	0.2	0.2	0.044	0.052	ca	n	7.3	1.0	High		980	High	0	P/H
2,4-D [1, 2]	**70**	**70**	**370**	**370**	**nc**	**n**	**4500**	**NR**	**High**		**15**	**Low**	**16**	**P/H**
Dinoseb	7	7	NR	37	nc	n	52	NR	High		24	Low	<1	P/H
Picloram	500	500	NR	NR	nc	n	430	NR	Medium		100	Medium	0	P/H
Dalapon	200	200	NR	1100	nc	n	800,000	NR	High		16	Low	0	P/H
Diquat	20	20	NR	80	nc	n	700,000	NR	Low		infinite	Infinite	0	P/H
Endothall	100	100	NR	730	nc	n	100,000	NR	Medium		10	Low	0	P/H
Glyphosate	700	700	NR	3700	nc	n	11,600	NR	Low		60	Medium	0	P/H
Ancillary Pollutants (Years 1 and 2)														
1,1,1-Trichloroethane	N/A	200	840	73000	nc	y	1300	1	High		200	Medium	1	V
1,2,4-Trimethylbenzene	N/A	NR	12	13	nc	y	NR	NR		High	20	Low	1	V
1,3,5-Trimethylbenzene	N/A	NR	12	12	nc	y	NR	NR		High	10	Low	1	V
2-butanone [MEK]	N/A	NR	NR	7100	nc	y	220,000	1	High		4	Low	1	V
2,4,5-trichlorophenoxy acetic acid [2,4,5-t]	N/A	NR	NR	370	nc	n	NR	NR		Medium	25	Low	1	P/H
2(2,4,5-Trichlorophenoxy) propionic acid [2,4,5-tp]	N/A	50	NR	290	nc	n	NR	NR		Medium	17	Low	<1	P/H
3-methylphenol	N/A	NR	NR	1800	nc	n	NR	NR		Low		Medium	3	SV
4-methylphenol	N/A	NR	NR	180	nc	n	22,000	0.01	Low			Medium	3	SV
4-Isopropyltoluene	N/A	NR	NR	NR			NR	NR		High	20	Low	5	V
Acetone	N/A	NR	NR	5500	nc	y	-0.24	1	High		4	Low	5	V
Acenaphthylene	N/A	NR	NR	NR			16	0.001	Low		50	Medium	2	PAH
Acenaphthene	N/A	NR	370	370	nc	y	3.6	0.0001	Low		60	Medium	<1	PAH
Acifluorfen	N/A	NR	NR	NR						Medium	60	Medium	<1	P/H
Anthracene	N/A	NR	1800	1800	nc	y	0.043	0.0001	Low		250	Medium	3	PAH
Bentazon	N/A	NR	NR	1100	nc	n	NR	NR		Low	20	Medium	1	P/H
Benzo(a)anthracene	N/A	NR	.029	0.029	ca	n	0.0094	0.0001	Low		400	Medium	24	PAH

	MADL	MCL[1]	DEQ RBCs for Ground-water[2]	Region 6 Residential Water Screening Value	ca/nc[4]	VOC (yes/no)[5]	Solubility (mg/L)[6]	EPA Mobility Ranking[7]	Mobility of Pollutant	Mobility of Pollutant (assumed)	Persistence (half-life [days])[8]	Persistence Ranking	Frequency of Detection (Years 1 and 2) (%)[9]	Pollutant Category[10]
	µg/L	µg/L	µg/L											
Benzo(b)fluoranthene	N/A	NR	.029	0.029	ca	n	NR	NR		Low	490	Medium	40	PAH
Benzo(ghi)perylene	N/A	NR	.0029	NR			0.00026	0.0001	Low		620	High	35	PAH
Benzo(k)fluoranthene	N/A	NR	.29	0.29	ca	n	0.0008	0.0001	Low		1525	High	19	PAH
Benzoic acid	N/A	NR	NR	150,000	nc	n				High	2	Low	3	SV
Benzyl alcohol	N/A	NR	NR	11,000	nc	n				High		Low	3	SV
Butyl benzyl phthalate	N/A	NR	NR	7300	nc	n	2.7	0.0001	Low		4	Low	2	SV
Carbon disulfide	N/A	NR	NR	1000			1200	1	High				1	V
Chloroform	N/A	NR	.18	0.17	ca	y	7900	1	High		100	Medium	2	V
Chrysene	N/A	NR	2.9	2.9	ca	n	0.0063	0.0001	Low		685	High	61	PAH
Dicamba	N/A	NR	NR	1100	nc	n	NR	NR		Medium	28	Low	3	P/H
Dichloroprop	N/A	NR	NR	NR			NR	NR		Medium	14	Low	1	P/H
Di-n-butyl phthalate (dibutyl phthalate)	N/A	NR	NR	3700	nc	n	11	0.0001	Low		12	Low	1	SV
Di-n-octyl phthalate	N/A	NR	NR	NR	nc	n	0.02	0.0001	Low		17	Low	7	SV
Dibenzo(a,h)anthracene	N/A	NR	.0029	0.0029	ca	n	0.0025	0.0001	Low		650	High	8	PAH
Diethyl phthalate	N/A	NR	NR	29,000	nc	n	1100	0.01	Low		30	Low	1	SV
Dimethyl phthalate	N/A	NR	NR	370,000	nc	n				Low	4	Low	<1	SV
Fluoranthene	N/A	NR	1500	1500	nc	n	0.21	0.0001	Low		300	Medium	54	PAH
Fluorene	N/A	NR	240	240	nc	n	2	0.0001	Low		50	Medium	4	PAH
Indeno(1,2,3-cd)pyrene	N/A	NR	.029	0.029	ca	n	0.000022	0.0001	Low		665	High	27	PAH
Methoxychlor	**N/A**	**40**	**NR**	**180**	**nc**	**n**	**0.045**	**0.0001**	**Low**		**270**	**Medium**	**7**	**P/H**
Methylene chloride	N/A	5	NR	4.3	ca	y	13,000	1	High		17	Low	<1	V
Naphthalene	**N/A**	**NR**	**6.2**	**6.2**	**nc**	**y**	**31**	**0.01**	**Low**		**10**	**Low**	**27**	**PAH**
nButylbenzene	N/A	NR	61	61	nc	y	NR	NR		High		Low	<1	V
Phenanthrene	N/A	NR	NR	NR			1.1	0.0001	Low		108	Medium	72	PAH
Pyrene	N/A	NR	1100	180	nc	y	1.4	0.0001	Low		1055	High	67	PAH
tertButylbenzene	N/A	NR	NR	61	nc	y	NR	NR		High		Low	<1	V

Table notes:

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

[1] 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] Preliminary Remediation Goal (PRG). U.S. EPA Region 6: Superfund. http://www.epa.gov/Region6/6pd/rcra_c/pd-n/screenvalues.xls (Accessed 5/16/08)

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

[5] Volatile organic compound (VOC)

[6,7] 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)

[8] 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

[9] City of Portland Stormwater Discharge Monitoring Report data (BES, 2006; BES, 2007)

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

Table 4-2: Summary Statistics of Selected Stormwater Pollutants

Pollutant	MADL (ug/L)	Statistic	Zero[a]			1/2 Detection Limit[b]			Detection Limit[c]		
			Estimate (ug/L)	Lower 95% Confidence Interval (ug/L)	Upper 95% Confidence Interval (ug/L)	Estimate (ug/L)	Lower 95% Confidence Interval (ug/L)	Upper 95% Confidence Interval (ug/L)	Estimate (ug/L)	Lower 95% Confidence Interval (ug/L)	Upper 95% Confidence Interval (ug/L)
Methoxychlor	180 [d]	90Pct	0.00	0.00	0.21	0.05	0.05	0.60	0.10	0.10	0.60
		95Pct	0.06	0.00	0.60	0.09	0.05	0.60	0.12	0.10	0.60
		Mean	0.02	-0.01	0.05	0.07	0.04	0.10	0.12	0.09	0.14
2,4-D	70	90Pct	0.72	0.29	2.10	0.76	0.32	2.13	0.80	0.36	2.16
		95Pct	1.36	0.65	6.56	1.40	0.69	6.58	1.44	0.73	6.60
		Mean	0.36	0.07	0.64	0.40	0.12	0.68	0.45	0.17	0.73
Benzo(a)pyrene	0.2	90Pct	0.02	0.01	0.04	0.02	0.02	0.04	0.02	0.02	0.04
		95Pct	0.03	0.02	0.13	0.03	0.02	0.13	0.03	0.02	0.13
		Mean	0.01	0.00	0.01	0.01	0.01	0.02	0.02	0.01	0.02
DEHP	6.0	90Pct	4.28	3.46	15.78	4.37	3.46	15.95	4.48	3.51	16.11
		95Pct	10.31	3.72	20.67	10.50	3.80	20.67	10.69	3.92	20.67
		Mean	2.55	1.53	3.57	2.79	1.78	3.80	3.03	2.03	4.03
Copper	1,300	90Pct	17.64	13.38	21.43	17.64	13.38	21.43	17.64	13.38	21.43
		95Pct	20.59	18.30	28.62	20.59	18.30	28.62	20.59	18.30	28.62
		Mean	8.77	7.65	9.89	8.77	7.65	9.89	8.77	7.65	9.89
Lead	50	90Pct	19.25	16.28	27.36	19.25	16.28	27.36	19.25	16.28	27.36
		95Pct	24.50	19.34	33.69	24.50	19.34	33.69	24.50	19.34	33.69
		Mean	7.88	6.25	9.51	7.88	6.25	9.51	7.88	6.25	9.51
Naphthalene	6.2[d]	90Pct	0.05	0.04	0.07	0.07	0.05	0.18	0.07	0.06	0.30
		95Pct	0.06	0.05	0.29	0.18	0.07	0.27	0.25	0.08	0.36
		Mean	0.03	0.02	0.04	0.04	0.03	0.05	0.06	0.04	0.07
PCP	1.0	90Pct	1.17	0.91	1.86	1.17	0.91	1.86	1.17	0.91	1.86
		95Pct	1.69	1.18	2.62	1.69	1.18	2.62	1.69	1.18	2.62
		Mean	0.49	0.38	0.60	0.49	0.38	0.60	0.49	0.38	0.60
Toluene	1,000	90Pct	4.11	3.70	5.13	4.29	3.84	5.18	4.46	3.99	5.23
		95Pct	4.60	4.06	7.99	4.65	4.24	8.08	4.76	4.43	8.17
		Mean	1.48	1.07	1.89	1.65	1.25	2.05	1.81	1.42	2.21

a) Samples reported as less than method report limit were replaced with 0 for estimation of the summary statistic.
b) Samples reported as less than method report limit were replaced with 1/2 the MRL for estimation of the summary statistic.
c) Samples reported as less than method report limit were replaced with the MRL for estimation of the summary statistic.
d) EPA Region 6 Media Specifc Screening Value for Residental Water (EPA, 2007)

Shaded values indicate concentration is >MADL or screening level value.

Shaded values are the 95th Upper Confidence on the mean

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Figures

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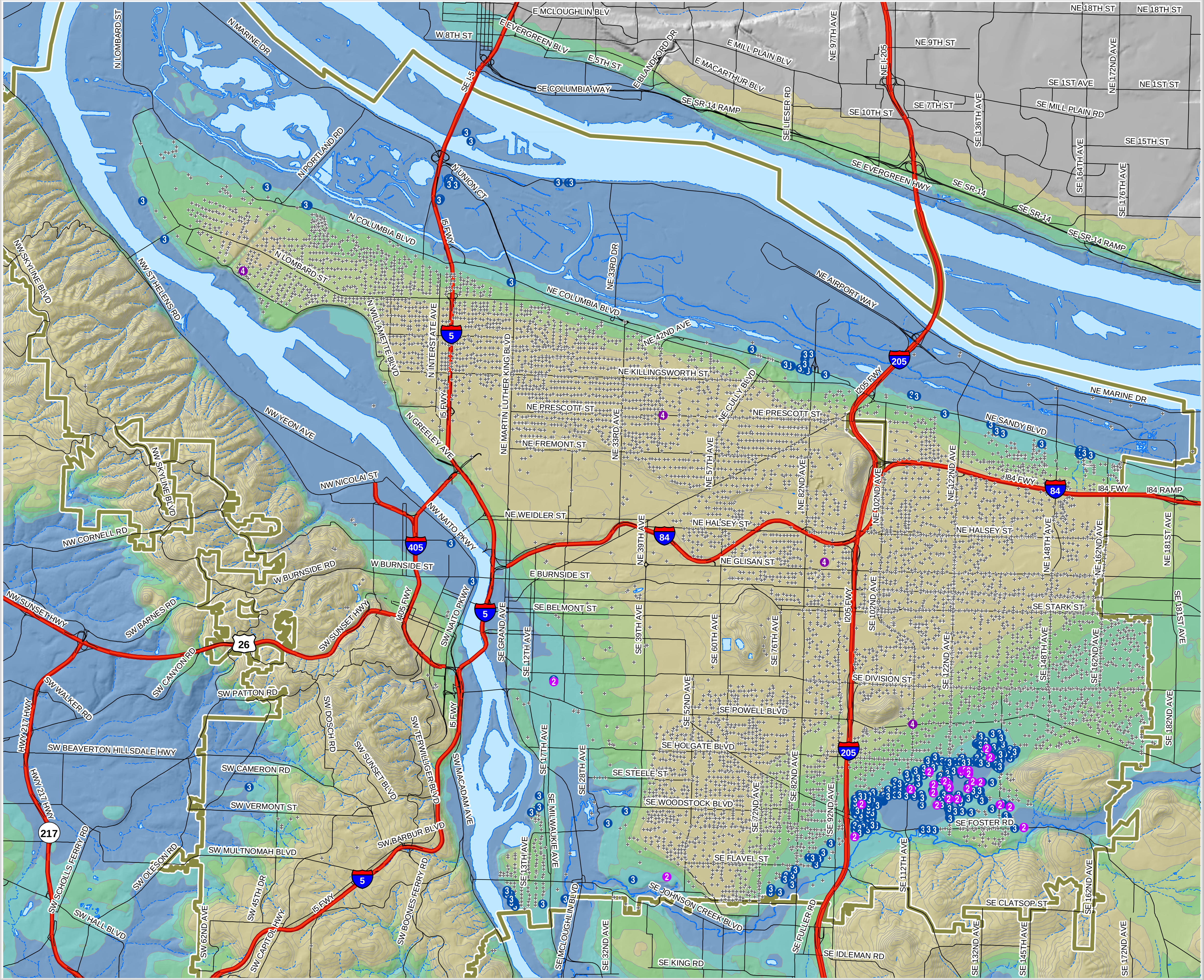
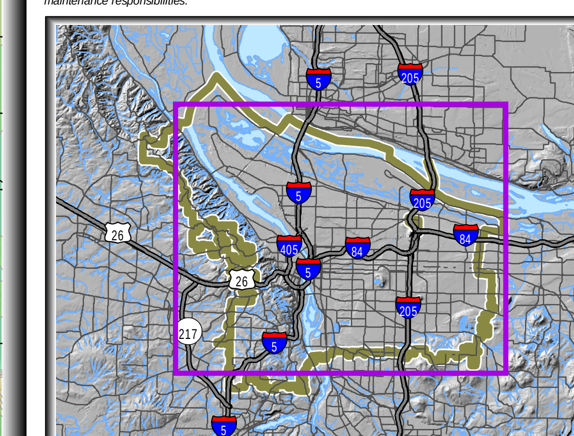




City of Portland Overview

Inset corresponds to City of Portland Overview map

State of Oregon Overview

Inset corresponds to main map

Figure 3-1*

Portland Area Corrective Action UICs
by Compliance Category
(29 Cat-2 UICs)
(338 Cat-3 UICs)
(4 Cat-4 UICs)
(371 TOTAL)

0 0.5 1 2 Miles

*Map originally presented in UICMP Annual Report No. 2 November 1, 2007

Legend

- City of Portland
- Rivers and Lakes
- Stream Lines
- Cat-2 UIC (29)
- Cat-3 UIC (338)
- Cat-4 UIC (4)
- All City-Owned UICs

2007 Estimated Depth to Seasonal High Groundwater 20-ft Contours

Source: Draft USGS Portland Area Depth to Groundwater. Ranges in Feet.

- <20
- 20-40
- 40-60
- 60-80
- 80-100
- >100

City of Portland Environmental Services
Systems Analysis
Spatial Analysis and Modeling

Printing Date : Jun 16, 2008

This map was produced in support of the City of Portland's Water Pollution Control Facilities Permit #102830 for Class V Stormwater Underground Injection Control Systems, issued by Oregon Department of Environmental Quality on June 1, 2005.
Data were compiled from various sources. This product was developed through digital means and may be updated without notification. No warranty is made by the City of Portland Bureau of Environmental Services as to the accuracy, reliability, or completeness of these data. Data shown are to be used for reference purposes only; maps should not be used to determine jurisdictional authority, ownership, or operations and maintenance responsibilities.

UNDERGROUND INJECTION CONTROL PROGRAM MAP

Produced by Systems Analysis: Map Request 4697 (JRGB) June 2nd, 2008 \\Cassio\GIS2\PROJECTS\7750\TASKS\Task3N_Compliance_Evaluation\MXD\Figure3-1_Cat234_B.mxd

Figure 4-1: Cumulative Distribution Function Plot: VOCs – Toluene

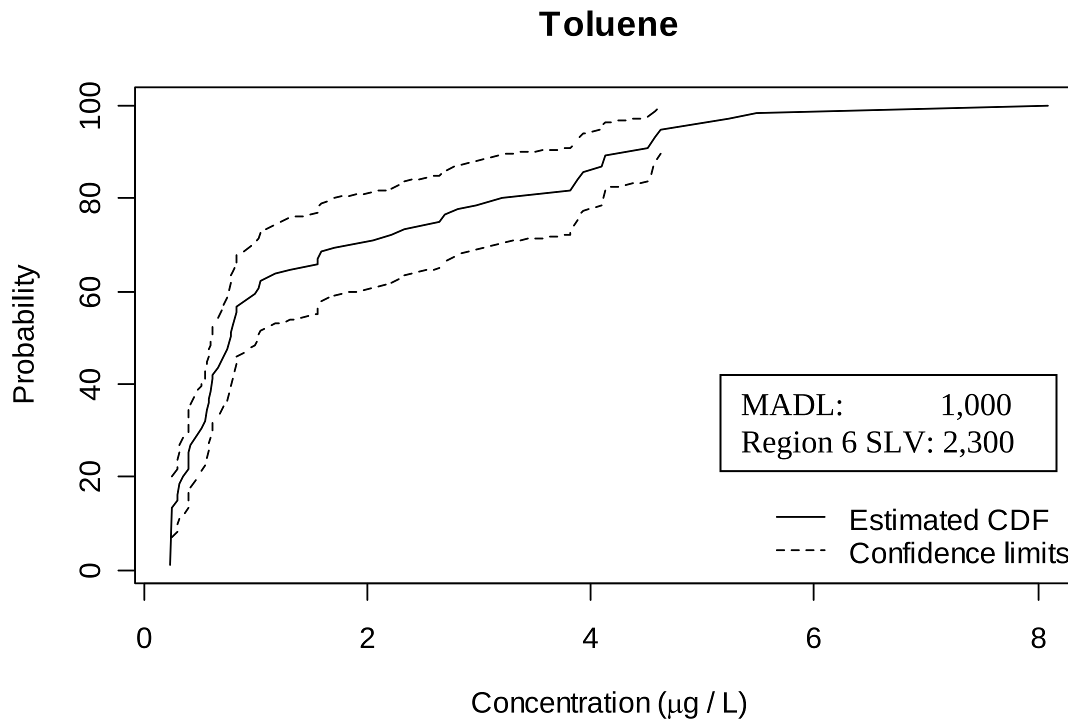


Figure 4-2: Cumulative Distribution Function Plot: SVOCs – Pentachlorophenol

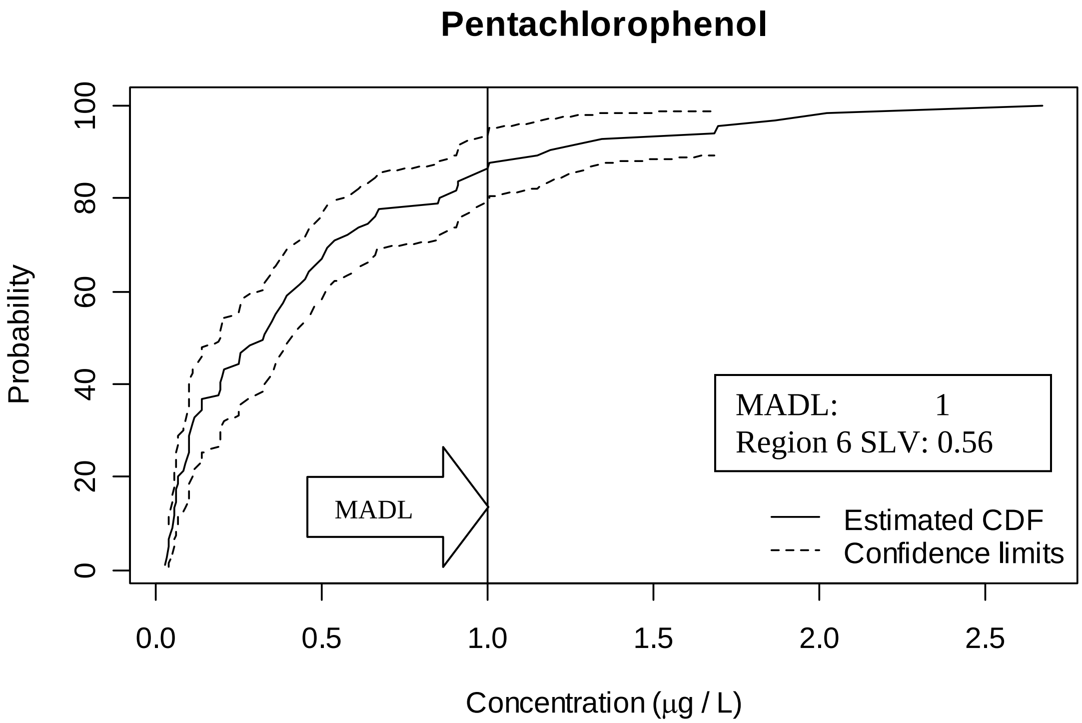


Figure 4-3: Cumulative Distribution Function Plot: SVOCs – Di(2-ethylhexyl)phthalate (DEHP)

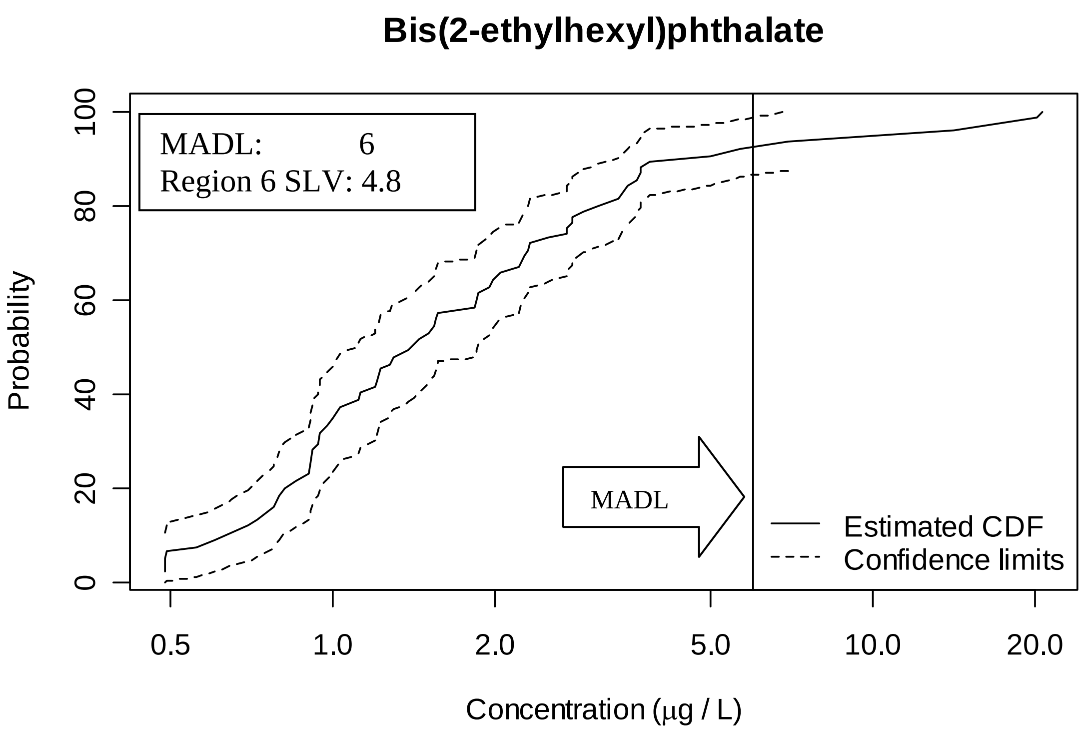


Figure 4-4: Cumulative Distribution Function Plot: PAHs – Benzo(a)pyrene

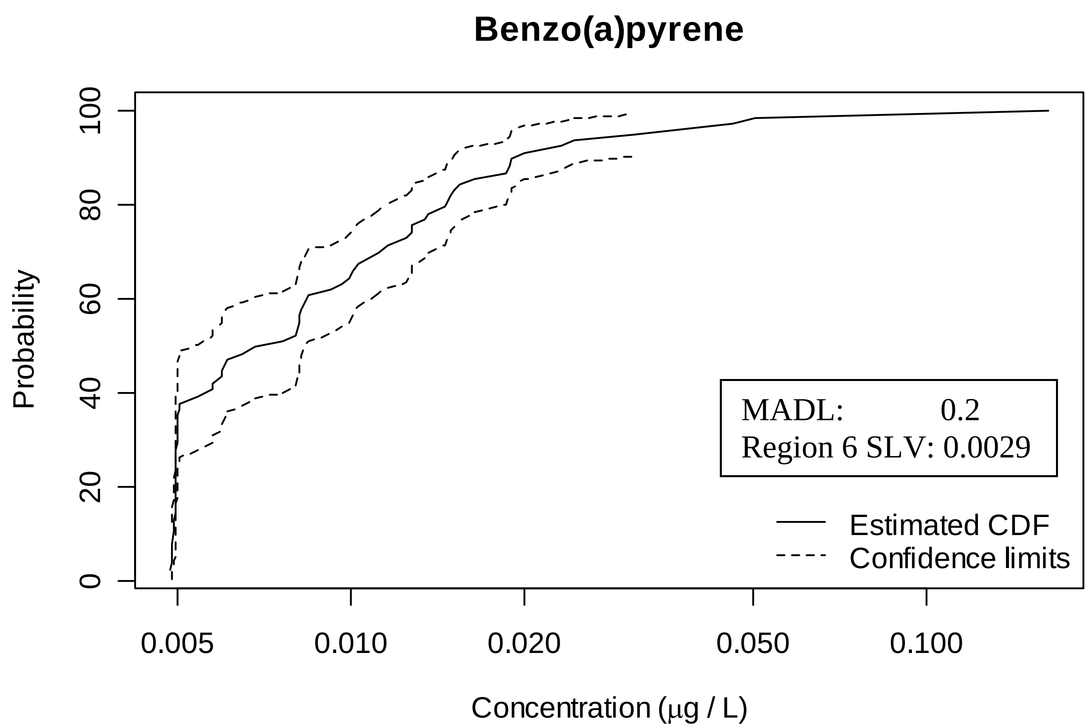


Figure 4-5: Cumulative Distribution Function Plot: PAHs - Napthalene

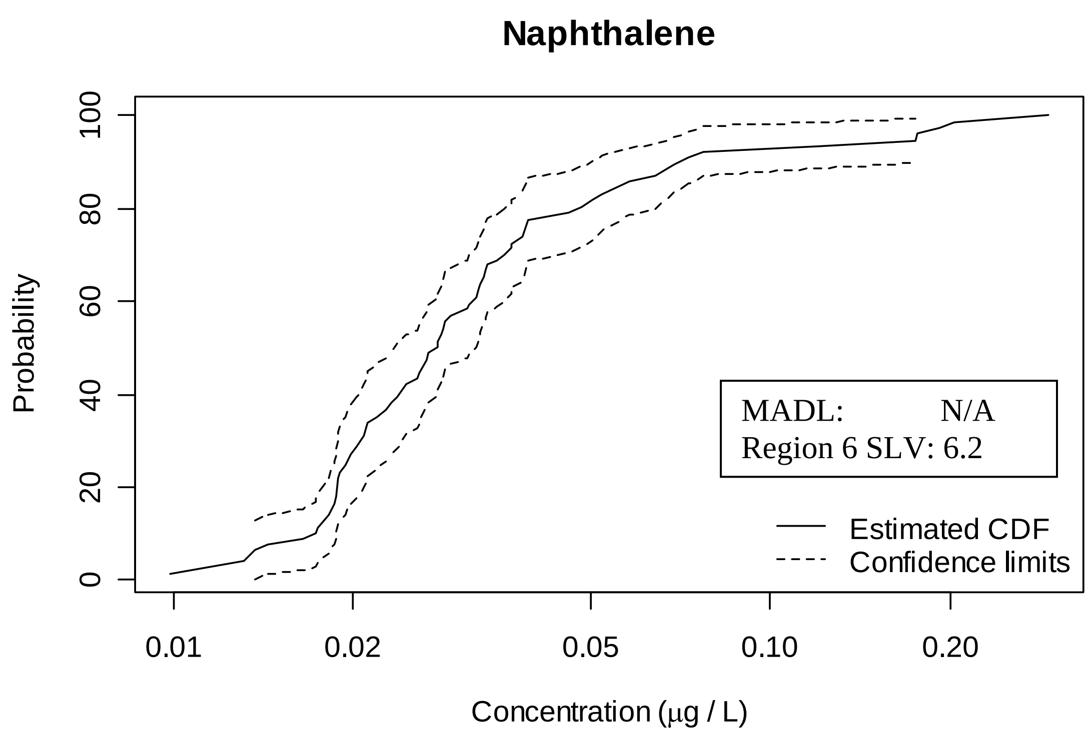


Figure 4-6: Cumulative Distribution Function Plot: Pesticides/Herbicides – 2,4-d

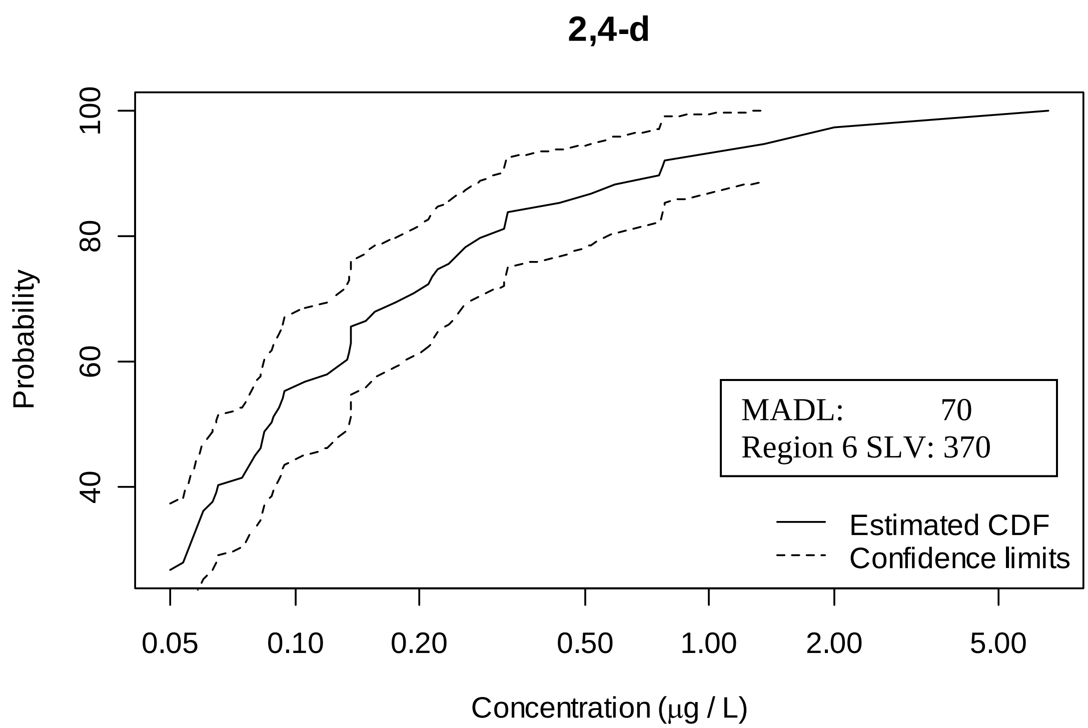


Figure 4-7: Cumulative Distribution Function Plot: Pesticides/Herbicides - Methoxychlor

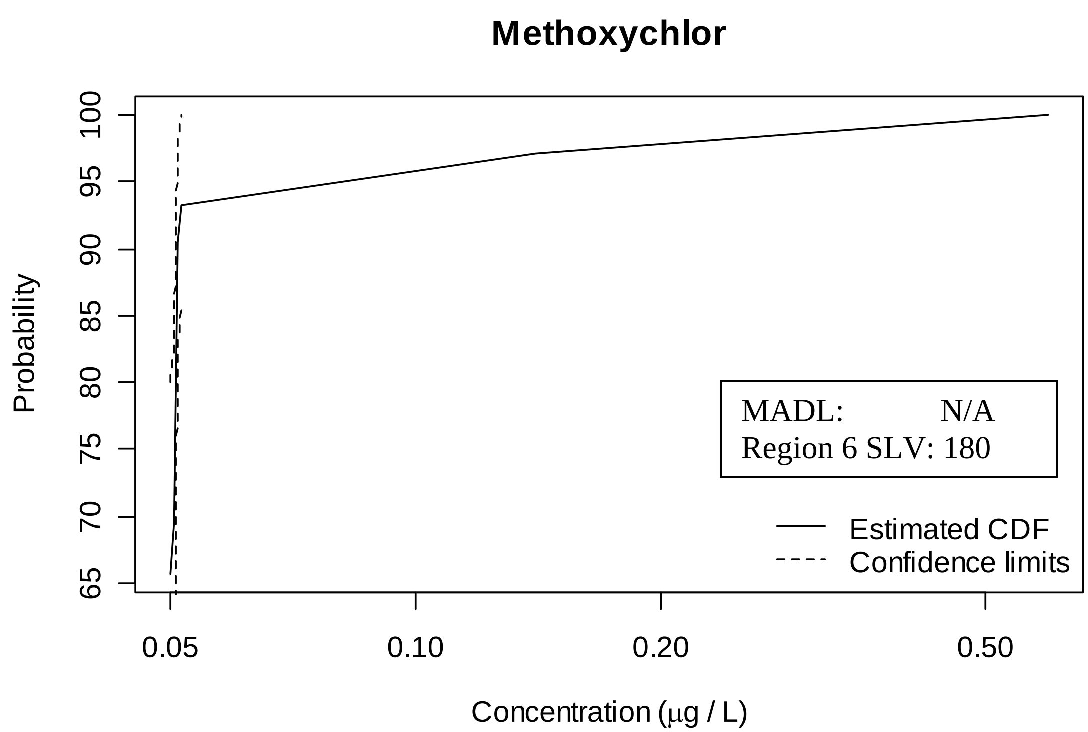


Figure 4-8: Cumulative Distribution Function Plot: Metals - Copper

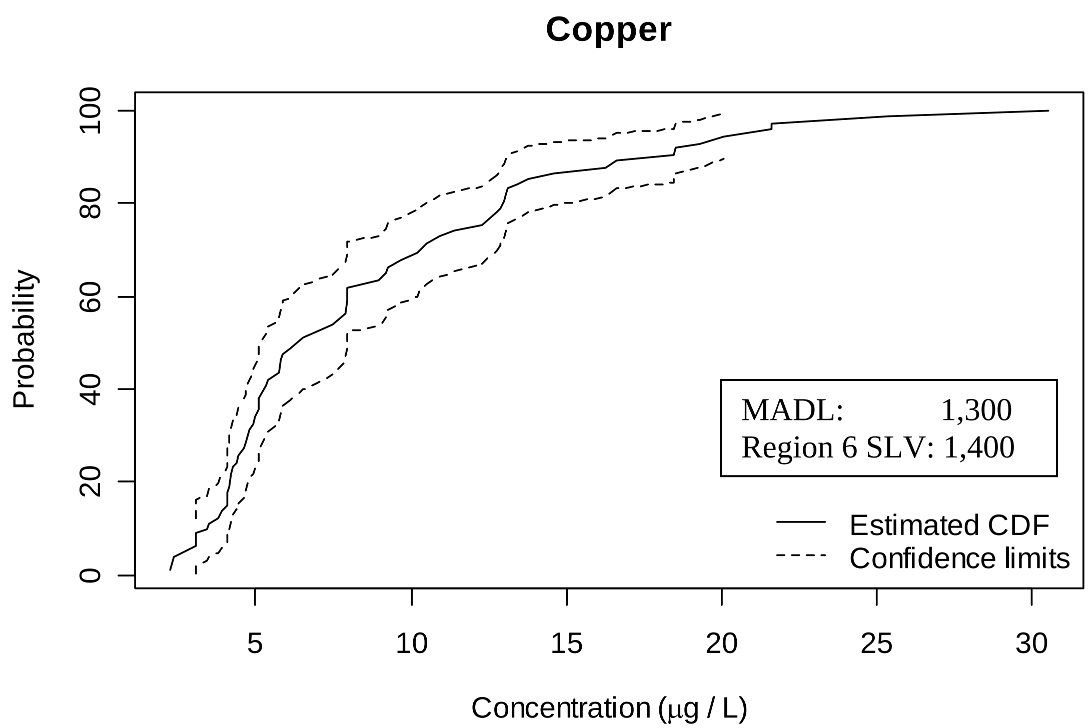


Figure 4-9: Cumulative Distribution Function Plot: Metals - Lead

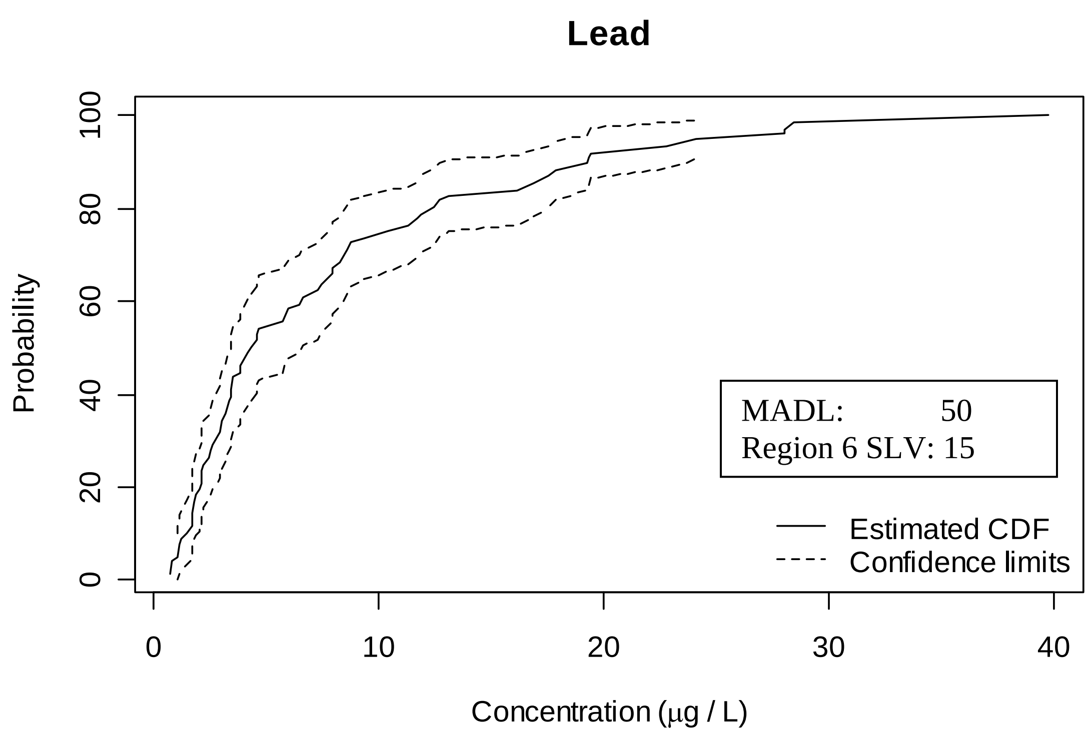
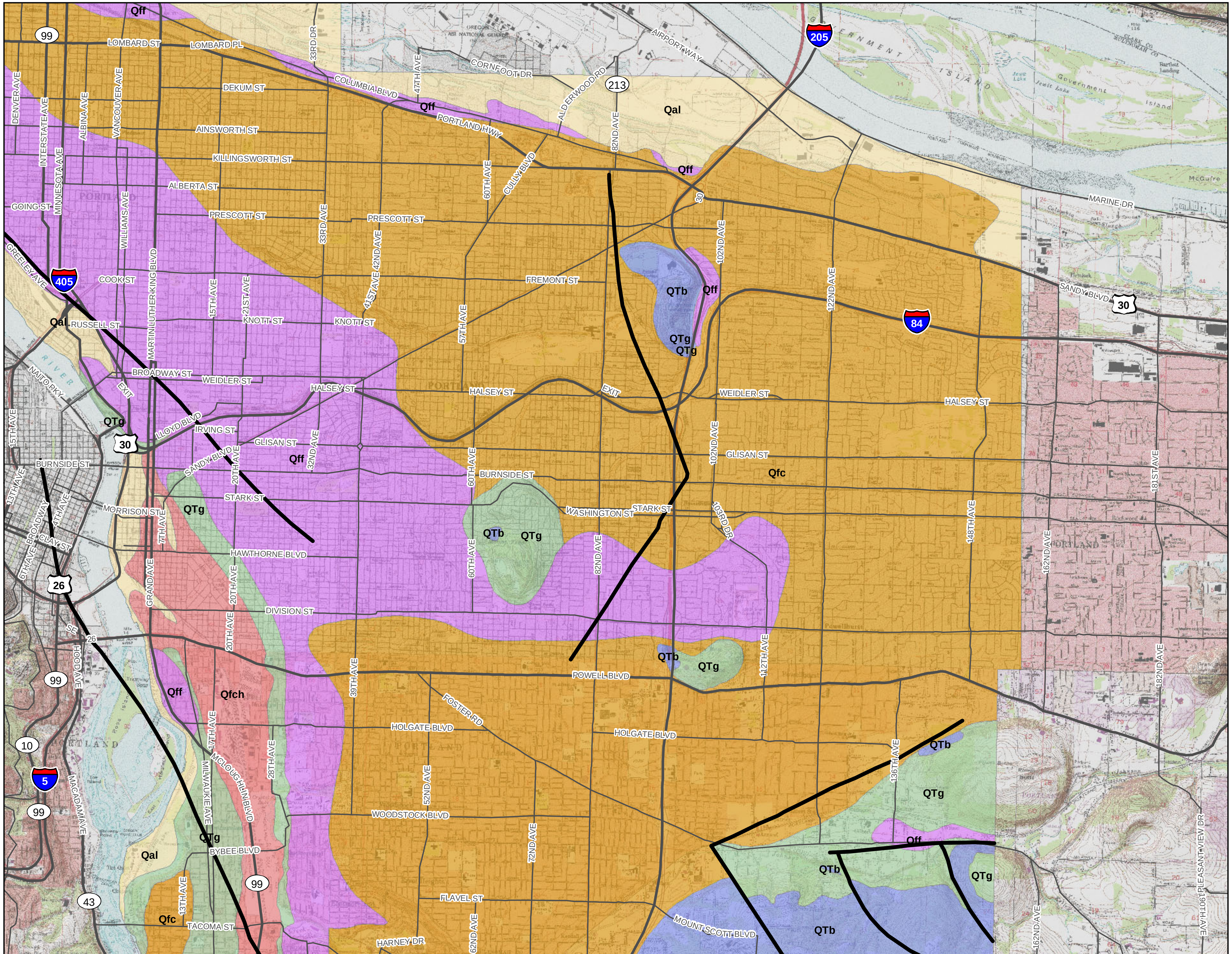


FIGURE 6-2
Portland Basin Geology
BES UIC Program



LEGEND

Geologic Units

Alluvial Aquifer

- Qal - Alluvium

Unconsolidated Gravel Aquifer

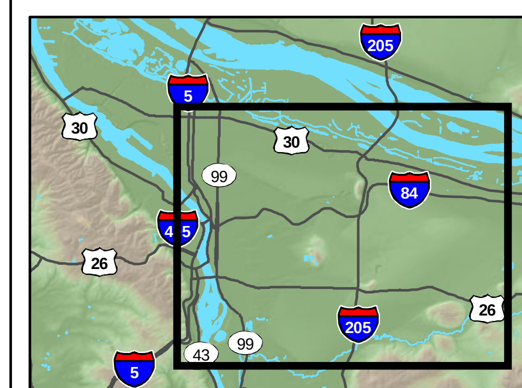
- Qff - fine-grained facies
- Qfc - coarse-grained facies
- Qfch - channel facies

Troutdale Gravel Aquifer

- QTg - Troutdale Formation gravels
- QTb - Boring Lava
- Faults
- Freeways and Highways
- Major Roads

NOTES

1) Geology modified from DOGAMI (1990) OFR 0-90-2
2) Surficial geology (i.e. <30 feet bgs) not shown
3) Artificial fill (Qaf) not shown



N

Scale

1:54,000

0 2250 4500 6750 9000

Feet

MAP NOTES:
Projection: Oregon State Plane North Zone
Datum: North American Datum of 1983
Date: May 30, 2008
Data Sources: City of Portland BES, DOGAMI, ESRI, Aerial Photos taken in July 2005 by USDA

GSI Water Solutions, Inc.

File Path: P:\110 - BES\010 - UIC Program (EnviroIssues)\Project_GIS\Project_mxds\Figure1_Portland_Basin_Geology.mxd, Date: May 30, 2008 11:28:17 AM

Appendix A

Category 4 Corrective Actions NFA Letter

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Oregon
Theodore Kulongoski, Governor

Department of Environmental Quality
Northwest Region Portland Office
2020 SW 4th Avenue, Suite 400
Portland, OR 97201-4987
(503) 229-5263
FAX (503) 229-6957
TTY (503) 229-5471

May 30, 2008

Ms. Mary Stephens, Manager.
Underground Injection Control Program
City of Portland
1120 SW 5th Avenue, Room 1000
Portland, Oregon 97204-1912

Re: No Further Action Determination
Category 4 UICs – Corrective Action
City of Portland
DEQ Water Pollution Control Facilities Permit No. 102830

Dear Ms. Stephens:

The Department of Environmental Quality (DEQ) completed its review of the information submitted to date regarding the recommended corrective actions for four noncompliant Category 4 Underground Injection Control systems (UICs). Corrective action, as defined by the Water Pollution Control Facilities (WPCF) permit issued to the City of Portland (DEQ Permit No.102830), can consist of groundwater monitoring, risk assessment using DEQ-approved protocols, or structural retrofitting at the UIC. The corrective action selected by the City of Portland's Bureau of Environmental Services (BES) for the UICs listed below is a Groundwater Protectiveness Demonstration (i.e., risk assessment).

The following UICs were identified as noncompliant Category 4 UICs because the annual mean detected pentachlorophenol (PCP) concentrations at the point of compliance exceeded the MADL of 1 microgram per liter (μg/L) for two consecutive years:

Category 4 UICs Identified in Year 2

Location Code	Approximate Address	BES UIC No.	Traffic Category (TPD)	Estimated Separation Distance (ft) [1]	Year 1 Annual Geometric PCP Concentration (μg/L)	Year 2 Annual Geometric PCP Concentration (μg/L)
P1_1	6940 N. Macrum Ave.	AAG769	< 1000	64	1.1	1.2
P6_1	3500 SE 112th Ave.	ADW577	≥ 1000	62	1.2	1.0
P6_7	608 NE 87 Ave.	ADV645 [2]	< 1000	147	2.0	1.8
P6_14	4289 NE Prescott St.	AD1252	≥ 1000	162	1.5	1.4

DEQ reviewed the following documents submitted by BES to support the selected corrective actions:

1. *Category 4 UIC Corrective Actions - Groundwater Protectiveness Demonstrations* (GWPD) prepared by GSI Water Solutions (GSI) and EnviroIssues under the direction of the BES UIC Program staff. This technical memorandum is dated April 7, 2008.

2. *Peer Review of UIC Category 4 Groundwater Protectiveness Demonstration – Draft dated March 3, 2008* prepared by S.S. Papadopulos & Associates. This technical memorandum is dated April 6, 2008.

3. *Category 4 – UICs Corrective Action.* Letter from Rod Struck, BES to Rodney Weick, DEQ identifying DEQ of the BES identified Groundwater Protectiveness Demonstrations (e.g., risk assessment) as the recommended corrective action for the four Category 4 UICs. This letter requested DEQ approval of the selected corrective action and no further action determinations.

4. *Category 4 UICs – Corrective Actions.* This April 15, 2008 letter (Rod Struck, BES to Rodney Weick, DEQ) provided a table showing how key comments made by S.S. Papadopulos (April 6, 2008) were incorporated into the final GSI technical memorandum dated April 7, 2008.

5. *No Further Action Request – Category 4 UICs – Corrective Action.* This May 30, 2008 letter (Rod Struck, BES to Rodney Weick, DEQ) provides a response to DEQ's April 29, 2008 comments on the documents listed above.

6. *Category 4 UIC Corrective Actions Updated Groundwater Protectiveness Demonstrations* prepared by GSI Water Solutions (GSI) under the direction of the BES UIC Program staff. It provides the revised groundwater protectiveness demonstration for the 4 Category 4 UICs based in DEQ's comments. This technical memorandum is dated May 23, 2008.

DEQ has concluded that the methodology and assumptions used in these documents provide a good analytical framework for evaluating pollutant transport in unsaturated zone soil beneath City-owned UICs. The above technical memoranda demonstrate that for these Category 4 UICs, PCP concentrations are attenuated (i.e., treats, removes) by subsurface soils. Therefore, it can be concluded that stormwater discharges to the subject UICs are protective of beneficial uses of groundwater and public health and the environment as required by OAR 340-040.

It is DEQ's determination that no further action (NFA) is required at the four Category 4 UIC locations listed above. The Groundwater Protectiveness Demonstration, presented in the above referenced documents, is the approved corrective action for these UICs. The NFA determinations are based on the analyses presented in the above referenced documents and available UIC stormwater discharge monitoring data which indicate PCP concentrations are generally present at very low concentrations and within a narrow concentration range (between 0.04 and 3 μg/l). Based on UIC stormwater monitoring data collected for the 2006-2007 and 2007-2008 wet seasons, DEQ concurs with BES that PCP concentrations are not expected to significantly increase in the future. The likely PCP source is strongly suspected to be leaching or weathering of PCP treated wood utility poles.

DEQ's NFA determination will not be applicable if new or undisclosed facts become available and show that the fate and transport analyses or assumptions are not valid or do not comply with the permit or OAR 340-040. We recommend that a copy of all information be maintained with the permanent site records.

If you have questions please feel free to contact me (503) 229-5886.

Sincerely,

Rodney Weick

Rodney Weick, Manager
NWR Stormwater and UIC Programs

Cc: Permit File No. 102830
Rod Struck, BES

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Appendix B

Technical Memorandum:
Evaluation of Vertical Separation Distance
May 27, 2008

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— CITY OF PORTLAND
ENVIRONMENTAL SERVICES
1120 SW Fifth Avenue, Room 1000, Portland, Oregon 97204-1912 ▪ Sam Adams, Commissioner ▪ Dean Marriott, Director

May 30, 2008

Mr. Rodney Weick, CEG
Underground Injection Control System Permit Manager
Oregon Department of Environmental Quality
2020 SW 4th Avenue Suite 400
Portland, Oregon 97201

Subject: Evaluation of Vertical Separation Distance
Groundwater Protectiveness Demonstration
City of Portland
DEQ Water Pollution Control Facilities Permit No. 102830

Dear Rodney:

The purpose of this letter is to transmit the following final technical memorandum to the Oregon Department of Environmental Quality (DEQ):

> *Evaluation of Vertical Separation Distance - Groundwater Protectiveness Demonstration* prepared by GSI Water Solutions, S.S. Papadopulos & Associates, and EnviroIssues. This technical memorandum is dated May 27, 2008.

This memorandum was prepared under the direction of the City of Portland's Bureau of Environmental Services (BES) UIC Program staff. We appreciate DEQ's participation in developing the approach used in this analysis. The final memorandum was revised to address your verbal comments in our May 13, 2008 meeting.

This document was prepared in accordance with the Water Pollution Control Facilities (WPCF) permit (DEQ Permit No.102830) for the City's Class V Stormwater UICs; the *Underground Injection Control Management Plan* ([UICMP] submitted to DEQ by the City of Portland in December 2006), *UIC Evaluation and Response Guideline No. 6* (Appendix H of the UICMP) and the *Corrective Action Plan* (submitted to DEQ by the City of Portland in July 2006).

This memorandum presents the approach and results of the fate and transport analyses of representative stormwater pollutants through a 5 foot and 7 foot unsaturated separation distance between the bottom of a UIC and seasonal high groundwater. This analysis demonstrates that stormwater pollutants are treated by unsaturated soil by filtration, sorption and biodegradation processes and do not reach shallow groundwater under the conservative scenarios evaluated.

The analyses presented in this technical memorandum will be incorporated in the Generic Groundwater Protectiveness tool currently being prepared by BES to assist the City and DEQ in evaluating the fate and transport of pollutants discharged to the City's UICs and in developing a consistent, streamlined decision-making process for evaluating when response actions and corrective actions are needed. In addition, the findings of the evaluation presented in this technical memorandum, will be used to document that a groundwater protectiveness demonstration (i.e., risk assessment) is an appropriate corrective action response for selected Category 3 UICs (non-compliant due to inadequate separation distance).

The results of the analyses presented in this technical memorandum are consistent with DEQ's review of regional groundwater quality data that indicated operation of the City's UIC system did not result in adverse impacts to groundwater quality (DEQ, 2005). In addition, the results of the fate and transport evaluation support the overarching goal of the permit to protect the highest beneficial use of groundwater, while allowing underground injection of urban stormwater from city rights-of-way.

BES requests DEQ review and approve the approach, results, and conclusions contained in this report by May 22 and so that the City can move forward with completion and submittal of the Generic Protectiveness Demonstration and the PreDesign efforts on the Category 3 UICs.

Please call Rod at (503)823-5762 or Mary at (503)823-7580, if you have any questions or concerns.

Sincerely,

Rod Struck

Rod Struck, R.G.
UIC Program

Mary Stephens

Mary Stephens, Manager
UIC Program

Enclosures:

Technical Memorandum: *Evaluation of Vertical Separation Distance - Groundwater Protectiveness Demonstration. May 27, 2008* – 3 hard copies

Cc. Heidi Blischke, GSI Water Solutions
Dimitri Vlassopoulos, SSPA
UIC Project File
Matt Kohlbecker, GSI Water Solutions
Julie Wilson, EnviroIssues

Technical Memorandum

To: Rod Struck, RG/City of Portland, Bureau of Environmental Services

From: Heidi Blischke, RG, Matt Kohlbecker/GSI Water Solutions
Dimitri Vlassopoulos, Jessica Goin/S.S. Papadopulos
Julie Wilson/EnviroIssues

Date: May 27, 2008

Re: Evaluation of Vertical Separation Distance
Groundwater Protectiveness Demonstration
City of Portland
Water Pollution Control Facilities Permit (DEQ Permit No. 102830)

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1 Introduction

This technical memorandum is the second in a series of three reports prepared for Oregon Department of Environmental Quality (DEQ) to support implementation of the City of Portland's (City) Water Pollution Control Facilities (WPCF) Permit No. 102830 for Class V Stormwater Underground Injection Control Systems (UICs) (permit). All City-owned UICs are managed under this permit, which was issued by the DEQ to the City of Portland Bureau of Environmental Services (BES) in June 2005.

These three technical reports explain the three phases of work that have been identified to develop a tool that will provide a consistent, streamlined decision-making process for evaluating potential adverse impacts (i.e., risks) to groundwater associated with urban right-of-way stormwater entering City-owned UICs. The Generic Groundwater Protection Demonstration tool will support no further action decisions for non-compliant UICs, and identify individual UICs or groups of UICs where groundwater is protected or where additional evaluation and groundwater protection may be needed. The first two phases of work are considered the foundation of the tool. These demonstrations (with the exception of Phase 3, which is in progress) have been, and will be, reported in the following three memoranda/phases:

1) Category 4 UICs – Corrective Actions (Phase 1). This memorandum documents application of the tool to UICs that were identified as non-compliant due to exceedances of their annual mean pollutant concentrations for two consecutive years. *This technical memorandum was submitted to DEQ on April 7, 2008.* We understand DEQ's no-further action determination on these UIC is forthcoming.
2) Evaluation of Vertical Separation Distance (Phase 2). This memorandum evaluates whether UICs with vertical separation distances of less than 10 feet are protective of groundwater quality in accordance with OAR 340-040. *This is the current memorandum.*
3) Generic Groundwater Protectiveness Demonstration (Phase 3). *This report is yet to be developed*. It will utilize the information developed during Phases 1 and 2 to provide the tool for implementing the WPCF permit by providing:
    - A decision-making process applicable to all City-owned UICs (i.e., generic);
    - Screening level evaluations of potential adverse impacts to groundwater associated with UICs identified during development and implementation of the permit including:
        - UICs with inadequate separation distance between the bottom of the UIC and groundwater;
        - UICs located within permit specified setbacks from drinking water wells (private or public);
        - UICs with stormwater concentrations exceeding permit-specified maximum allowable discharge limits (MADLs) at end-of-pipe (EOP) where stormwater enters the UIC;
        - Ubiquitous pollutants that may be present in stormwater [e.g., pentachlorophenol (PCP), di(2)ethylhexylphthalate (DEHP)];
    - Processes for performing site-specific groundwater protectiveness demonstrations; and
    - Potential options for fulfilling the regulatory requirements associated with UIC permit compliance.

This memorandum presents the approach and results of Phase 2, an evaluation of the vertical separation distance needed between the bottom of a City-owned UIC and groundwater in order to protect groundwater quality from pollutants in urban stormwater discharges to public UICs. This technical memorandum was prepared in accordance with the permit, the *UIC Management Plan* (UICMP; BES, 2006a), and the *Corrective Action Plan* (CAP; BES, 2006b), and under the oversight of BES UIC Program staff. The methodology, key assumptions, and input value parameters used in this analysis were developed with DEQ input, as discussed in Section 5, and builds on the analyses conducted to support "no further action" corrective actions (i.e., "risk assessment") selected for four Category 4 UICs.

1.1 Background: Category 4 UICs Groundwater Protectiveness Demonstration

The Category 4 UIC Groundwater Protectiveness Demonstration technical memorandum was prepared under the oversight of BES UIC Program staff. The methodology, key assumptions, and input value parameters used in the analysis were developed with DEQ input, to support "no further action" corrective actions (i.e., "risk assessment") selected for four Category 4 UICs. The technical approach used to evaluate the Category 4 Corrective Actions is described in the following documents:

1. *Category 4 UIC Corrective Actions- Groundwater Protectiveness Demonstrations* prepared by GSI Water Solutions and EnviroIssues under the direction of the BES UIC Program staff. This technical memorandum is dated April 7, 2008.
2. *Peer Review of UIC Category 4 Groundwater Protectiveness Demonstration – Draft dated March 3, 2008* prepared by S.S. Papadopulos & Associates. This technical memorandum is dated April 6, 2008.

The Groundwater Protectiveness Demonstration conducted for the four Category 4 UICs concluded that: 1) unsaturated subsurface soil attenuates (i.e., treats, removes) PCP concentrations detected in stormwater discharges at concentrations above the permitted MADL; 2) PCP concentrations discharged to the four Category 4 UICs do not reach groundwater ; and 3) measured and predicted PCP concentrations in stormwater discharged to these four UICs (i.e., under both average and reasonable maximum conditions) are protective of beneficial uses of groundwater and public health and the environment as required by OAR 340-040.

The evaluation of vertical separation distances, presented in this technical memorandum, was built from the fate and transport analyses approach, key assumptions, and input value parameters used in the Category 4 UIC Groundwater Protectiveness Demonstration and developed with DEQ input. The approach used to evaluate vertical separation distances is described in detail in Section 5 of this memorandum.

1.2 Objectives

The permit requires the City to implement corrective actions for UICs that do not comply with permit requirements to protect groundwater quality in accordance with Oregon Administrative Rules (OAR) 340-040. One of the circumstances that can cause a UIC to be non-compliant is a vertical separation distance of less than 10 feet between the bottom of the UIC and the top of the saturated zone. Corrective action, as defined by the permit, can consist of groundwater monitoring, risk assessment using DEQ-approved protocols, or structural retrofitting at the UIC. This memorandum presents the technical approach used to evaluate the fate and transport of selected pollutants from their entry into the UIC through the unsaturated subsurface (i.e., soils above the water table and below the point of entry into the UIC) soil thickness of 5 and 7 feet (i.e., vertical separation distance). The objectives of this technical memorandum include:

- Develop the technical approach and identify the analyses input parameter values, with DEQ input, to evaluate whether vertical separation distances of less than 10 feet are protective of groundwater quality in accordance with OAR 340-040;
- Determine if groundwater quality is likely to be adversely impacted (i.e., pollutants reach groundwater at concentrations above the MADL set in the permit) below UICs with vertical separation distances of 5 and 7 feet. The analysis evaluates a broad category of pollutants selected from stormwater discharge data obtained from the

City's UIC monitoring program (documented in the Year 1 and Year 2 *Annual Stormwater Discharge Monitoring Reports,* BES, 2006c; BES, 2007a);

- Provide a framework for conducting a Groundwater Protectiveness Demonstration (i.e., risk assessment) as a corrective action for UICs with vertical separation distances of less than 10 feet (i.e., Category 3 UICs); and
- Develop conservative stormwater pollutant "action level" concentrations that are protective of groundwater quality (i.e., not reasonably likely to adversely impact groundwater quality) for vertical separation distances of 5 feet and 7 feet. The action levels represent concentrations that could enter the UICs and not be reasonably likely to have an adverse affect on groundwater quality in accordance with OAR 340-040.

1.3 UIC Conceptual Model

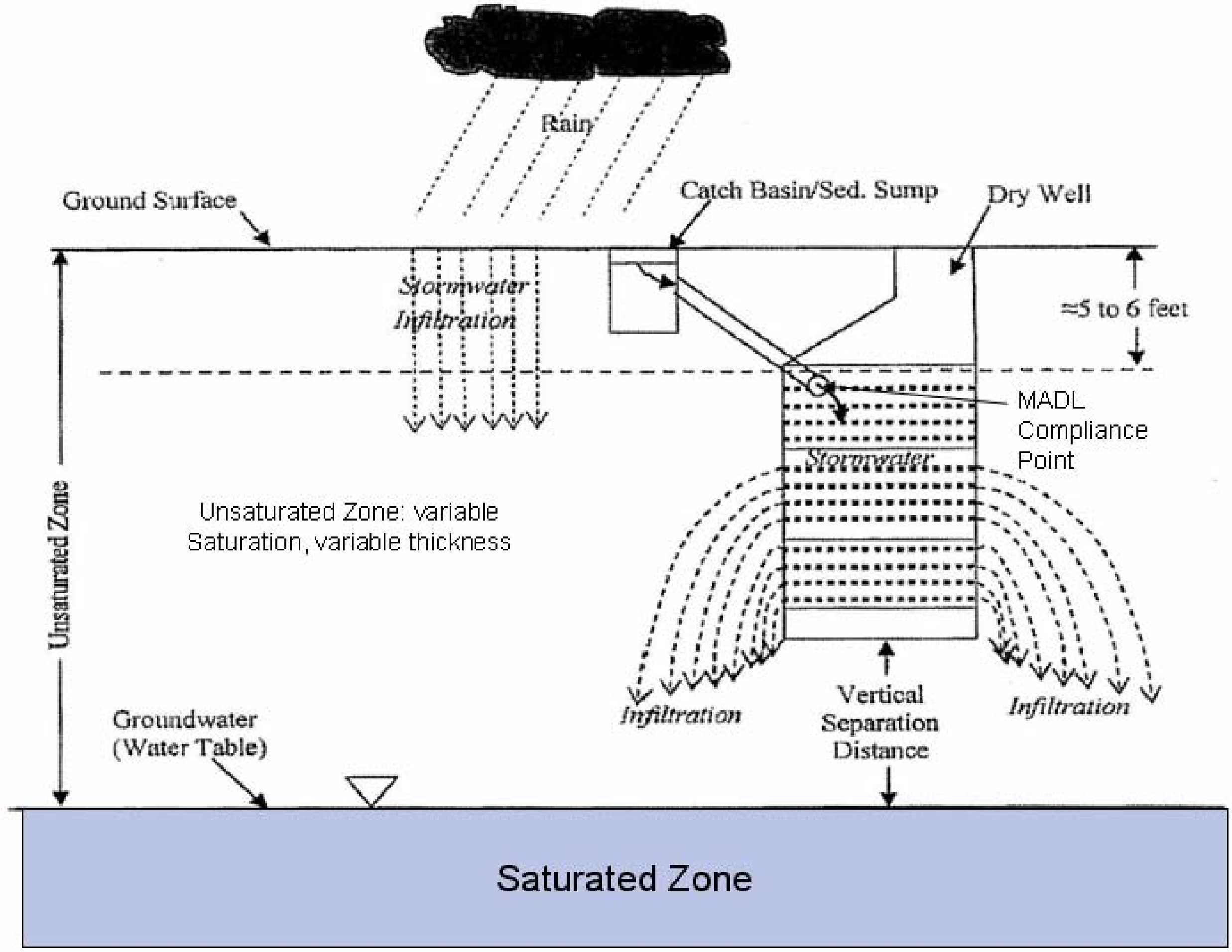
This document presents the technical methodology used to evaluate the fate and transport of pollutants entering individual UICs at various separation distances and was prepared in accordance with the Groundwater Protectiveness Demonstration described in the UICMP - *Evaluation and Response Guideline No. 6* (BES, 2006a). As used here and described in the UICMP, a Groundwater Protectiveness Demonstration is a fate and transport analysis performed to evaluate and document whether stormwater pollutant concentrations entering the UIC are reduced to levels that meet OAR 340-040 at the point the infiltrated stormwater reaches groundwater.

UICs are used to manage stormwater by infiltrating precipitation (e.g., stormwater runoff) into the ground. For many areas east of the Willamette River, UICs are the only form of stormwater disposal available. UICs are an essential element of the City's comprehensive watershed management program to use stormwater as a resource by infiltrating it back into the ground. Infiltration of stormwater into the ground maintains aquifer recharge and promotes watershed health in an urbanized area. The conceptual site model for stormwater infiltration fate and transport calculations is shown schematically in Figure 1.

A typical City-owned UIC system consists of a stormwater inlet (e.g., catch basin), sedimentation manhole, and the UIC. The sedimentation manhole is a solid concrete cylinder generally 3 to 4 feet in diameter and 10 feet deep, located upstream of the UIC. Sedimentation manholes provide pretreatment prior to stormwater discharging to the UIC, by allowing sediment in stormwater to settle before entering the UIC and by preventing floatables (e.g., debris, oil, and grease) from flowing into the UIC. Water leaves the sedimentation manhole though a "bent elbow" drainpipe that extends below the water surface to the UIC.

UICs are generally 4 feet in diameter and range in depth from about 2 feet to 40 feet. Most of the City-owned UICs are approximately 30 feet deep. In accordance with the permit, the compliance point for pollutants in stormwater is the EOP where stormwater is discharged into the UIC downstream of any pretreatment device (e.g., sediment manhole).

Figure 1: UIC Conceptual Model (modified from DEQ, 2005)



As shown in Figure 1, stormwater discharges into the UIC system, passes through perforations in the UIC cylinder, infiltrates through the unsaturated zone, and recharges groundwater. For the purposes of this analysis, it is assumed that infiltration through the unsaturated zone may occur under near-saturated conditions due to the assumed near-constant infiltration of water during the rainy season. Prior to entering the unsaturated zone, settleable particulate matter (which pollutants may be sorbed to) fall out of suspension into a sump (e.g., sediment trap ring) at the bottom of the UIC. During transport through the unsaturated zone, pollutant concentrations attenuate due to degradation, dispersion, volatilization, and retardation. Therefore, pollutant concentrations in the unsaturated zone beneath the UIC are lower than pollutant concentrations measured at the stormwater inlet.

1.4 Memorandum Organization

This technical memorandum is organized as follows:

Section 1: Introduction, outlines the conceptual model for stormwater infiltrating a UIC, and describes the City-owned UICs that have a limited separation distance. It also provides a brief description of the primary sections of this technical memorandum.

Section 2: Separation Distance Review, provides the definition of separation distance, permit requirements, and recommendations and requirements from other states**.**

Section 3: Pollutant Selection for Fate and Transport Analysis, provides the rationale for pollutant selection for fate and transport analysis.

Section 4: Bacteria Attenuation in the Unsaturated Zone, provides a literature review on separation distances required for septic systems, field study results from the literature, and an analysis of bacteria transport in the unsaturated zone using a probabilistic model, developed by the U.S. Environmental Protection Agency (EPA).

Section 5: Technical Approach for Evaluation of Vertical Separation Distance, describes the approach and site-specific parameters used to assess the fate and transport of the selected representative pollutants through unsaturated soil to determine at what influent concentrations groundwater quality is protected in accordance with OAR 340-040 at various separation distances.

Section 6: Results of the Separation Distance Analyses, presents the results of the quantitative groundwater protectiveness evaluation of vertical separation distances less than 10 feet.

Section 7: Pollutant Action Levels, describes stormwater influent action levels that are protective of groundwater quality for vertical separation distances of 5 feet and 7 feet. These action levels may be used for determining when further evaluation, response actions, or corrective actions may be required.

Section 8: Findings and Recommendations, summarizes the findings of the vertical separation distance analyses and provides recommendations for using results of this analyses in demonstrating groundwater protection at selected Category 3 UICs with vertical separation distances of less than 10 feet and in developing the Generic Groundwater Protectiveness Demonstration.

Section 9: Works Cited.

2 Separation Distance Review

This section defines vertical separation distance, provides the permit requirements for separation distance in City-owned UICs, and presents the framework for how the analyses presented in this technical memorandum may be used to demonstrate that a vertical separation distance of less than 10 feet (i.e., 5 and 7 feet) is protective of groundwater quality in accordance with OAR 340-040. As defined by the permit, a Groundwater Protectiveness Demonstration (i.e., risk assessment) may be an appropriate corrective action. This section also introduces a map showing the locations of City-owned UICs with separation distances of less than 10 feet.

2.1 WPCF Permit Separation Distance Requirements

Unsaturated zone soils function as part of the stormwater quality treatment system (DEQ, 2005). To assure that the unsaturated zone functions as intended, a vertical separation distance sufficient to remove pollutants must be present between the bottom-most perforation of the UIC and the seasonal high groundwater level. The separation distances included in the permit are based on the ability of unsaturated soils to remove bacteria (e.g., fecal and *E. coli* bacteria) from stormwater before it reaches the groundwater and are assumed to adequately remove stormwater pollutants.

As mentioned above, City-owned UICs are regulated by WPCF Permit No. 102830, issued to the City in June 2005 (DEQ, 2005). Schedule F, Section 5(tt) of the permit states:

> "***Separation Distance*** means the distance in the unsaturated zone, confinement barrier or engineered filtration medium between the bottom of the public UIC and groundwater, and prevents pollutants from reaching groundwater. Under no circumstance shall a separation distance between groundwater and the bottom of the public UIC be less than 5 feet, unless specifically authorized in writing by the Department, that protects groundwater to primary drinking water regulations under the federal Safe Drinking Water Act (SDWA), or complies with the groundwater protection requirements specified in Oregon Administrative Rules (OAR) 340-40, including Concentration Limit Variances (CLVs) established as a permit condition under OAR 340-040-0030, or may protect human health. For this permit, minimum separation distance between the bottom of a public UIC and groundwater and must meet the following conditions to physically remove fecal coliform and *E. coli* bacteria established in Table F-1. "

TABLE F-1
Minimum Separation Distance for Biological Filtration

Depth from Ground Surface to Bottom of UIC	Minimum Separation Distance Between Bottom of UIC and Groundwater[1]
≤5 Feet	5 Feet
>5 Feet	10 Feet

[1] For a dry well, it is distance measured from the last perforation, or joint with bottom sediment trap ring within the dry well. If there is no sediment rap ring, then the distance is measured from the bottom of the dry well. For a soakage trench, French drain, or other infiltration trench, it is the distance measured from the trench bottom.

The basis for the conclusion that groundwater is not endangered at a 10 foot separation distance is based on biological filtration and is described in DEQ's *Fact Sheet and Class V Underground*

*Injection Control (UIC) WPCF Permit Evaluation (*DEQ, 2005) in *Section 4.3.2 Bacteria Monitoring Exclusion*. DEQ concludes that:

> " …bacteria (fecal coliform and *E. coli*) in stormwater discharge to a UIC in the Permittee does not pose an endangerment to groundwater quality, provided minimum separation distances established in the Permit are maintained."

The permit-required separation distances are supported by DEQ's review of groundwater quality data in areas of Portland served by UICs for stormwater management. DEQ found that the groundwater data demonstrated bacteria were not present in groundwater. The data reviewed includes a historic period in Portland when approximately 25 million gallons a day of raw sewage were discharged into on-site septic systems (e.g., cesspools and septic tanks and drainfields). In addition, DEQ presents a case study of an on-site septic system in La Pine, Oregon (located in Central Oregon). The systems in La Pine discharge into rapidly draining soils with groundwater at depths of less than 10 feet below ground surface (bgs). No fecal coliform or *E. coli* bacteria were detected in groundwater collected from the drainfield monitoring wells. It is assumed that the bacteria concentrations discharged from raw sewage into these systems would be significantly higher than bacteria concentrations present in urban right-of-way runoff. Because the concentration of bacteria in stormwater is significantly lower than that found in septic systems, these required separation distances should be considered conservative for stormwater UICs.

2.2 City-owned UIC Vertical Separation Distances

Vertical separation distances for City-owned UICs were initially evaluated and reported in the permit-required *Systemwide Assessment* report (BES, 2006d). Separation distances were calculated using depth to groundwater estimates generated by the United States Geological Survey (USGS). The USGS also estimated seasonal groundwater depth variations, in a cooperative study with the City of Portland, DEQ, and other local governments (USGS, 2008). USGS has provided the City with several draft versions of the estimated groundwater depths since the *Systemwide Assessment* report was submitted. Final depth to groundwater values were provided to the City by the USGS in April 2008.

UICs with potentially inadequate separation distances were identified in the *UICMP Annual Report: Year 1* (BES, 2006e) and UICs determined to be non-compliant with permit conditions were identified in the *UICMP Annual Report: Year 2* (BES, 2007b). These non-compliant UICs are referred to as Category 3 UICs and require corrective action. The locations the Category 3 UICs are shown in Figure 2.

Corrective action, as defined by the permit, can consist of groundwater monitoring, risk assessment using DEQ-approved protocols, or structural retrofitting of the UIC. The purpose of this document is to evaluate whether a vertical separation distance of less than 10 feet (i.e., 5 and 7 feet) is protective of groundwater quality and whether a Groundwater Protectiveness Demonstration (i.e., risk assessment) may be an appropriate corrective action for selected Category 3 UICs. The term "risk assessment," as referenced in the permit and as used in the UICMP, is an evaluation and/or demonstration that stormwater discharging into City-owned UICs complies with OAR 340-040 and does not adversely affect the beneficial uses of

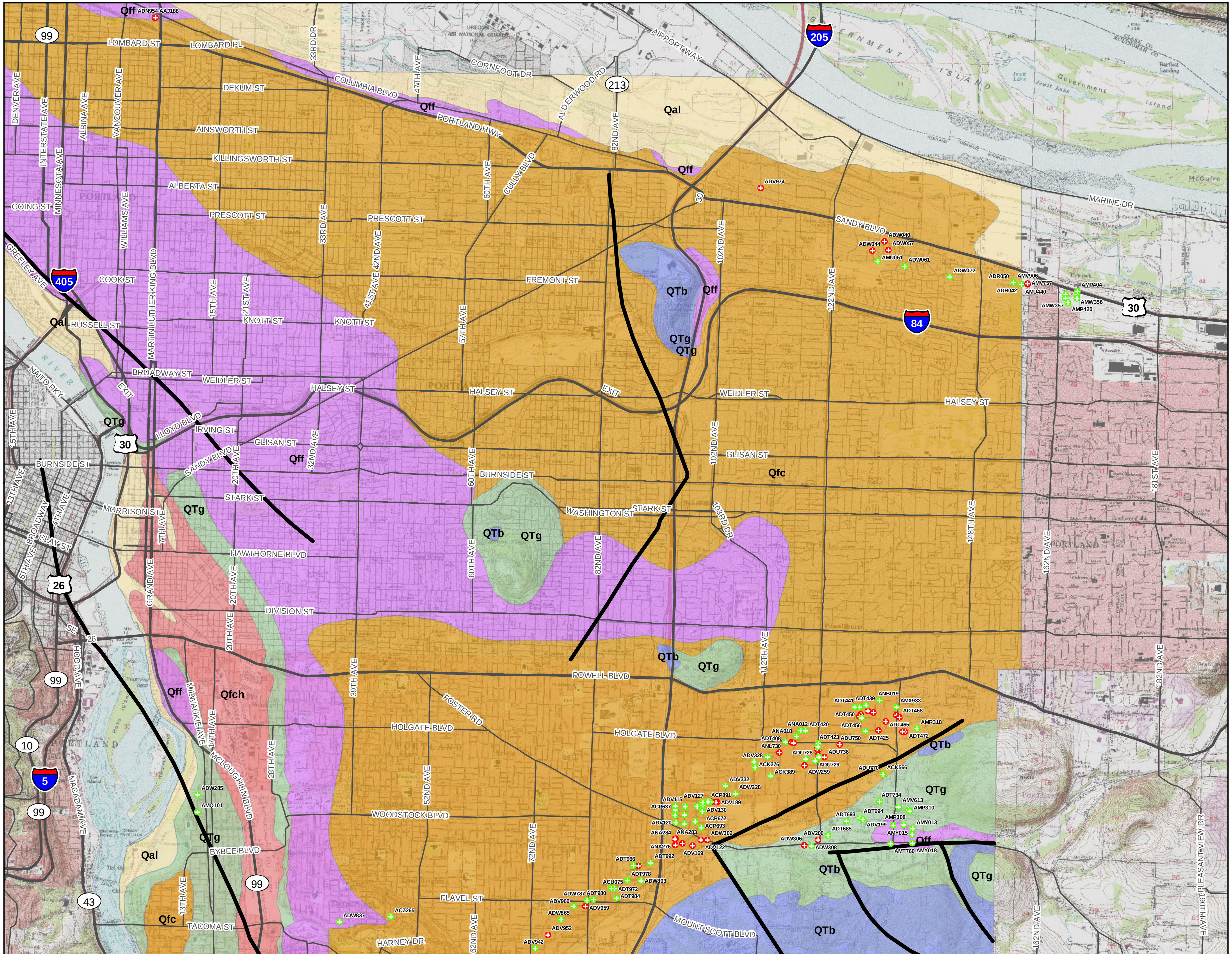


FIGURE 2

Geology and Category 3 UICs

BES UIC Program

LEGEND

Geologic Units

Alluvial Aquifer

- Qal - Alluvium

Unconsolidated Gravel Aquifer

- Qff - fine-grained facies
- Qfc - coarse-grained facies
- Qfch - channel facies

Troutdale Gravel Aquifer

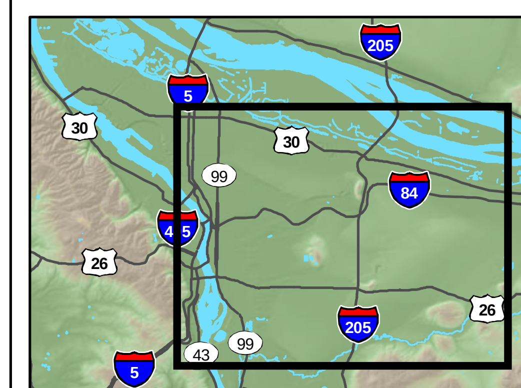
- QTg - Troutdale Formation gravels
- QTb - Boring Lava
- Faults

UICs - Groundwater Separation Distance

- 5 feet - 7 feet with UIC depth
- 7 feet - 10 feet with UIC depth
- Freeways and Highways
- Major Roads

NOTES

1) Geology modified from DOGAMI (1990) OFR 0-90-2
2) Surficial geology (i.e. <30 feet bgs) not shown
3) Artificial fill (Qaf) not shown



N

Scale

1:54,000

0 2250 4500 6750 9000

Feet

MAP NOTES:

Projection: Oregon State Plane North Zone
Datum: North American Datum of 1983
Date: May 30, 2008
Data Sources: City of Portland BES, DOGAMI, ESRI, Aerial Photos taken in July 2005 by USDA

GSI Water Solutions, Inc.

File Path: P:\110 - BES\010 - UIC Program (EnviroIssues)\Project_GIS\Project_mxds\Figure2_Geology_and_Category_3_UICs_all_UICs.mxd, Date: May 30, 2008 11:52:04 AM groundwater, and that any such discharges are protective of human health and the environment.

Corrective actions for Category 3 UICs will be identified, evaluated, and selected in accordance with the *Corrective Action Plan* (BES, 2006b) and the *Systemwide Assessment Follow-up Actions* workplan (BES, 2006f). Potential corrective actions for the Category 3 UICs were described in the *UICMP Annual Report: Year 2* (BES, 2007b) as follows:

- **< 5 feet vertical separation distance**: Corrective actions would focus on increasing the vertical separation distance by installing new shallower UICs or horizontal UICs, or utilizing surface infiltration features (e.g., swales, curb extensions) combined with overflows to new shallow UICs or an existing piped system as needed to meet the design storm.
- **>5 feet and < 7 feet separation distance**: Corrective actions may include increasing the separation distance as described above or reducing the required separation distance for specific UICs or groups of UICs through a Groundwater Protectiveness Demonstration as described in the UICMP (BES, 2006a).
- **> 7 feet separation distance**: Corrective actions would focus on reducing the required separation distance for specific UICs or groups of UICs through a groundwater protectiveness demonstration as described in the UICMP (BES, 2006a).

This document develops the technical methodology to determine if pollutants in stormwater are attenuated during transport through the unsaturated zone (i.e., soils above the water table and below the point of entry into the UIC) using separation distances of 5 and 7 feet. The pollutant fate and transport analyses methodology is then used to evaluate whether these separation distances (5 and 7 feet) are protective of beneficial uses of groundwater and public health and the environment as required by OAR 340-040.

Separation distance is defined by the permit as the approximate distance between the bottom-most perforations in the UIC and the approximate seasonal-high groundwater level. The separation distance is calculated using the following formula:

$$S_d = GW - UIC_{perf}$$

where,

S_d = separation distance (feet);
GW = estimated depth to seasonal high groundwater (feet bgs);
UIC_{perf} = estimated depth to bottom-most UIC perforation in feet bgs (note: the bottom most perforation is defined as the bottom of the UIC minus 2 feet. Two feet are added to the separation distance to account for the standard depth of the sediment trap ring based on a standard City UIC design.)

The City used Geographic Information System (GIS) analysis to estimate the vertical separation distance between the bottom of the UIC and groundwater at each UIC location using depth to groundwater and seasonal groundwater variation data from the USGS (2008) and UIC completion depths from the City's Hansen database. The process for estimating the depth to groundwater is described in the *Systemwide Assessment* report (BES, 2006d).

Separation distance estimates are considered conservative (i.e., estimated minimum distance) as used in fate and transport analyses, because the distances are based on the seasonal high water table. The seasonal high water level is not representative of the groundwater levels over the entire year. As shown in Figure 3, which presents a hydrograph for a well located near Holgate Lake over a 10-year period between 1998 and 2008, the water table fluctuates seasonally between 5 and 10 feet. Seasonal high water levels occur for less than month in most years (i.e., < 10% of the year). UICs receive stormwater runoff throughout the year when the separation distance would be increased. The mean water level is reported by the USGS to be approximately 3 feet less than the seasonal high for much of the Portland area. Further, as shown in the conceptual model in Figure 1, stormwater entering a UIC can infiltrate soil throughout its perforated length (i.e., above the base of the UIC) providing additional travel distance over which significant pollutant attenuation can occur.

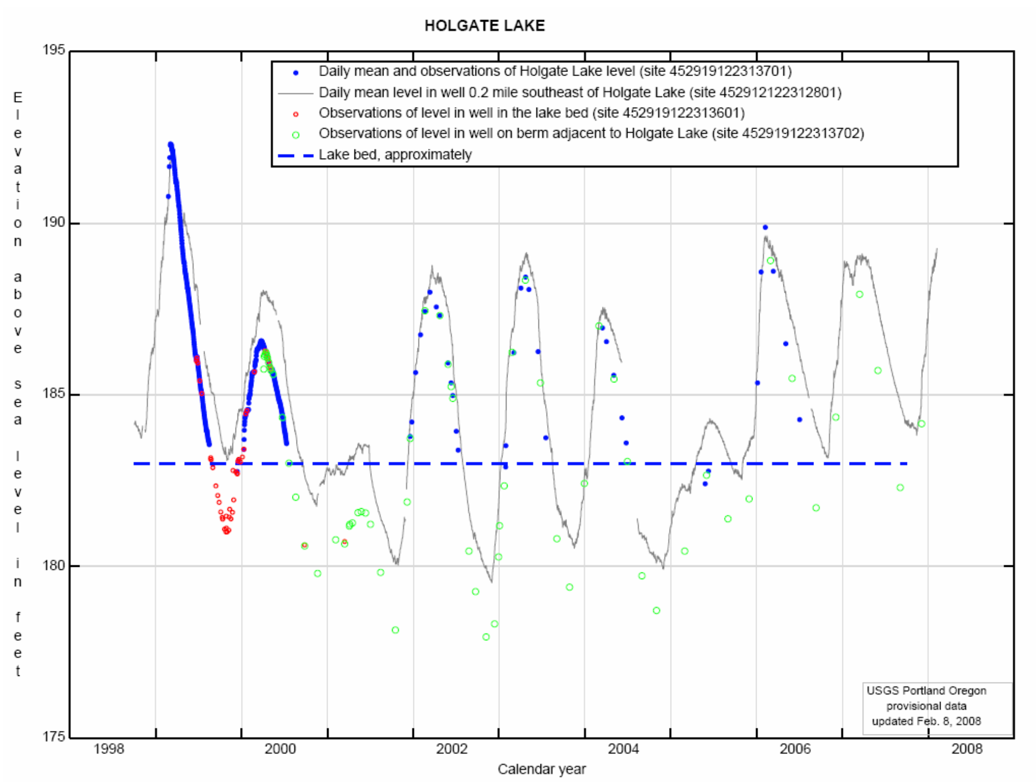


Figure 3: Groundwater Hydrograph from Holgate Lake Area in Portland

2.3 Review of Separation Distances in Other States

Vertical separation distance guidelines/requirements for septic systems in other states were researched and vary from 1 to 6 feet as presented in Table 1. This section summarizes the results of that research.

The EPA Design Manual (EPA, 1980) recommends a minimum unsaturated separation distance of 2 to 4 feet between the UIC bottom and the water table. EPA (1980) and Hansel and Machmeier (1980) report that bacteria are adequately removed within 3 to 4 feet. Bouma (1972, in Hagedon review 1981) found that fecal coliform is reduced to background within 2 feet of the surface.

In Queensland, Australia, vertical separation distances of unsaturated soil to the water table are 1.2 meters (3.9 feet) for primary effluent; 0.6 meters (2 feet) for secondary effluent and 0.3 meters (1 foot) for advanced secondary effluent (Department of Local Government & Planning, 2004). Stormwater concentrations of bacteria are more similar to those in secondary or advanced secondary effluent; thus, approximately 1 to 2 feet would be required for stormwater based on bacteria.

The Health Department in England (Cave and Kolsky, 1999) recommends that the bottom of a septic pit should be 2 meters (6.5 feet) above the water table, and at least 15 meters (50 feet) from any well used for drinking water purposes.

Vertical separation distance guidelines in other states specifically for stormwater in Class V UICs vary from 2 to 10 feet as presented in Table 2. (One exception is found in Washington, where guidance suggests that low treatment capacity soils should have a 25 foot vertical separation distance. This guidance recommendation is not based on quantitative analysis and is conservative because that distance is expected to be applied without site-specific sampling or analyses to determine actual separation distance protective of groundwater.) In some states, these vertical distances may be modified based upon data, engineering support, site-specific conditions, or best management practices (e.g., Alaska, Idaho, Washington). Several states referenced best professional judgment or EPA guidelines as the justification for setting vertical separation distances, and in only one case did a state contact cite a model or other mathematical equation for this purpose (Idaho)[1].

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[2] Idaho utilizes a modified Theis equation to compute a zone of endangering influence. This equation is based upon specified parameters and should be calculated for an injection time period equal to the expected life of the injection well or pattern. See Idaho CFR Title 40, Part 146.6.

Table 1: Minimum Vertical Separation Distances from Groundwater for On-Site Sewer Systems

Jurisdiction	Vertical Separation Distance (Feet)		References
Alabama	1.5	Min	Hall, Selden. 1990. Vertical Separation: A Review of Available Scientific Literature and a Listing from 15 Other States. Washington Department of Health, Office of Environmental Health and Safety, Olympia, WA.
Colorado	4	May be reduced if designed by a registered engineer and approved by the local board of health (domestic waste)	
Florida	3.5	To impervious layer	
Florida	2	To highest level of the water table	
Idaho	3-6	To water table or fractured bedrock, depending upon soil type; 4 feet to impervious layer	
Louisiana	2	To max level of water table	
Maine	1-2		
New Jersey	4		
North Carolina	1		
Oregon	1	To permanent water table	
Oregon	0.5	To impervious layer when bottom of trench is in rapidly or very rapidly permeable soil	
Oregon	0	To temp water table or permanent water table that is determined by GW study that degration of the GW and public health hazard will not occur and where water table is 2-feet BGS.	
Pennsylvania	4		
South Dakota	4		
Utah	2		
West Virginia	3		
Wisconsin	3		
Wyoming	4		
US EPA	2-4	minimum water-unsaturated soil thickness	U.S.EPA. 1980. Design Manual: Onsite Wastewater Treatment and Disposal Systems, EPA 625/1-80-012. U.S.EPA, Washington D.C.
Queensland, Australia	1.2 meters	Primary effluent	Department of Local Government and Planning. 2004. On-Site Sewerage Facilities: Guidelines for Vertical and Horizontal Separation Distance, January 2004
	0.6 meters	Secondary Effluent	
	0.3 meters	Advanced secondary effluent	
England	2 meters	Bottom of pit to water table	Cave, B. and Pete Kolsky. 1999. Groundwater, Latrines and Health, Task No. 163: Well Water Environmental Health at London and Loughborough.

Table 2: State UIC Program Minimum Separation Distances and Setbacks for Class V Stormwater Wells

State	Vertical Separation Distance (SD) (Feet)		Contact	Justification/ method/model	Reference	Notes	Setback/distance to drinking water wells
Alaska	4-6	Contact indicated 6-feet, but regs reflect 4-feet to max water table elevation, and 6-feet to impermeable layer.	Bill Reese, Wastewater Div of DEC 907-4269-7519	EPA's 2-feet was lacking, using 6-feet to be on safer side. Unaware of modeling or other technical justification.	Title 18 AAC, Chapter 80 for drinking water/horizontal sep. distance, Chapter 72 for stormwater/ vertical sep. distance	Distances can be waived with data and engineering support. Greater SD can be required based upon soil type, groundwater conditions, topo, geology, past experience, "or other factors".	200-foot maximum (for Class A public which serves >25 people at least 60 dys of the yr)
California (4,000)	5		Liz James, USEPA Region 9 415-972-3537			Contact thinks the Lahontan Regional Water Resources Control Board uses 5-feet	
Idaho (5,000)	10	Between bottom of well and seasonal high groundwater, in alluvial formations. Wells in fractured basalt are exempt from SD.	Brian Regan, ID Dept of Water Resources 208-287-4934	For distance to drinking water wells: zone of endangering influence may be based upon the parameters listed and should be calculated for an injection time period equal to the expected life of the well or pattern. Suggests a modified Theis equation (see CFR Title 40, Part 146).	Title 37, Chapter 3	Director may reduce SD requirements if the quality of the injected fluid is improved through Best Management Practices/treatment.	Distance is based upon the avg. volume injected during the week of greatest injection in an average water year (cfs), and ranges between an 8-foot radius for 0-0.20 cfs, to a 4,000-foot radius for 4.01-5 cfs. Contact indicated that this is based upon studies from 20 years ago, which they are trying to recreate (Title 37, Ch. 3, p.17).
Illinois	N/A	For class I UICs only. Well must go below the lowest USDW	Bur Filson 217-782-6070				200 to 400-feet. 200-feet is typical of state. 400-feet is required in unconsolidated sand and gravel. 75-feet required for residential septic.
Maine			Erich D. Kluck, Division of Water Resource Management, Maine DEP, 287-7814 or erich.d.kluck@maine.gov .			The DEP will be proceeding with a major revision to the UIC Rules, the first since 1983. The UIC Rules cover the subsurface disposal of all wastes not covered by the Subsurface Rules, primarily industrial and process wastes with characteristics dissimilar to domestic wastewater. Sections 203.1 and 203.2 of the Subsurface Rules CMR 241 presently define which Agency has jurisdiction over a particular waste.	
Maryland	2-4	From seasonal high water table	No contact	No justification is given	EPA, 1989, Stormwater Drainage Well Guidance, Interim Final, May 1998.	EPA references Maryland DOE, 1984	100 feet from any water supply well
Massachusetts	2	Between bottom of structure and seasonal high groundwater (draft standard)	Ken Pelletier, UIC Program Coordinator 617-348-4014; Thomas Maguire, Regional Coordinator Wetlands Program (email)	The 100 feet was established based on our best guess to protect wetlands, septic systems, and drinking water supplies. One setback was set for each criteria, versus establishing different setbacks based on design flow, distance to high groundwater, slope of the hydraulic gradient, and thickness of the saturated zone. (T. Maguire email dated 12/21)	Draft MA DEP Stormwater Handbook (1997 handbook does not reference separation distance). This will be guidance on stormwater policy. Working to incorporate standards into UIC regulations.	Guidance on measures that the DEP considers acceptable for meeting the general requirements are set forth in the regs, but there may be acceptable alternatives for achieving compliance.	Private well: 100-feet; Public well: (with approved yields of >100,000 gpd), 400 feet radius, (tubular wellfields) 250-foot radius, all other public water system wells are determined by the following equation: radius in feet = (150 x log of pumping rate in gpd) - 350. This equation is equivalent to the chart in the Guidelines and Policies for Public Water Systems.

State	Vertical Separation Distance (SD) (Feet)		Contact	Justification/ method/model	Reference	Notes	Setback/distance to drinking water wells
Michigan (1,000)	N/A	USGS doesn't regulate Class V UICs for stormwater, only process brine return wells	Ray Vugrinovich 517-241-1532				
Nebraska	4	Between the bottom of the UIC casing and the static water level, seasonal high groundwater, or confining bed. May be increased based upon characteristics of injection fluid.	Marty Link NE DEQ 402-471-4270	No justification is given.	Title 122, Chapter 17, Section 5	It appears that UICs can be constructed into aquifers with certain construction standards.	100 feet minimum setback distance from domestic and other water wells; 1,000 feet minimum from community water wells; 25-100 feet from water lines. Setback distances are guidance and subject to siting review on a case by case basis.
New Jersey	4		Anthony Washington 609-633-7021		Rule is NJAC 7:14	4-feet is not "hard and fast" except if bacteriological issues. Also 4-feet for septic.	N/A
Rhode Island	3-4	From base of the infiltration system to the maximum groundwater elevation; 5 feet to bedrock. If the infiltration rate is greater than 7.5 inches per hour; SD should be increased to 4 feet.	No contact	No justification is given.	Regulation: Rhode Island, September 1993; Stormwater Design and Installation Manual	EPA references Rhode Island DEM, 1994	400 feet from public wells; 100 feet from private wells. May vary depending on hydrogeologic conditions.
Texas	N/A		David Murray 512-239-6080		UIC Rule is Chapter 331.132		
Vermont	3	From bottom of UIC basin to seasonal high water table or bedrock	Allison Lowry (UIC); Padraick Monk (Stw Program) 802-241-1453	Justification unknown	Stormwater Management Rule - Chapter 18 - and VT Stormwater Management Manual; UIC Rule - Chapter 11		100-feet horizontal setback from water supply well
Washington (22,000)	3-5	Between base of UIC well and the seasonal high water table, bedrock, hardpan or other low permeability layer.* High treatment capacity classification (can go to 3-feet if GW mounding analysis, volumetric water holding capacity of the zone receiving water, and the design on the overflow/bypass structures are judged adequate.)	Mary Shaleen Hansen, Ecology, 360-407-6143	Mary was unaware of any modeling, etc. used to develop SDs. Per Mary, Karen DiNicola (from the guidance team) indicated it was BPJ.	Guidance for UIC Wells that Manage Stormwater. Prepared by Ecology Water Quality Program. 12/06	Each of the treatment zones is associated with a vadose zone layer description - see table 5.2 below. From guidance: If 5-feet cannot be met, can use demonstrative approach: May consider 3-ft SD if pretreatment requirements are met, and a groundwater mounding analysis, volumetric water holding capacity of the zone receiving water, and design of the overflow/bypass structure are judged adequate to prevent overtopping and meet site suitability criteria.	>100-feet from drinking water or spring used for drinking water supply (WAC 173-160-171). There may be local siting conditions (e.g. setbacks) especially at critical areas - may have 6 month, 1 year, 5 year, or 10 year time of travel zones.
	10	Med treatment capacity classification					
	25	Low treatment capacity classification					
	None	Minimum thickness not applicable					

Notes

[1] (#) Number in parentheses indicates the number of stormwater UICs in 1999 per U.S. EPA (1999) Class V UIC Study, Volume 3, Stormwater Drainage Wells; EPA/816-R-99-014. p.2.

3 Pollutant Selection for Fate and Transport Analysis

Selected stormwater pollutants are identified in this section for use in the fate and transport analyses described in Section 5. The selected pollutants are representative of the Common Pollutants, Priority Pollutant Screen, and ancillary pollutants that are monitored under the City's WPCF permit (see the *Stormwater Discharge Monitoring Plan,* BES, 2006g). The selected pollutants will be used as surrogates for similar pollutants (i.e., within the same general pollutant categories) to evaluate potential adverse impacts to groundwater associated with urban stormwater discharge to UICs.

3.1 Pollutant Selection Process for Fate and Transport Analysis

A subset of pollutants was selected to be representative of the Common Pollutants, Priority Pollutants, and ancillary pollutants that are monitored and discharged to City-owned UICs under the City's WPCF permit. This subset of pollutants was selected, based on consideration of the following factors:

- Toxicity;
- Frequency of detection, as determined from the results of the City's Year 1 and Year 2 UIC stormwater discharge monitoring program;
- Mobility; and
- Persistence in the environment.

Pollutants were selected to represent each of the following six broad chemical categories monitored under the permit (see the *Stormwater Discharge Monitoring Plan,* BES, 2006g):

- Volatile organic compounds (VOCs);
- Semivolatile organic compounds (SVOCs):
- Pesticides/Herbicides;
- Metals;
- Polynuclear aromatic hydrocarbons (PAHs); and
- Miscellaneous.

The following process was used to select pollutants according to toxicity, mobility, persistence, and frequency of detection, as a basis of selection for further analysis:

1) Pollutants were assigned a toxicity category, based upon Oregon DEQ Risk Based Concentrations (RBCs) for Groundwater Ingestion and Inhalation from Tapwater, Residential (DEQ, 2007) and EPA Region 6 Human Health Medium-Specific Screening

Values (EPA, 2007) and EPA Maximum Contaminant Levels (MCLs) (EPA, 2008a) for public drinking water systems, where available. Pollutant toxicity was ranked as follows; the lower PRG concentrations correspond to higher toxicity (i.e., potential adverse effects on human health):

- High (PRG <10 μg/l);
- Medium (PRG 10-100 μg/l); or
- Low (PRG >100 μg/l).

2) Pollutants were assigned a mobility category, based on their EPA groundwater mobility ranking value (for liquid, non-karst). Mobility values were obtained from EPA's *Superfund Chemical Data Matrix Methodology*, Appendix A (EPA, 2004). In the absence of an EPA mobility ranking value, mobility categories were estimated, based upon best professional judgment and knowledge of general pollutant characteristics. Chemical mobility was ranked as:

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

   Pollutant solubility in water was also considered as an independent check on the EPA mobility ranking. The review of pollutant solubilities did not result in modifying pollutant selection.

3) Pollutants were evaluated based on their persistence in the environment. Persistence represents the time a pollutant may remain in the environment. This was primarily evaluated using available degradation rates. Persistence was ranked, based on the pollutants' estimated half-life (days), using information provided in *Canadian Environmental Modeling Center Report No. 200104* (Mackay, 2001), as follows:

   - Low (0-49 days^{-1});
   - Medium (50-499 days^{-1});
   - High (500 and greater days^{-1}); or
   - Infinite (does not break down).

4) Pollutants were evaluated with respect to frequency of detection, as determined by the average frequency of detection during Years 1 and 2 of the City's stormwater discharge monitoring program (see Year 1 and Year 2 *Annual Stormwater Discharge Monitoring Reports,* BES, 2006c; BES, 2007a). Frequency of detection was ranked as follows:

   - High (75-100%);
   - Medium (21-74%); or
   - Low (<20%).

The information used to evaluate pollutants and assign rankings for the categories described above is presented in Table 3. Pollutants were selected by this ranking process in a manner that would include pollutants from each of the six broad chemical categories listed above. For each of these six chemical groups, the pollutant characteristics were considered in the following order:

1) Frequency of detection [Pollutants in the low category (58 pollutants) were not considered further. Fifty-four (54) of these pollutants were detected in < 5% of samples.];
2) Mobility (Pollutants in the low category were not considered further.);
3) Persistence; and
4) Toxicity.

In the event that multiple pollutants collectively scored in a similar manner, pollutants from the Common Pollutant and Priority Pollutant lists were selected before those from the ancillary pollutant list.

3.2 Pollutants Selected for Fate and Transport Analysis

Based upon the above process, the following pollutants were selected for use in the analysis of vertical separation distance:

- VOCs: Toluene
- SVOCs: PCP
DEHP
- PAHs: Benzo(a)pyrene (BaP)
Naphthalene
- Pesticides/Herbicides: 2,4-D
Methoxychlor
- Metals: Copper
Lead

Note: No representative pollutants were selected from the miscellaneous category, which includes nitrates and cyanide.

The objective of the pollutant selection process was to identify pollutants that are representative of:

- Pollutants most commonly detected by the City's UIC monitoring program;
- Various pollutant categories (VOCs, PAHs, metals, etc.) monitored under the permit; and

- Other pollutants detected in stormwater within the broad category (e.g., VOCs) of the selected pollutant, and to determine if the selected pollutant (e.g., toluene) can be used as a surrogate to evaluate whether other pollutants (e.g., benzene, xylenes) within the given category (e.g., VOCs) are protective of groundwater.

Selection of representative pollutants for the six groups was fairly “clear-cut”, with the exception of the PAHs. Many PAHs have a high frequency of detection and high toxicity, but low mobility. Benzo(a)pyrene was selected because it is the only PAH on the Common and Priority Pollutant lists (all other PAHs are considered ancillary pollutants). Naphthlene was also selected because it represents a “low molecular weight, noncarcinogenic PAH” and is relatively mobile compared to the other PAHs. While other PAHs exhibit similar frequencies of detection and have higher toxicity, they were not selected because they are less mobile and naphthalene can be used as a surrogate for these compounds (i.e., if naphthalene is determined to not adversely impact groundwater quality, then it can be determined that the other PAHs are unlikely to impact groundwater quality because they are less mobile at similar concentrations).

The selected pollutants are believed to be representative of the pollutants detected by the City’s UIC stormwater monitoring program and regulated by the permit. The pollutants will be used as indicators /surrogates of similar pollutants to evaluate potential adverse impacts to groundwater associated with urban stormwater discharge to UICs.

Table 3: Properties of WPCF Permit Pollutants Used in Selection of Representative Indicator Pollutants - Revised

	MADL	MCL[1]	DEQ RBCs for Ground-water[2]	Region 6 PRG[3]	ca/nc[4]	VOC (yes/no)[5]	Solubility (mg/L)[6]	EPA Mobility Ranking[7]	Mobility of Pollutant	Mobility of Pollutant (assumed)	Persistence (half-life [days])[8]	Persistence Ranking	Frequency of Detection (Years 1 and 2) (%)[9]	Pollutant Category[10]
	μg/L	μg/L	μg/L											
Common Pollutants														
Benzene	5	5	0.35	0.35	ca	y	1800	1	High		10	Low	1	V
Toluene	**1000**	**1000**	**2300**	**2300**	**nc**	**y**	**530**	**1**	**High**		**0.5**	**Low**	**37**	**V**
Ethylbenzene	700	700	1300	1300	nc	y	170	1	High		0.3	Low	1	V
Xylenes	10,000	10,000	210	200	nc	y	180	1	High		17.5	Low	1	V
Pentachlorophenol	**1**	**1**	**0.47**	**0.56**	**ca**	**n**	**2000**	**1**	**High**		**100**	**Medium**	**82**	**SV**
Di(2-ethylhexyl)phthalate	**6**	**6**	**4.1**	**4.8**	**ca**	**n**	**0.34**	**0.0001**	**Low**		**14**	**Low**	**62**	**SV**
Benzo(a)pyrene	**0.2**	**0.2**	**0.0029**	**0.0029**	**ca**	**n**	**0.0016**	**0.0001**	**Low**		**300**	**Medium**	**24**	**PAH**
Arsenic (Total)	10	10	0.038	0.045	ca	n	120000	0.01	Medium		infinite	infinite	100	M
Cadmium (Total)	5	5	18	18	nc	n	1700	0.01	Medium		infinite	infinite	41	M
Chromium VI	100	100	110	110	nc	n	600000	0.01	Medium		infinite	infinite	80	M
Copper (Total)	**1300**	**1300**	**1400**	**1400**	**nc**	**n**	**570**	**0.01**	**Medium**		**infinite**	**infinite**	**100**	**M**
Lead (Total)	**50**	**15**	**15**	**15**			**870**	**0.01**	**Medium**		**infinite**	**infinite**	**100**	**M**
Zinc (Total)	5000	NR	NR	11,000	nc	n	1400	0.01	Medium		infinite	infinite	100	M
Nitrate-nitrogen	10,000	10,000	NR	NR			High in soil & water	NR	High		infinite	infinite	30	O
Priority Pollutant Screen														
Antimony (Total)	6	6	NR	15	nc	n	170,000	0.01	Medium		infinite	infinite	97	M
Barium (Total)	2000	2000	7300	7300	nc	n	2,800	0.01	Medium		infinite	infinite	100	M
Beryllium (Total)	4	4	73	73	nc	n	84,000	0.01	Medium		infinite	infinite	12	M
Selenium (Total)	50	50	NR	180	nc	n	2.60E+06	1.0	High		infinite	infinite	3	M
Thallium (Total)	2	2	NR	2.6	nc	n	8600	0.01	Medium		infinite	infinite	0	M
Mercury (Total, inorganic)	2	2	11	3.7	nc	n	450	0.01	Medium		infinite	infinite	50	M
Cyanide (Total)	200	200	730	730	nc	n	NR	1.0	High		infinite	infinite	0	O
Alachlor	2	2	NR	0.84	ca	n	240	0.01	Medium		14	Low	0	P/H
Atrazine	3	3	NR	0.3	ca	n	70	0.01	Medium		100	Medium	0	P/H
Bis(2-chloroisopropyl)ether	0.8	NR	NR	NR	ca	y	1,700	NR	Medium		100	Medium	0	SV
Bis(2-chloroethyl)ether	0.3	NR	NR	0.0098	ca	y	17,200	NR	Medium		100	Medium	0	SV
Carbofuran	40	40	NR	180	nc	n	351	NR	Medium		110	Medium	0	P/H
Carbon Tetrachloride	5	5	0.17	0.17	ca*	y	790	1.0	High		265	Medium	0	V
Chlorobenzene	100	100	90	91	nc	y	470	1.0	High		110	Medium	<1	V
o-Dichlorobenzene	600	600	50	49	nc	y	4000	1.0	High		slow	High	0	V
p-Dichlorobenzene	75	75	0.48	0.47	ca	y	79	1.0	High		104	Medium	0	V
1,3-Dichlorobenzene	5.5	NR	15	14	nc	y	125	NR	High		42	Low	0	V
1,2,4-Trichlorobenzene	70	70	12	8.2	nc	y	35	1.0	High		104	Medium	0	V
Chlordane	2	2	0.16	0.19	ca*	n	0.056	0.01	Medium		812	High	0	P/H
Lindane[HCH(gamma)]	0.2	0.2	0.044	0.052	ca	n	7.3	1.0	High		980	High	0	P/H
2,4-D [1, 2]	**70**	**70**	**370**	**370**	**nc**	**n**	**4500**	**NR**	**High**		**15**	**Low**	**16**	**P/H**
Dinoseb	7	7	NR	37	nc	n	52	NR	High		24	Low	<1	P/H
Picloram	500	500	NR	NR	nc	n	430	NR	Medium		100	Medium	0	P/H
Dalapon	200	200	NR	1100	nc	n	800,000	NR	High		16	Low	0	P/H
Diquat	20	20	NR	80	nc	n	700,000	NR	Low		infinite	Infinite	0	P/H
Endothall	100	100	NR	730	nc	n	100,000	NR	Medium		10	Low	0	P/H
Glyphosate	700	700	NR	3700	nc	n	11,600	NR	Low		60	Medium	0	P/H
Ancillary Pollutants (Years 1 and 2)														
1,1,1-Trichloroethane	N/A	200	840	73000	nc	y	1300	1	High		200	Medium	1	V
1,2,4-Trimethylbenzene	N/A	NR	12	13	nc	y	NR	NR		High	20	Low	1	V
1,3,5-Trimethylbenzene	N/A	NR	12	12	nc	y	NR	NR		High	10	Low	1	V
2-butanone [MEK]	N/A	NR	NR	7100	nc	y	220,000	1	High		4	Low	1	V
2,4,5-trichlorophenoxy acetic acid [2,4,5-t]	N/A	NR	NR	370	nc	n	NR	NR		Medium	25	Low	1	P/H
2(2,4,5-Trichlorophenoxy) propionic acid [2,4,5-tp]	N/A	50	NR	290	nc	n	NR	NR		Medium	17	Low	<1	P/H
3-methylphenol	N/A	NR	NR	1800	nc	n	NR	NR		Low		Medium	3	SV
4-methylphenol	N/A	NR	NR	180	nc	n	22,000	0.01	Low			Medium	3	SV
4-Isopropyltoluene	N/A	NR	NR	NR			NR	NR		High	20	Low	5	V
Acetone	N/A	NR	NR	5500	nc	y	-0.24	1	High		4	Low	5	V
Acenaphthylene	N/A	NR	NR	NR			16	0.001	Low		50	Medium	2	PAH
Acenaphthene	N/A	NR	370	370	nc	y	3.6	0.0001	Low		60	Medium	<1	PAH
Acifluorfen	N/A	NR	NR	NR						Medium	60	Medium	<1	P/H
Anthracene	N/A	NR	1800	1800	nc	y	0.043	0.0001	Low		250	Medium	3	PAH
Bentazon	N/A	NR	NR	1100	nc	n	NR	NR		Low	20	Medium	1	P/H
Benzo(a)anthracene	N/A	NR	.029	0.029	ca	n	0.0094	0.0001	Low		400	Medium	24	PAH

	MADL	MCL[1]	DEQ RBCs for Ground-water[2]	Region 6 PRG[3]	ca/nc[4]	VOC (yes/no)[5]	Solubility (mg/L)[6]	EPA Mobility Ranking[7]	Mobility of Pollutant	Mobility of Pollutant (assumed)	Persistence (half-life [days])[8]	Persistence Ranking	Frequency of Detection (Years 1 and 2) (%)[9]	Pollutant Category[10]
	µg/L	µg/L	µg/L											
Benzo(b)fluoranthene	N/A	NR	.029	0.029	ca	n	NR	NR		Low	490	Medium	40	PAH
Benzo(ghi)perylene	N/A	NR	.0029	NR			0.00026	0.0001	Low		620	High	35	PAH
Benzo(k)fluoranthene	N/A	NR	.29	0.29	ca	n	0.0008	0.0001	Low		1525	High	19	PAH
Benzoic acid	N/A	NR	NR	150,000	nc	n				High	2	Low	3	SV
Benzyl alcohol	N/A	NR	NR	11,000	nc	n				High		Low	3	SV
Butyl benzyl phthalate	N/A	NR	NR	7300	nc	n	2.7	0.0001	Low		4	Low	2	SV
Carbon disulfide	N/A	NR	NR	1000			1200	1	High				1	V
Chloroform	N/A	NR	.18	0.17	ca	y	7900	1	High		100	Medium	2	V
Chrysene	N/A	NR	2.9	2.9	ca	n	0.0063	0.0001	Low		685	High	61	PAH
Dicamba	N/A	NR	NR	1100	nc	n	NR	NR		Medium	28	Low	3	P/H
Dichloroprop	N/A	NR	NR	NR			NR	NR		Medium	14	Low	1	P/H
Di-n-butyl phthalate (dibutyl phthalate)	N/A	NR	NR	3700	nc	n	11	0.0001	Low		12	Low	1	SV
Di-n-octyl phthalate	N/A	NR	NR	NR	nc	n	0.02	0.0001	Low		17	Low	7	SV
Dibenzo(a,h)anthracene	N/A	NR	.0029	0.0029	ca	n	0.0025	0.0001	Low		650	High	8	PAH
Diethyl phthalate	N/A	NR	NR	29,000	nc	n	1100	0.01	Low		30	Low	1	SV
Dimethyl phthalate	N/A	NR	NR	370,000	nc	n				Low	4	Low	<1	SV
Fluoranthene	N/A	NR	1500	1500	nc	n	0.21	0.0001	Low		300	Medium	54	PAH
Fluorene	N/A	NR	240	240	nc	n	2	0.0001	Low		50	Medium	4	PAH
Indeno(1,2,3-cd)pyrene	N/A	NR	.029	0.029	ca	n	0.000022	0.0001	Low		665	High	27	PAH
Methoxychlor	**N/A**	**40**	**NR**	**180**	**nc**	**n**	**0.045**	**0.0001**	**Low**		**270**	**Medium**	**7**	**P/H**
Methylene chloride	N/A	5	NR	4.3	ca	y	13,000	1	High		17	Low	<1	V
Naphthalene	**N/A**	**NR**	**6.2**	**6.2**	**nc**	**y**	**31**	**0.01**	**Low**		**10**	**Low**	**27**	**PAH**
nButylbenzene	N/A	NR	61	61	nc	y	NR	NR		High		Low	<1	V
Phenanthrene	N/A	NR	NR	NR			1.1	0.0001	Low		108	Medium	72	PAH
Pyrene	N/A	NR	1100	180	nc	y	1.4	0.0001	Low		1055	High	67	PAH
tertButylbenzene	N/A	NR	NR	61	nc	y	NR	NR		High		Low	<1	V

Table notes:

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

[1] 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] Preliminary Remediation Goal (PRG). U.S. EPA Region 6: Superfund. http://www.epa.gov/Region6/6pd/rcra_c/pd-n/screenvalues.xls (Accessed 5/16/08)

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

[5] Volatile organic compound (VOC)

[6,7] 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)

[8] 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

[9] City of Portland Stormwater Discharge Monitoring Report data (BES, 2006; BES, 2007)

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

4 Bacteria Attenuation in Unsaturated Soil

The vertical separation distance required by the permit is based on bacteria attenuation. This section addresses bacteria attenuation in the unsaturated soil from both a qualitative and quantitative approach. A literature review was conducted to determine if a separation distance of less than 10 feet would attenuate bacteria concentrations in the unsaturated zone and be protective of groundwater. In addition, an EPA model was used to demonstrate that bacteria attenuation within the first 5 feet of unsaturated soil is significant.

4.1 Literature Review of Bacteria Attenuation

The primary source of bacteria in urban stormwater is animal (e.g., dog, raccoon, rodent) and bird excrement washed off paved surfaces and yards (EPA, 1999). Fecal coliform levels in stormwater are reported to routinely exceed drinking water standards by a factor of 50 to 75 (Schueler, 1999). Pitt (1998) reports a mean fecal coliform concentration in urban stormwater runoff of about 20,000 colony forming units per milliliter (ml), based on 1,600 stormwater runoff samples. These samples were collected primarily during the EPA Nationwide Urban Runoff Program (NURP) study. The primary drinking water standard for total coliform is a monthly average of 1 colony forming unit/100 ml, with individual measurements permitted to exceed this standard; however, no fecal coliform may be present in any sample. The influent wastewater (septic waste) typically carries 1 to 2 million bacteria per liter[2].

The risks of bacteria reaching the groundwater table and migrating to a drinking water well are substantially affected by local hydrogeology. There are three zones of varying degrees of water saturation in the subsurface:

- Unsaturated zone (also referred to as the aeration zone);
- Saturated capillary zone (a layer of saturated soil where all the pore space is occupied by water at less than atmospheric pressure and is held by capillary forces between soil particles); and
- Saturated zone (where the water pressure exceeds atmospheric pressure).

The extent of the capillary zone depends on the soil type (i.e., grain size and particle size gradation) and soil density (i.e., packing of soil particles). In the Unconsolidated Gravels (UG; see Section 5.2) of east Portland where many of the City's UICs are located, the capillary zone is reported to be small, on the order of a few centimeters (USGS, 2008).

Pathogens (e.g., bacteria, viruses) do not travel farther or faster than the water in which they are suspended (Cave and Kolsky, 1999). Water typically flows very slowly in unsaturated soils, as flow occurs primarily along a thin and tortuous path along the surface of individual soil particles. Groundwater velocities in the unsaturated zone do not normally exceed 0.3 m/d

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[2] Cost-Effective Wastewater Treatment Process for Removal of Organics and Nutrients; http://www.case-environmental.org/technical.htm. Downloaded May 2, 2008.

(Cave and Kolsky, 1999). Flow is much more rapid in the saturated zone, as flow occurs directly through the soil pores. A key factor that affects the removal and elimination of bacteria from wastewater or stormwater is the time required for water to move through unsaturated soils from the point of discharge to the groundwater table. The major bacterial removal mechanisms in soil are (Alexander, et. al., 1991):

- Filtering/straining at the soil surface and at inter-grain contacts (i.e., between soil particles);
- Sedimentation;
- Sorption onto soil particles; and
- Inactivation (i.e., death).

In the case of stormwater discharged to UICs, the greater the distance between the UIC and shallow groundwater, the more time the bacteria resides in the unsaturated zone and the greater the chance the bacteria will be mechanically filtered or die. The UG/Upper Troutdale Gravel Aquifer (TGA; see Section 5.2) has a mixture of grain sizes ranging from clay to silt to gravel (Trimble, 1963; Madin, 1990), which are anticipated to provide effective filtering and sorption (DEQ, 2005). Bacteria, which have many nutritional requirements, usually die off once filtered from the nutrient rich effluent. Survival times of bacteria in the soil are generally reduced by higher temperatures, lower nutrient content, acidic conditions, lower moisture conditions, and the presence of indigenous soil microflora (Cantor and Knox, 1985).

The main mechanism limiting the movement of bacteria through the unsaturated zone appears to be filtration at the infiltration surface. During the years of stormwater infiltration into the UICs, it is expected that organic material (e.g., degraded/composted pollen, pine needles, leaves, bacteria) will accumulate in the soil adjacent to and below the UIC and form an area populated by microorganisms capable of capturing or destroy bacteria similar to, but not to the extent of, that found on sand filters used in some septic systems. This is supported by the observation by City maintenance staff that, within 10 years, the infiltration capacity of the UICs may be reduced by approximately 50% and tends to remain at that reduced capacity.

The removal of bacteria from wastewater is partially a biological process. Microorganisms remove bacteria, small particles, and pollutants from the infiltrating stormwater. Bacteria range in size from 0.2 micrometer (μm) to 5 μm (Azadpour-Keely, et. al., 2003) as shown in Figure 4. Ziebell and others (1974) found that within 1 foot of the zone beneath a septic system where microorganisms and organic carbon accumulate, the bacterial population fell close to the population level in a control soil sample. Caldwell and Parr (1937) found that fecal coliform were detected 10 meters (32 feet) away from a newly constructed latrine which was completed below the water table. Within 3 months, after a population of micro-organisms formed around the latrine, the bacterial dispersion reduced significantly. Further, as mentioned in Section 2, DEQ found that bacteria were not present in groundwater near septic systems delivering millions of gallons of bacteria-laden water to the subsurface in Portland.

Bacteria are readily adsorbed to clays under appropriate conditions, and the higher the clay content, the higher the removal. Soluble organic matter has been shown to compete with bacteria for adsorption sites on the soil particles (Lewis, et. al., 1980). However, with the low concentration of organic matter and bacteria in stormwater relative to sanitary system effluents, and the high number of sorption sites given the clay coatings described on clasts from the UGs and Upper TGA gravels (Hartford and McFarland, 1989, presented in the DEQ's *Fact Sheet* for the Permit, 2005), this is not considered an issue with stormwater UICs. In fact, it is assumed that the low concentrations of organic carbon in the stormwater will enhance the attenuation of organic and metal pollutants found in stormwater (see Section 5.3.4.3).

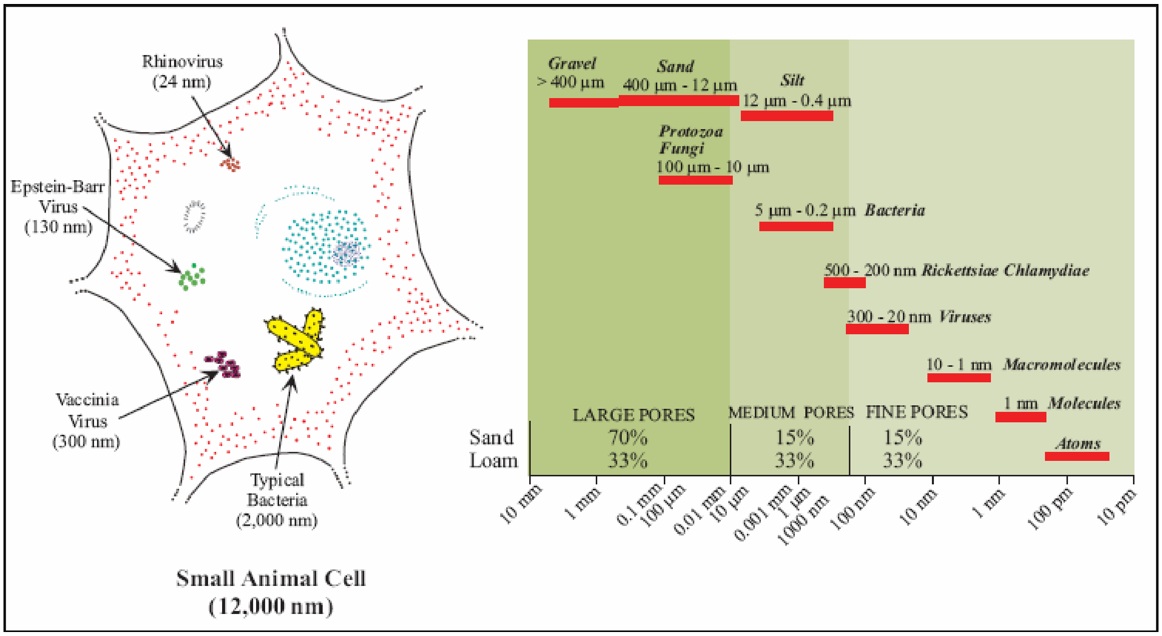

Figure 4: Comparison of size for various pathogens (EPA, 2002).

Information on bacterial survival in groundwater is limited. In general, it is accepted that:

- Bacteria survive in groundwater longer than in surface water due to the absence of sunlight and because competition for nutrients is not as great (Lewis, et. al., 1980).
- Moisture and temperature are the dominant factors controlling the survival of bacteria in unsaturated soil. Survival time is less in sandy soils than in soils with greater moisture holding capacity (e.g., silts). Bacteria have a shorter survival time in acid soils (pH 3-5) than in alkaline soils.
- Bacterial survival in an aerobic environment is low. Wilhelm and others (1994) conducted a study of the fate and transport of domestic septic system pollutants and found the sandy unsaturated zone beneath a septic system to be an environment in which oxygen is plentiful (i.e., aerobic). In the UG and TGA formations in which many of the City's UICs are completed (USGS, 2008; DEQ, 2005), the unsaturated soil is expected to be aerobic with a fairly fast rate of drainage and good oxygen exchange with the surface.
- Ionic strength of the inflowing solution, bacterial density, and velocity of water flow were found to have an effect on breakthrough on bacteria movement through sandy aquifer material (Alexander, et. al., 1991).

Based on the literature review presented above, it appears that a 5 foot vertical separation distance will attenuate the concentrations of bacteria typically found in stormwater and be protective of groundwater. This is supported by the review of vertical separation distance guidelines for on-site septic systems and UICs in other states (see Table 2).

4.2 Quantitative Analysis of Bacteria Attenuation

EPA developed a probabilistic model, *Virulo*, for predicting virus attenuation in the unsaturated zone (Faulkner, et. al., 2002). Probabilistic (i.e., Monte Carlo) methods are used to generate simulations of virus attenuation due to physical, biological, and chemical factors in unsaturated soil. The processes that are considered in the model include advection, dispersion, sorption, and inactivation.

Virulo is a one-dimensional, variably saturated, groundwater flow and contaminant transport model. *Virulo* generates the number of cases in which a certain level of virus attenuation (reduction) was or was not achieved. Attenuation is defined as the ratio of total mass leaving the system (layer) to the total mass entering it. The model generates a probability of failure to achieve a chosen degree of attenuation. For viruses, it is recommended that treatment achieve a 99.9 attenuation (also referred to as a "4-log" reduction) and this value is used as the model default.

Virulo makes use of a conceptual model that simplifies the types and rates of natural processes that govern variably saturated groundwater flow and virus transport. Simplifications and assumptions used in *Virulo* include the following (Faulkner, et. al., 2002):

- One-dimensional, vertical, uniform, variably saturated, ground-water flow;
- Gravity drainage only;
- Random soil water content representing random, instantaneous recharge from precipitation;
- No soil water hysteresis and water content is random, rather than cyclical, wetting and drying (results are very sensitive to the water content);
- Variably saturated groundwater flow through uniform layers of porous media without preferential flow pathways; and
- Virus transport may be simulated by linear sorption typical of dissolved contaminants rather than by colloidal filtration theory specific to colloidal particles.

In order to quantify uncertainty in model outputs, *Virulo* employs the Monte Carlo method. The method in *Virulo* works by assuming the values of the parameters vary randomly. It is suggested that the hydraulic parameters remain unchanged because of the variance-covariance matrix already computed for the twelve types of available soils modeled.

The *Virulo* model can be modified by adjusting input parameters to simulate bacteria by changing the size parameter to match those for bacteria which as significantly larger. For those parameters where values are not readily available for bacteria, the viral parameters were used. This is conservative, because bacterial indicators have a much higher inactivation rate as compared to viruses (Azadpour-Keeley, et. al., 2003). Investigations on the persistence of bacteria indicate that viruses survive for longer periods of time (Keswick, et. al., 1982; Yeager and O'Brien, 1979) because they are more resistant to environmental conditions. Die-off rate for *E. coli* was estimated by McFeters and others (1974) as 0.45 days^{-1} (as –log10 C_t/C_o) in groundwater with a pH of 7.5 and temperature range of 9-12^{o}C. Default sorption rates for viruses were used in absence of finding documented sorption rates for bacteria under the assumption that the viral sorption rates are conservative. See Figure 5 for bacteria input parameters used in the simulations.

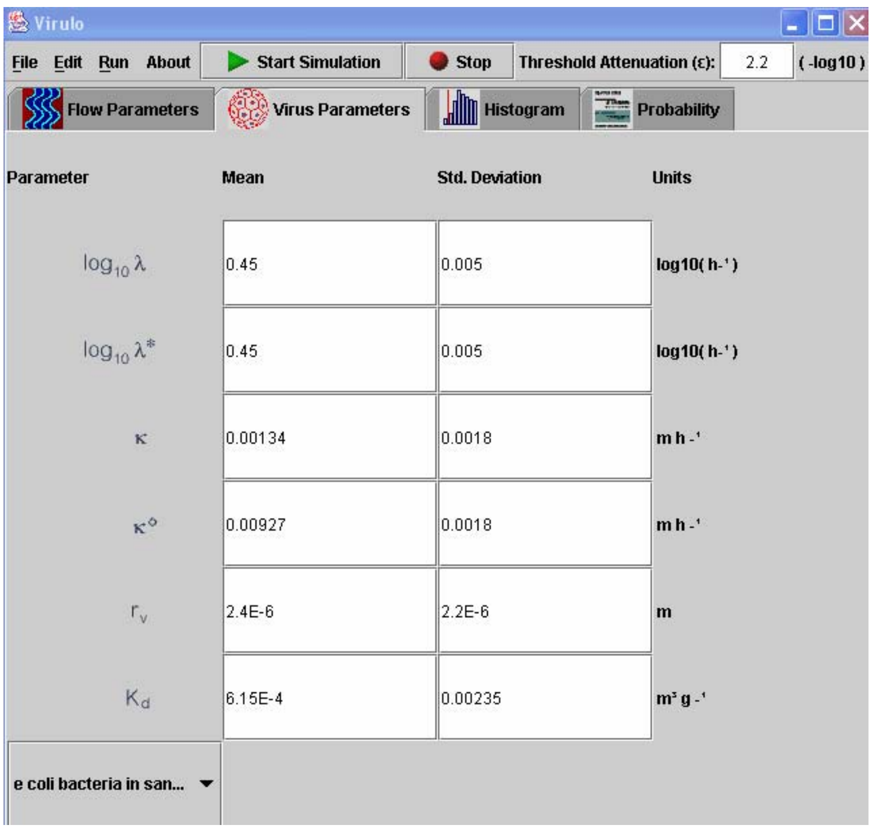

Figure 5: Bacteria Input Parameters

Bacteria Input Parameters:

- Mobile virus inactivation rate constant, $\log_{10}(\gamma)$: The die-off rate of 0.45 day^{-1} as $-\log_{10}$ C_t/C_o for fecal coliform was used from McFeters and others (1974) in Azadpour-Keeley, et. al. (2003).
- Solid- Sorbed virus inactivation rate constant, $\log_{10}(\gamma*)$: The die-off rate of 0.45 day^{-1} as $-\log_{10}$ C_t/C_o for fecal coliform was used from McFeters and others (1974) in Azadpour-Keeley, et. al. (2003).

- Mass transfer coefficient, mobile phase to solid-water interface sorbed, K: The *Virulo* default value for virus was used as it is more conservative than the sorption rate for bacteria. The value used was 0.00134 meters/hour (m/h).
- Mass transfer coefficient, mobile phase to air-water interface sorbed, K*: The *Virulo* default value for virus was used, as it is more conservative than the sorption rate for bacteria. The value used was 0.00927 m/h.
- Mean virus radius: This was changed to the average size of a bacteria, 2.4×10^{-6} m, with a standard deviation of 2.2×10^{-6} m to simulate the size range of bacteria (See Figure 4).
- Equilibrium partitioning coefficient for viruses sorbing to soil particles, K_d: The *Virulo* default value for viruses was used as it is more conservative than the sorption rate for bacteria. The value used was 6.15×10^{-4} cubic meters per gram (m^3/g).

The model was run using a sandy loam which best fits the larger distribution in grains sizes and the hydrogeologic parameters of the 12 soils that EPA simulated with the *Virulo* Model. It was run for approximately 5 feet (1.65 meters). See Figure 6 for the input parameters for flow used in the simulations.

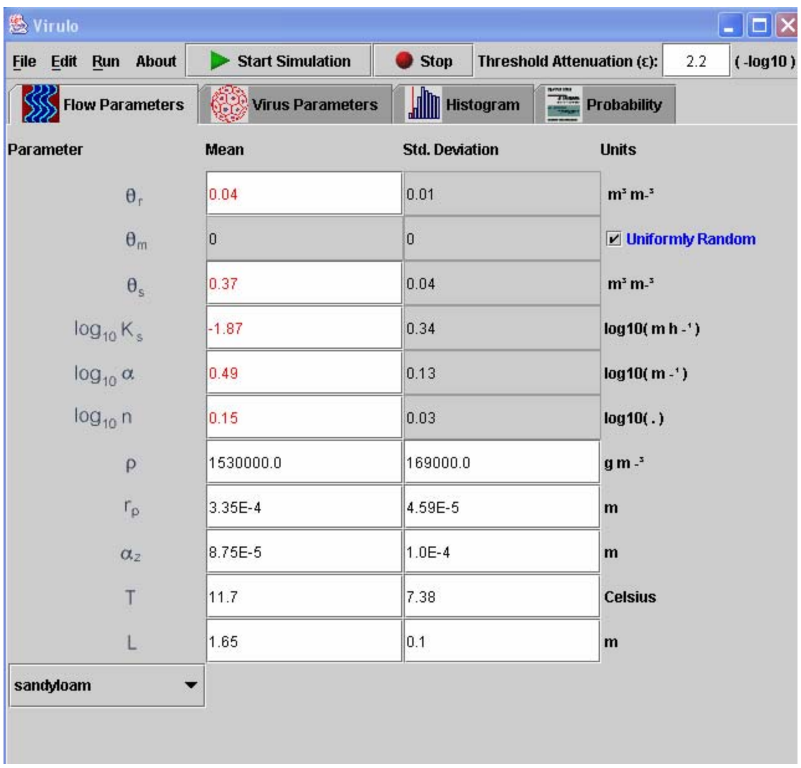

Figure 6: Input Parameters for Flow

Flow Input Parameters (flow input parameters are the *Virulo* default values for a sandy loam):

- Residual water content, θ_r: The *Virulo* default value for a sandy loam was used. (fraction)

- Water content, θ_m: This is the fraction of the pore space containing water. The model simulates random water contents within the range of potential water contents. (fraction)
- Saturated water content, θ_s: This is equal to the porosity. (fraction)
- Saturated hydraulic conductivity, $\log_{10}(K_s)$: This is the hydraulic conductivity that the soil would have if it was saturated. (in $\log_{10}(m\ h^{-1})$
- Van Genuchten parameter, $\log_{10}(\alpha)$: Predicted value for a sandy loam. (in $\log_{10}[m\ h^{-1}]$)
- Van Genuchten parameter, $\log_{10}(n)$: Predicted for a sandy loam. (in $\log_{10}$)
- Soil dry bulk density, ρ_b: Soil bulk density for a sandy loam. (in g/m^3)
- Mean soil particle radius, r_p: This is the default value for a sandy loam; however, the grain size is similar to matrix material of the UG. (in meters)
- Hydrodynamic dispersivity, α_z: This is the vertical dispersivity for a sandy loam in the unsaturated zone. (in meters)
- Mean soil temperature, T: This is used to compute the molecular dispersivity of the bacteria, a component of dispersion. (in ^oC)
- Separation Distance, L: This is the thickness of the barrier layer; in this case, the separation distance. (in meters)

As discussed above, the model was run to predict the probability of bacteria entering groundwater above a model user-chosen degree of attenuation. For viruses, EPA recommends that treatment achieve a 99.9 attenuation; this value is used as the model default. The probability of failure at a 99.9% (4-log) reduction[3] with a separation distance of approximately 5 feet was zero.

These simulations were conservative in that for most of the bacterial parameters, default parameters for viruses were used although the flow assumption of a sandy loam may not be conservative. However, the UGs containing a silt and sand matrix with clay (Trimble, 1963; Madin, 1990) are satisfactorily represented by the sandy loam simulation (See Section 5.2).

This conclusion is supported by the World Health Organization (WHO, 2006), which modeled the reduction needed for grey water. It is assumed that, for the purpose of this project, the levels of bacteria in grey water (e.g., sink, washwater) may be similar to the levels of bacteria in stormwater. WHO found that if grey water is discharged to groundwater, the pathogens of concern, Campylobactor, Salmonella, Giardia, and Cryptosprodium, require less than a 2.2 log reduction in concentration.

4.3 Conclusions Regarding Bacteria Attenuation

The risk of bacteria discharging in stormwater to a UIC and migrating through 5 feet of unsaturated soil (i.e., separation distance of 5 feet) to groundwater is expected to be very low to

[3] A Log Reduction Value (LRV) is a ration of the log to the base 10 of the initial concentration divided by the filtrate or post die-off concentration. It is most often used when there is a high concentration of a single material, such as bacteria. The LRV equals: LRV = Log_{10} Initial Concentration/Attenuated Concentration.

zero, based on the above literature review and *Virulo* probability analysis. Stormwater contains relatively small concentrations of bacteria and other pathogens as compared to septic effluent; therefore, these reviewed studies are conservative relative to stormwater. EPA's *Virulo* model was adapted to estimate the probability that bacteria concentrations would be significantly attenuated (i.e., meet a 99.9% reduction) in a 5 foot thickness of unsaturated sandy loam. The model indicated that there was a zero probability of failure for the modeled 5 foot separation distance. Based on this analyses, it can be concluded that it is not "reasonably likely that groundwater quality would be adversely impacted" by reducing the vertical separation distance between the bottom of the UIC and seasonal high groundwater to 5 feet. As previously, noted the assumption of a 5 foot separation distance is conservative, in that seasonal high water levels only occur for less than 1 or 2 months of the year and separation distances could be as much as 3 feet greater (> 8 feet) during the summer and fall months.

5 Technical Approach for Separation Distance Evaluation

This section describes the approach used to determine whether a vertical separation distance of less than 10 feet is protective of groundwater quality, based on Portland-specific data.

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

The stormwater MADLs mandated by the permit are based on Oregon groundwater protection standards regulating pollutants in groundwater, federal drinking water standards regulating pollutants in drinking water, and other health based limits. Permit compliance is based on pollutant concentrations detected at the point stormwater enters the top of the UIC (i.e., EOP) and 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 approach described in this section was developed to estimate pollutant attenuation during transport through the unsaturated zone (i.e., soils above the water table) prior to reaching groundwater.

Stormwater discharge into 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 (in Section 1.0).

Pollutants are attenuated during transport through the unsaturated zone by:

- **Volatilization.** Volatilization is pollutant attenuation due to transfer from the dissolved phase to the vapor phase. Because soil pores are only partially filled with water, pollutants 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 the pollutants evaluated in this Groundwater Protectiveness Demonstration is low and volatilization is not significant at depths below most UIC bottoms (i.e., 30 feet), volatilization is not included in the fate and transport calculations (EPA, 2001).
- **Adsorption.** Adsorption is pollutant attenuation due to 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 contaminant molecule and the ions of the soil molecule's surface. Adsorption is a function of the organic carbon content (f_{oc}) and the organic carbon absorption coefficient (K_{oc}).
- **Degradation.** Degradation is pollutant attenuation due to biotic and abiotic processes. Abiotic degradation includes hydrolysis, oxidation-reduction, and photolysis. Biotic degradation involves microorganisms metabolizing pollutants through biochemical reactions. However, this technical memorandum conservatively uses only the biotic degradation pathway. Degradation is described by a first-order decay constant.

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

BES and GSI Water Solutions, Inc. (GSI) met with DEQ on numerous occasions during the development of the conceptual site model and the fate and transport approach. BES and GSI incorporated DEQ input into the analyses throughout the process. During these meetings, DEQ and BES agreed:

- Unsaturated subsurface soils are part of the treatment prior to the stormwater reaching groundwater. Permit compliance is based on concentrations detected at the point stormwater enters the top of the UIC (i.e., end-of pipe) and does not account for the treatment/removal (i.e., attenuation) of pollutants by subsurface soils between the point of discharge and seasonal high groundwater.
- Regarding the general hydrogeological conceptual site model for evaluating pollutant fate and transport, it is recognized that the system is complex due to pulsed stormwater inputs, soil wetting and drying cycles, variability in soil type and texture with depth, etc.
- Fate and transport analysis is an appropriate method to evaluate and document groundwater protection.
- The evaluation should include chemical, physical, and biological processes occurring in unsaturated subsurface soils between the point of stormwater discharge and seasonal high groundwater.
- It is appropriate to include biotic degradation in the analyses.
- The use of a one-dimensional, constant source advection dispersion equation that incorporates sorption and degradation is appropriate to assess pollutant fate and transport.
- Because of the complexities in the hydrogeologic system and variability in stormwater concentrations, it is appropriate to evaluate "average" conditions for representing soil characteristics, degradation rates, etc. and determining potential groundwater impacts. The "reasonable maximum" scenario, as defined by DEQ and EPA guidance, would be used to provide an evaluation of uncertainties in the fate and transport calculations.
- The evaluation should incorporate Portland-specific data to the extent available and appropriate.
- The approach and methodology is sufficiently conservative to evaluate whether groundwater is reasonably likely to be impacted in accordance with OAR 340-040.
- The approach and methodology address pollutant persistence and toxicity.
- The approach and methodology can be used to support the evaluation of the highest and best practical corrective action or response action as required by OAR 340-040.

As noted above, the evaluation presented in this technical memorandum includes consideration of both "average" and "reasonable maximum" scenarios. These scenarios are defined below:

- **Average Scenario** (i.e., central tendency): is defined as the arithmetic mean or expected value of the input parameter values used in the fate and transport analyses.

- R**easonable Maximum Scenario**: is defined as a plausible upper-bound or high-end value of the input parameter values used in the fate and transport analyses. This evaluation uses the 90th percentile upper confidence limit (90% UCL) on the arithmetic mean of input parameters or uses best professional judgment to define the highest value that can reasonably be expected for the given parameter.

The advantage of the two-case approach is that the resulting range of fate and transport analyses results provides some measure of the uncertainty surrounding these estimates. The disadvantage of this approach is that the upper-bound fate and transport estimate may be overly conservative, due to the compounded conservatism in the analyses. The intent of the reasonable maximum scenario is to provide a conservative exposure case (i.e., well above the average or expected case) that is still within the range of possible exposures.

5.2 Geology and Hydrogeology

Shallow geology in the Portland basin consists of coarse-grained (Qfc) and fine-grained (Qff) catastrophic flood deposits underlain by cemented gravel of the Troutdale Formation (Madin, 1990) and are described below:

- **Coarse-Grained Facies (Qfc).** Gravel with silt and coarse sand matrix. Gravel size ranges from pebbles to boulders.
- **Fine-Grained Facies (Qff).** Coarse sand and silt.
- **Troutdale Gravel (QTg).** Cemented gravel with sand and silt matrix. Gravel size ranges from pebbles to boulders.

USGS (1998a) groups these geologic units into two hydrogeologic units: the Unconsolidated Gravels (UG) and the Troutdale Gravel Aquifer (TGA). The relatively high permeability UG [i.e., 200 ft/day (USGS, 1996a)] consists of the Qff and Qfc geologic units, and the relatively low permeability TGA [i.e., 7 ft/day (USGS, 1996a)] consists of the QTg geologic unit.

5.3 Unsaturated Soils Pollutant Fate and Transport Equation

A one-dimensional pollutant fate and transport equation was used to estimate the magnitude of pollutant attenuation during unsaturated zone transport. This constant source Advection Dispersion Equation (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:

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

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), and
$C(y, t)$ is pollutant concentration at depth y and time t (M/L^3).

Equation (1) is an exact solution to the 1-dimensional ADE. The exact solution must be used for short transport distances [i.e., less than about 3.5 meters (~11 feet)] (Neville and Vlassopoulos, 2008). Because the separation distances at Category 3 UICs are less than 3.5 meters, this technical memorandum uses the exact solution to the ADE in the fate and transport calculations.

The key assumptions in applying this equation include:

- Transport is one-dimensional vertically downward from the bottom of the UIC to the water table.
- 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 stormwater are constant.
- Pollutant concentrations in water discharging into the UIC are uniform and constant throughout the period of infiltration. (Note: PCP concentrations are variable 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.
- 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:

- UICs are typically constructed with a solid concrete bottom and approximate 2 foot deep sediment sump 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 will periodically 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 as it predicts the maximum infiltration that would be expected at the water table sustained over the duration of the period over which the UIC contains water.
- Metal concentrations are assumed to be constant while in reality they are variable throughout storm events. This is conservative for a few reasons: the 90% UCL is used for the reasonable maximum which likely over-predicts the concentration throughout the duration of a storm event. In addition, the Groundwater Protectiveness Demonstration does not take into account pollutant attenuation that occurs while in the UIC prior to entering the surrounding soil.

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

5.3.1 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).

5.3.2 Dispersion Coefficient

Dispersion is the spreading of a contaminant plume caused by pore water mixing. 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 can be estimated as (e.g., 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) (e.g., 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 technical memorandum 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.

5.3.3 Vertical Groundwater Velocity

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

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

where:

q is specific discharge (L/T),
Ku 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 Qff and Qfc flood deposits), $\left(\frac{\partial \psi}{\partial y}\right)$ = 0. Under these conditions, equation (6) reduces to (e.g., Stephens, 1996):

$$q_y = -K_u \tag{7}$$

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

5.3.4 Parameters

The following sections describe the parameters used to solve for velocity (equation 7), dispersion coefficient (equation 3), retardation factor (equation 2), and concentration (equation 1). These parameters include total porosity, soil bulk density, fraction organic carbon, organic carbon partitioning coefficient, distribution coefficient, hydraulic conductivity, biodegradation rate, and infiltration time. Retardation factors were discussed in Section 5.3.1

5.3.4.1 Total Porosity

Total porosity (h) is the percent of pore space in soil. Porosities are correlated with soil type; therefore, porosities of the fine-grained facies (Qff), coarse-grained facies (Qfc), and Troutdale Gravels (QTg) were estimated from references. According to Freeze and Cherry (1979), the total porosity of the Qff (i.e., a sand) is 0.375, and the total porosity of the Qfc and QTg (i.e., gravels) is 0.325.

5.3.4.2 Soil Bulk Density

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

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

Soil bulk densities for the Qff, Qfc, and QTg were calculated using the porosities from Freeze and Cherry (1979) discussed above. According to equation (8), the soil bulk density for the Qff is 1.66 g/cm^3 and the soil bulk density for the Qfc and QTg is 1.79 g/cm^3.

5.3.4.3 Fraction Organic Carbon

Fraction organic carbon (f_{oc}) is a dimensionless measure of the quantity of organic carbon in soil (i.e., g_{carbon} / g_{soil}). The average of the EPA (1996) soil screening guidance default value (i.e., 0.006) and an empirical value from EPA (1996) for a soil that is 87% sand (i.e.0.00187) was used in the Category 4 UIC Corrective Action analysis (GSI, 2008). DEQ (2008) recommended that a site-specific value be used since f_{oc} is a sensitive parameter in the fate and transport of pollutants. Therefore, Portland-specific data were used to estimate the organic content (f_{oc}) in soil beneath a UIC for use in the pollutant fate and transport analyses.

The range of total organic carbon (TOC) concentrations in stormwater is 11 mg/L to 250 mg/L (Schmidt, 1985, reported in EPA, 1999). The majority of organic carbon found in urban stormwater is in the form of particulate matter (suspended solids), which would filter out of the stormwater and accumulate in the soil adjacent to and beneath a UIC. Dissolved organic carbon would also adsorb to some extent to the soil particles. Sampling by BES indicates that stormwater entering the UICs contains significant amounts of organic carbon. Preliminary TOC sampling results of the stormwater entering the UICs indicate a minimum concentration of about 4 mg/L, and mean concentration of about 9 mg/L. Therefore, as stormwater infiltrates into the surrounding soils below the UIC, the f_{oc} is expected to increase over time due to the ongoing addition of organic carbon (e.g., degraded leaves, pine needles, pollen).

An estimate of f_{oc} based on the filtering of TOC as suspended solids was performed using:

- An average annual stormwater infiltration volume of 68,874 cubic feet (1.95×10^9 cm^3) estimated using the average impervious area of a UIC catchment (BES, 2007a);
- The annual precipitation rate in permit Years 1 and 2 (BES, 2007a);
- Total organic carbon concentration in stormwater; and
- Estimated volume of soil into which the organic carbon would be expected to accumulate due to filtration and adsorption (assumed to be $5{,}34 \times 10^6$ cm^3; the volume of soil between from 3 feet above the base of the UIC to 5 feet below the base of the UIC extending 1 foot out from the UIC).

Average Scenario. For the average scenario, the grams (g) of TOC entering the UICs annually were calculated from 9 mg/L (the mean of the BES empirical data and the minimum reported in EPA, 1999). Because TOC is continuously present in the environment (leaves, pollen, etc.) it will continue to be added to the system. Therefore, the amount of organic carbon added to the system was estimated on an annual basis and because the majority of the UICs have been around for a minimum of 10 years, the amount of carbon added to the system over 10 years of operation was calculated as follows:

$$1.95 \times 10^9 \text{ cm}^3 \text{ stormwater/yr} * 9 \text{ mg TOC}/1000 \text{ cm}^3 * 10 \text{ years} * 1\text{g/L} \times 10^6 \text{ mg} =$$

$$175{,}500 \text{ g of TOC added to the system over 10 years}$$

Therefore, 175,500 grams of organic carbon can be assumed to have accumulated in the soil beneath the UICs over a 10 year period. Given an estimated area into which the TOC would accumulate of 5.34 X 10^6 cm^3, then the TOC per cubic centimeter of soil would equal:

175,500 g TOC/5.34 X 10^6 cm^3 soil =

0.033 g TOC/cm^3 soil

Given a bulk density of 1.79 g/cm^3, the f_{oc} is equal to:

f_{oc} = 0.033 g TOC/(1.79 g soil + 0.033 g TOC) =

f_{oc} = 0.018 g TOC/g soil

Reasonable Maximum Scenario. For the reasonable maximum scenario, the same calculation was performed using 4 mg/L TOC in stormwater, resulting in an **f_{oc} of 0.008.** Because these are significantly higher than the f_{oc} present in the UG or TGA, these f_{oc} values were used without adding the f_{oc} already existing in the formation prior to discharging stormwater into the UICs.

5.3.4.4 Organic Carbon Partitioning Coefficient

The organic carbon partitioning coefficient (K_{oc}) is defined for each contaminant, and specifies the degree to which the contaminant 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} values for each pollutant are listed in Table 4 below. Except for PCP, K_{oc} values for each pollutant were estimated from field studies discussed in the literature. The K_{oc} value for the average scenario was estimated by using an average value from Fetter (1994), EPA (1996), EPA (2008b), EPA (2008c), or EPA (2008d). The K_{oc} value for the reasonable maximum scenario was estimated by using the lowest (i.e., most-conservative) value from Fetter (1994), EPA (1996), EPA (2008b), EPA (2008c), or EPA (2008d). Because K_{oc} for PCP is pH-dependent, the K_{oc} for PCP was estimated based on the range of soil pH values in east Portland. Soil and groundwater pH are in equilibrium; therefore, soil pH can be estimated from groundwater pH. pH has been measured in 12 USGS wells screened at or near the water table on the east side of the Willamette River in Portland from 1997 to 2007. The average groundwater pH at the wells is 6.4, and was used for the average scenario. The PCP organic carbon partitioning coefficient when pH = 6.4 is 877 L/kg (EPA, 1996). The average maximum groundwater pH at the USGS wells is 6.6 units. The PCP organic carbon partitioning coefficient when pH = 6.6 is 703 L/kg (EPA, 1996).

Table 4: K_{oc} Values for Stormwater Pollutants in Liters per Kilogram

Pollutant	Average	Reasonable Maximum
Benzo(a)pyrene	282,185	282,185
Naphthalene	1,300	830
PCP	877	703
Bis-(2-ethylhexyl) phthalate	12,200	12,200
2,4-D	201	20

Pollutant	Average	Reasonable Maximum
Methoxychlor	97,700	9,700
Toluene	182	37

5.3.4.5 Distribution Coefficient

The distribution coefficient, K_d, was estimated differently for organics and for metals. For organics, K_d was estimated from the following equation (e.g., Watts, 1998):

$$K_d = f_{oc}K_{oc} \tag{9}$$

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:

$$K_d = \frac{C_s}{C_w} \tag{10}$$

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). However, K_d values can be determined empirically for a particular situation from equation (1) (Bricker, 1998).

Lead (up to 85.7 and 149 µg/L during Year 1 and Year 2 Monitoring, respectively) and copper (up to 67.2 and 212 µg/L during Year 1 and Year 2 Monitoring, respectively) were detected in stormwater runoff entering the UICs. During infiltration to groundwater, dissolved concentrations are expected to be reduced by sorption onto soil particles in the unsaturated zone and the rate of metal transport to the water table will be retarded. Site-specific K_d values are needed for copper and lead in the unsaturated zone in order to estimate the travel time and concentrations of metals reaching groundwater.

An empirical approach was used to derive site-specific K_d's for lead and copper. The partitioning coefficients were estimated from total and dissolved metals concentrations and total suspended solids (*TSS*) data for 150 stormwater samples collected from 30 different locations during five sampling events (BES, 2006c; BES, 2007a). The stormwater chemistry data are summarized in Table 5.

Table 5: Stormwater quality data for Portland UICs (N=150) (Year 1 Data)

Parameter	Average	Minimum	Maximum	Median
Total Copper (µg/L)	8.17	0.73	67.20	5.15

Parameter	Average	Minimum	Maximum	Median
Dissolved Copper (µg/L)	2.92	0.20	15.50	2.11
Total Lead (µg/L)	7.34	0.28	85.70	2.93
Dissolved Lead (µg/L)	0.29	0.10	3.40	0.14
TSS (mg/L)	37	2	415	15
pH	6.4	5.1	8.4	6.2

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

$$K_d = \frac{\left([Me]_t - [Me]_d\right)}{[Me]_d \times TSS} \times 10^6 \qquad (11)$$

where:

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

Note that in equation (11), metals concentrations are in until of 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 7 and summarized in Table 6. The median K_d value for copper (76,000 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).

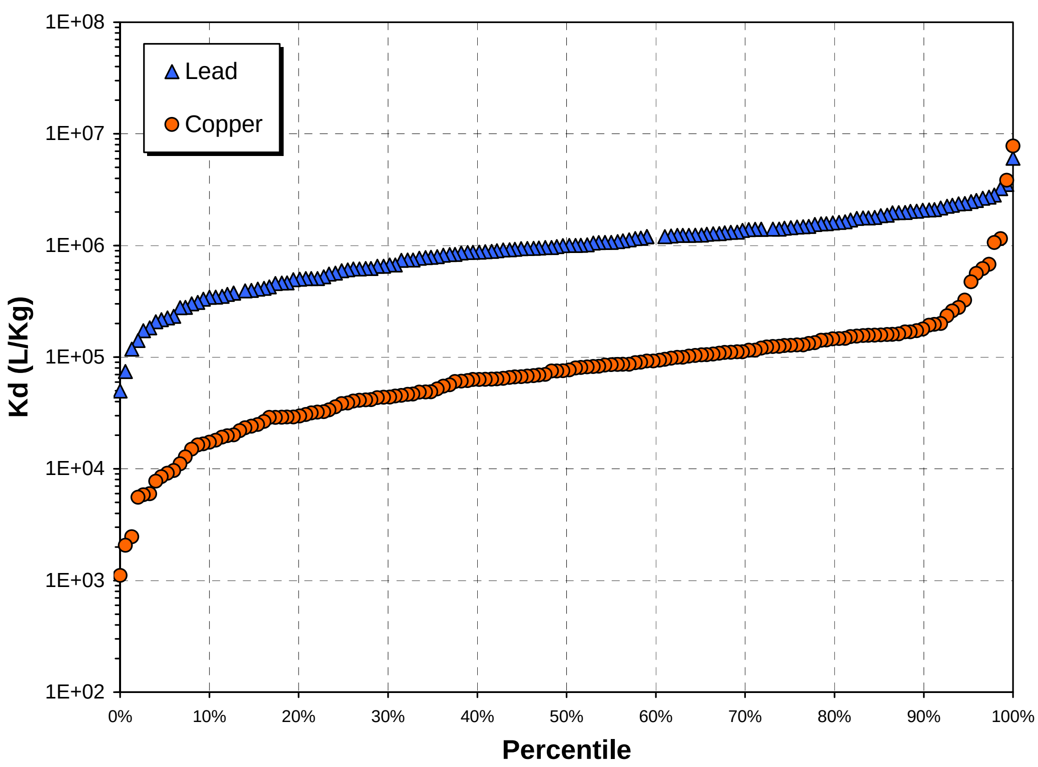

Figure 7: Calculated K_d distributions for lead and copper in Portland stormwater runoff

Table 6: Calculated K_d values for copper and lead

K_d	Minimum	Maximum	Median	10th Percentile
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 10th percentile K_d values.

The distributions of calculated partition coefficients derived for copper and lead in 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 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 Portland stormwater (pH ranges from 5.1 to 8.4, Table 4).

Table 7: Compiled K_d values for lead and copper (Allison and Allison, 2005)

K_d	Median	Minimum	Maximum
Lead	130,000	100	10,000,000
Copper	13,000	5.0	1,600,000

The calculated K_d distributions can also be compared to similarly calculated K_d's 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 Seattle (Engstrom, 2004) and California (Kayhanian, et. al., 2007). The data and calculated K_d values are summarized in Table 8. 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 Portland stormwater, the median values for Seattle are closer to the median Portland values.

Table 8: Stormwater quality from various sources and calculated K_d values

	NSQD	*California*			*Seattle*		
Parameter	**Median**	**Min**	**Max**	**Median**	**Min**	**Max**	**Median**
Total Lead (µg/L)	17	1.	2600	12.7	3.90	38.70	11.6
Dissolved Lead (µg/L)	3.0	1.	480	1.2	0.28	14.20	0.96
Total Copper (µg/L)	16	1.2	270	21.1	8.23	44.80	13.85
Dissolved Copper (µg/L)	8	1.1	130	10.2	1.80	28.10	7.10
TSS (mg/L)	58	1.	2988	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

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_d's 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_d's 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.

5.3.4.6 Hydraulic Conductivity

Saturated hydraulic conductivity, K_s, in the fine grained facies (Qff) and coarse grained facies (Qfc) was estimated from pump-in tests conducted by BES. Because data was not available to measure unsaturated hydraulic conductivity (K_u), saturated hydraulic conductivity was calculated and used in equation (7) to calculate water velocity. Due to 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.

A UIC capacity test (i.e., pump in test) consists of injecting water into a UIC at a known rate, and allowing the water level in the UIC to stabilize. Figure 8 shows a conceptual diagram of a UIC during a pump-in test.

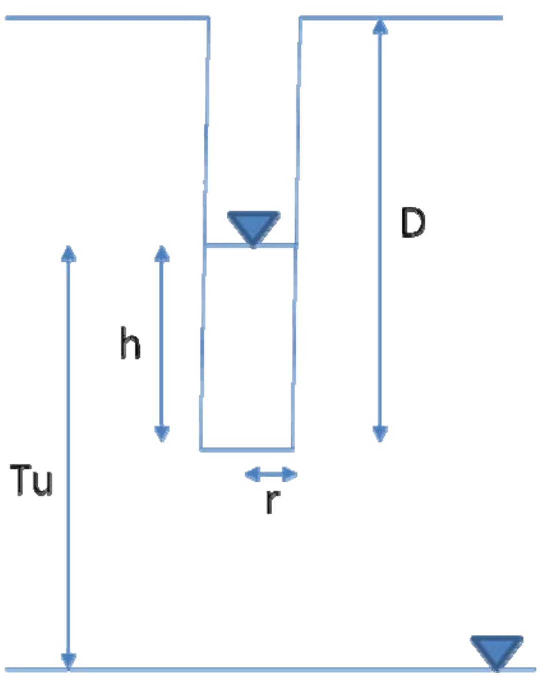

Figure 8: Pump in Test Conceptual Model

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

$K_s =$

$$\frac{\left[\ln\left(\frac{h}{r}+\sqrt{\left(\frac{h}{r}\right)^2+1}\right)-1\right]Q}{2\pi h^2} \quad \text{if } T_u \geq 3h \tag{12}$$

$$\frac{\left[\ln\left(\frac{h}{r}+\sqrt{\left(\frac{h}{r}\right)^2+1}\right)-1\right]Q}{2\pi h^2} \quad \text{if } 3h \geq T_u \geq h \tag{13}$$

where:

K_s is saturated hydraulic conductivity (L/T),

h is the height of the stable water level above the UIC 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, b), the ratio of horizontal to vertical hydraulic conductivity in the TGA and UG (which contains the Qff and Qfc facies) aquifers is 100: 1. Therefore, vertical hydraulic conductivity was calculated by dividing the horizontal hydraulic conductivity by 100.

Hydraulic conductivities were calculated from about 100 pump-in tests conducted in east Portland. About 40 of the pump-in tests were from the Qff, and about 60 of the pump-in tests were from the Qfc. None of the tests were from the QTg, partly due to the low permeability of the QTg and relatively few UICs completed in the QTg. After calculating saturated hydraulic conductivity by equations (12) and (13) and converting to vertical hydraulic conductivity, EPA's *ProUCL* software was used to analyze the hydraulic conductivity data. Hydraulic conductivity in the fine-grained facies (Qff) and coarse-grained facies (Qfc) are summarized in Table 9. Qff hydraulic conductivity followed a gamma probability distribution at the 10% confidence level, and Qfc hydraulic conductivity was non parametric at the 10% confidence level.

Table 9: Hydraulic conductivity in the coarse-grained facies (Qfc) and fine-grained facies (Qff) from Pump-In Tests

	Number of Tests	Minimum K_v (m/day)	Maximum K_v (m/day)	Median K_v (m/day)	90% UCL K_v (m/day)
Qff	41	0.02	1.71	0.47	0.67
Qfc	64	0.014	3.48	1.05	2.47

NOTES
K_v = vertical hydraulic conductivity
UCL = upper confidence limit
[1] 90% UCL is the gamma UCL
[2] 90% UCL is the upper percentile

Vertical hydraulic conductivities calculated from pump-in testing were compared to ranges of hydraulic conductivity for different soil lithologies, as summarized in Anderson and Woessner (1992). Because Anderson and Woessner provide horizontal hydraulic conductivities, a $K_H : K_V$ anisotropy ratio of 100 : 1 was used to calculate vertical hydraulic conductivities.

- **Qff vertical hydraulic conductivity.** The Qff consists of coarse sand and silt (Madin, 1990). The range vertical hydraulic conductivity calculated from pump-in testing (0.017 m/day to 1.7 m/day) is generally within the range of vertical hydraulic conductivity for silt and coarse sand (0.005 m/day to 1.0 m/day), as reported in Anderson and Woessner (1992). Therefore, the pump-in testing hydraulic conductivities are consistent with literature values.
- **Qfc vertical hydraulic conductivity.** The Qfc consists of gravel with a silt and coarse sand matrix (Madin, 1990). Because the Qfc has a silt and coarse sand matrix, we would expect hydraulic conductivities measured in the Qfc to fall in the range of hydraulic conductivity for a silt and coarse sand. The range of vertical hydraulic conductivity calculated from pump-in testing (0.01 m/day to 3.5 m/day) is generally within the range of vertical hydraulic conductivity for silt and coarse sand (0.005 m/day to 1.0 m/day), as reported in Anderson and Woessner (1992).
- **QTg vertical hydraulic conductivity.** Pump-in tests were not available for the QTg. Because this cemented gravel has a lower permeability than the gravels of the Qfc, it was assumed that QTg vertical hydraulic conductivity is one order of magnitude less than Qfc vertical hydraulic conductivity.

The median vertical groundwater velocity (which is used for the average scenario) was 0.47 m/day for the Qff facies and 1.05 m/day for the Qfc facies. The 90% UCL velocity (which is used for the reasonable maximum scenario) was 0.67 m/day for the Qff facies and 2.47 m/day for the Qfc facies.

5.3.4.7 Biodegradation Rate

The organic pollutants evaluated in this technical memorandum are biodegradable under aerobic conditions (Aronson, et. al., 1999; MacKay, et. al., 2006); therefore, it is expected that these compounds will biodegrade to some extent within the unsaturated zone as stormwater infiltrates from the UIC to the water table. Aerobic soil biodegradation rates are available for these pollutants and are considered most appropriate for application to unsaturated zone degradation. The ranges of biodegradation rates representative of conditions expected to be encountered in the unsaturated zone beneath UICs are summarized in Table 10. For the average scenario, median biodegradation rate was used. For the reasonable maximum, the 25th percentile biodegradation rate was used.

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). Due to the low concentrations of the compounds of interest detected in stormwater, it is appropriate to consider biodegradation as a pseudo-first order rate process for the UIC unsaturated zone scenario.

Table 10: Summary of First Order-Aerobic Biodegradation Rates

Compound	First Order Biodegradation Rate (day^{-1})				
	Median	*Mean*	*Maximum*	*25th percentile*	*Minimum*
Benzo(a)pyrene	0.0013	0.0021	0.015	0.00026	ND[a]
Bis-(2-ethylhexyl)phthalate	0.019	0.0082	0.047	0.010	0.0040
Methoxychlor	0.011	0.0029	0.090	0.0044	0.0019
Naphthalene	0.0070	0.0051	0.39	0.025	0.0043
Toluene	0.39	0.11	0.53	0.082	0.013
2,4-D	0.0053	0.00066	0.48	0.0022	0.00012

[a] not detectable under experimental conditions

Aerobic biodegradation rate constants were compiled from a review of the scientific literature, including general reference guides (e.g. Aronson, et. al., 1999; Howard, et. al., 1991; Mackay, 2006) 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. Summary statistics provided in the tables below include minimum, maximum, number of measurements, average, 10th, 25th, and 50th percentile (median) values.

Benzo(a)pyrene

Benzo(a)pyrene is a five-ring polycyclic aromatic hydrocarbon (PAH), and is therefore expected to biodegrade at a relatively slow rate (Aronson, et. al., 1999). Under aerobic conditions, reported degradation rate constants range from not detectable to 0.057day^{-1}.

Rate constants under aerobic conditions in soil were compiled from 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). The median value is 0.0013/day (Table 11).

Table 11: Aerobic Biodegradation Rates for Benzo(a)pyrene (day^{-1})

Maximum	0.015
Minimum	ND
N	38
Mean	0.0021
Median	0.0013
25th Percentile	0.00026
10th Percentile	ND

Di-(2-ethylhexyl)phthalate

Di-(2-ethylhexyl)phthalate is biodegradable under aerobic conditions. The rates reported from numerous studies in various media range from not detectable to 1.73 day^{-1}.

A compilation of aerobic soil biodegradation rates [Dorfler, et. al. (1996); Efroymson and Alexander (1994); Fairbanks, et. al. (1985); Fogel, et. al. (1985); 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)] gives a median rate of 0.015 day^{-1} (Table 12).

Table 12: Aerobic Biodegradation Rates for Di-(2-ethylhexyl)phthalate (day^{-1})

Maximum	0.082
Minimum	0.0020
N	34
Mean	0.021
Median	0.015
25th Percentile	0.010
10th Percentile	0.0046

Methoxychlor

Half lives of a few hours to a year have been reported for this pesticide in a variety of environmental conditions (Mackay, 2006). Aqueous aerobic biodegradation rates of 0.0019 to 0.0039 day^{-1} are reported in Howard, et. al. (1991). Methoxychlor has a half-life of 6 months to 1 year (0.0039 to 0.0019 day^{-1}) based on aerobic soil die-away tests (Fogel, et. al., 1982). Half lives of 1.5 weeks and 1 week (0.066 day^{-1}, 0.090 day^{-1}) are reported in soil (Kaufman, 1976). A half life of 42 days (0.017 day^{-1}) reported for use in screening model calculations (Jury, et. al., 1987). A field half life of 120 days (0.0058 day^{-1}) is reported by Hornsby, et. al. (1996) (Table 13).

Table 13: Aerobic Biodegradation Rates for Methoxychlor (day^{-1})

Maximum	0.090
Minimum	0.0019
N	6
Mean	0.031
Median	0.011
25th Percentile	0.0044
10th Percentile	0.0029

Naphthalene

This two-ring PAH is generally expected to biodegrade more rapidly than PAHs with three or more rings. Aronson, et. al. (1999) report a range of aerobic biodegradation rate constants in various media of non detectable to 5.0 day^{-1}. Biodegradation rates for naphthalene are much higher in studies working in contaminated systems than studies using material that has not been previously exposed to PAHs, suggesting that acclimation of the microbial community increases biodegradation rates.

Rate data was compiled for aerobic biodegradation in soil [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 Wischman and Steinhardt (1997)]. The median aerobic degradation rate in soil is 0.075 day^{-1} (Table 14).

Table 14: Aerobic biodegradation rates for naphthalene (day^{-1})

Maximum	0.39
Minimum	ND
N	22
Mean	0.14
Median	0.075
25^{th} Percentile	0.025
10^{th} Percentile	0.0074

Toluene

Toluene is expected to biodegrade rapidly under aerobic conditions (Aronson, et. al., 1999). The compilations of aerobic rates in Aronson, et. al. (1999) and Howard, et. al. (1991) ranges from not detectable to 42.5 day^{-1}. Aronson, et. al. (1999) point out that the studies finding no biodegradation were from experiments with low oxygen levels where the microcosms likely went anaerobic.

Rates were compiled for aerobic biodegradation in soil [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)] giving a median of 0.33 day^{-1} (Table 15).

Table 15: Aerobic Biodegradation Rates for Toluene (day^{-1})

Maximum	4.71
Minimum	0.0097
N	44
Mean	0.65
Median	0.33
25^{th} Percentile	0.082
10^{th} Percentile	0.023

2,4-D

Aerobic biodegradation rates range from 0.00012 to 0.48 $day^{-1}$and are generally higher in moist soil than dry soil (Howard, et. al., 1991; Mackay, et. al., 2006). Aerobic soil biodegradation rates were compiled from Chinalia and Killham (2006), McCall, et. al. (1981), Nash (1983), Torang, et. al. (2003) (Table 16).

Table 16: Aerobic Biodegradation Rates for 2,4-D (day^{-1})

Maximum	0.48
Minimum	0.00012
N	14
Mean	0.091
Median	0.0053
25th Percentile	0.0022
10th Percentile	0.00066

5.3.4.8 Infiltration Time

Infiltration time is the length of time during the water year (i.e., October through May) that stormwater discharges into a UIC. BES field staff responsible for implementing the UIC monitoring program (BES, 2006g) are responsible for tracking storm events suitable for sampling. Based on BES experiences over the first two years of the monitoring program, it is estimated that a storm needs to produce between 0.03 and 0.1 inches per hour (in/hr) in order to produce runoff into most UICs. Because stormwater discharges into UICs only when the precipitation rate exceeds a threshold value (assumed 0.04 in/hr; this is ½ the value stated in DEQ's 2005 permit *Fact Sheet*), the infiltration time is dependent on the occurrence of rain events equal to or greater than this amount. Infiltration time was estimated from precipitation rates measured at the Holgate and Kelly School rain gages in southeast Portland (where a majority of the Category 3 UICs are located) (HYDRA, 2008). The number of hours that precipitation rates exceeded 0.04 inches/hour was estimated for the 1998 – 1999 through 2006 – 2007 water years (i.e., the years for which precipitation rates were available). The number of hours that precipitation rates exceeded 0.04 inches/hour ranged from 169 hours (2000 – 2001, Kelly School Rain Gage) to 480 hours (1998 – 1999, Kelly School Rain Gage) and averaged 309 hours (12.86 days).

Generally, the average number of hours that precipitation rate exceeded 0.04 inches/hour (309 hours or ~12.86 days) was used as the initial input value for infiltration time in the fate and transport analyses. However, because the ADE only simulates contaminant breakthrough until the time at which the maximum contaminant concentration is reached, infiltration times were reduced for some pollutants (e.g., toluene, 2,4-D) that reached a maximum concentration after a shorter infiltration time. Infiltration times used for each pollutant for the average and reasonable maximum scenario are shown in tables presented in the Appendix A.

6 Results of Separation Distance Analysis

This section presents the results of the fate and transport analyses of selected stormwater pollutants potentially discharged to city-owned UICs. The evaluation focuses on determining whether vertical separation distances of 5 and 7 feet are protective of groundwater quality in accordance with OAR 340-040 and defining pollutant concentrations or "action levels" that can be used to conservatively identify when potential adverse impacts to groundwater should be either further evaluated or subject to corrective action.

The analyses presented in this document was performed using separation distances of 5 and 7 feet and based on Portland specific input parameters. Specifically, the evaluation looked at UICs with separation distances less than 10 feet (i.e., Category 3 UICs) in the geologic units (See Section 5.2) in which these UICS are completed in:

- **Coarse-Grained Facies (Qfc).** Gravel with silt and coarse sand matrix.
- **Fine-Grained Facies (Qff).** Coarse sand and silt.
- **Troutdale Gravel (QTg).** Cemented gravel with sand and silt matrix.

Pollutants representative of the stormwater discharged to City-owned UICs were also used in the fate and transport analyses. These pollutants were selected based on frequency of detection by the City's UIC monitoring program, mobility, persistence, and toxicity (See Section 3). The following pollutants were used to evaluate whether a vertical separation distance of less than 10 feet is protective of groundwater quality in accordance with OAR 340-040:

- VOCs: Toluene
- SVOCs: Pentachlorophenol (PCP)
  di(2)ethylhexylphthalate (DEHP)
- PAHs: Benzo(a)pyrene (BaP)
  Naphthalene
- Pesticides/Herbicides: 2,4-D
  Methoxychlor
- Metals: Copper
  Lead

The one-dimensional fate and transport equation and input parameters used in the analyses are described in Section 5. The results of the fate and transport analysis are presented in Appendix A and indicate that a vertical separation distance of 5 feet or greater, for UICs completed in the three geologic units evaluated, is protective of groundwater quality in accordance with OAR 340-040 (i.e., would not be reasonably likely to adversely impact groundwater quality).

The analyses further indicated that stormwater pollutants would not reach groundwater under the average scenario. The modeled pollutant concentrations were typically greater than 100 times the concentrations detected by Year 1 and Year 2 UIC monitoring program. It should be noted that separation distances less than 5 feet were not evaluated and in some cases shorter distances may be protective. Section 7 describes the stormwater influent pollutant concentrations or “action levels” that may be used to identify when further evaluation, response actions, or corrective actions may be warranted for vertical separation distances of 5 or 7 feet. As discussed in the following section, concentrations approximately 100 times the permit MADLs are not expected to result in reasonably likely adverse impacts to groundwater quality.

7.0 Pollutant Action Levels

This section describes UIC stormwater influent pollutant “action levels” that are protective of groundwater quality in accordance with OAR 340-040 for vertical separation distances of 5 feet and 7 feet. These action levels may be used for determining when further evaluation, response actions, or corrective actions may be required, as described in the UICMP (BES, 2006a).

Action levels for organic stormwater pollutants entering City-owned UICs category are estimated for two scenarios: average (i.e., central tendency) and reasonable maximum (see Section 5.1). The scenarios differ in whether average or reasonable maximum physical and chemical properties are used for unsaturated zone soils and each modeled pollutant. Calculations for the Groundwater Protectiveness Demonstration are provided in Appendix A.1 (Qfc, 5 feet separation distance), Appendix A.2 (Qfc, 7 feet separation distance), Appendix A.3 (Qff, 5 feet separation distance), Appendix A.4 (Qff, 7 feet separation distance), Appendix A.5 (QTg, 5 feet separation distance), and Appendix A.6 (QTg, 7 feet separation distance).

The pollutant action levels are set based on <u>hypothetical</u> stormwater influent concentrations. These levels were generally arbitrarily set at a stormwater concentration 100 times the MADL (or in some cases, 100 times the MCL or PRG for the pollutant) for selected pollutants (see Section 3). It should be noted that concentrations 100 times the MADL are significantly higher than the observed range of concentrations detected by the UIC monitoring program (BES, 2006c; BES, 2007a) for the pollutants monitored with the exception of DEHP in Year 2. The maximum DEHP concentration detected in Year 2 is a suspected outlier and likely associated with particulate matter (BES, 2007a). Based on the results of the Year 1 and Year 2 UIC stormwater discharge monitoring data, it is not anticipated that stormwater concentrations anywhere near 100 times the MADLs will be detected in stormwater. Therefore, this 100x factor was selected as a cap for action level concentrations for the risk evaluation and is believed to be conservative.

Under the both the average and reasonable maximum scenario, the selected pollutants would not be expected to enter groundwater at concentrations greater than the MADL if the separation distances was greater than 5 feet (i.e., 5 and 7 feet separation distances are both protective of groundwater) and the stormwater pollutant concentration was less than the action levels. Therefore, it can be determined that it is not reasonably likely that groundwater will be adversely impacted.

Under the reasonable maximum scenario, UICs completed in the coarse grained facies of the Unconsolidated Gravels (Qfc), a stormwater influent concentrations greater than 100 times the MADL for 2,4-D and toluene could theoretically reach the groundwater table at concentrations above the MADL. Therefore, these actions levels were set at lower concentrations (using the fate and transport analyses methodology) that would not result in an adverse impact to groundwater quality at the point infiltrated stormwater reaches groundwater. The stormwater influent concentrations less than 125 μg/L for 2,4-D and 1,900 μg/L for toluene would not result in infiltrated stormwater entering groundwater at concentrations less than the pollutants respective MADLs and therefore would be protective of groundwater quality. It is important to note that the maximum concentration measured in the stormwater entering the UICs for 2,4-D and toluene are 32.3 µg/L and 280 µg/L, respectively and the 90% UCL for these compounds, based on Year 1 and Year 2 data, are 3.0 µg/L and 6.2 µg/L, respectively. The maximum detected concentration and 90% UCLs for these pollutants are significantly less than the "action level"; therefore, it can be concluded that it is unlikely that adverse groundwater impacts will occur.

Organic Pollutants: Action levels are summarized in Table 17 (5 foot separation distance) and Table 18 (7 foot separation distance). These action levels are capped at 100 times the MADL. If a pollutant concentration or a pollutant's surrogate concentration is below the action level and the separation distance is equal to or greater than that evaluated, then it can be determined that groundwater is not reasonably likely to be adversely impacted and is protected in accordance with OAR 340-040. If a pollutant concentration or a pollutant's surrogate concentration is near or above the action levels for the applicable separation distance, then the UIC may not protective of groundwater and appropriate response and/or corrective action should be initiated as required by the permit and UICMP (BES, 2006a).

Table 17: Action Levels for Stormwater Pollutants at UICs with 5 Feet Separation Distance

	Average Scenario			Reasonable Maximum Scenario		
Pollutant (µg/L)	**Qfc**	**Qff**	**QTg**	**Qfc**	**Qff**	**QTg**
Benzo(a)pyrene	**200**	**200**	**200**	**200**	**200**	**200**
Naphthalene	**620**	**620**	**620**	**620**	**620**	**620**
PCP	**100**	**100**	**100**	**100**	**100**	**100**
Di-(2-ethylhexyl) phthalate	**600**	**600**	**600**	**600**	**600**	**600**
2,4-D	**7,000**	**7,000**	**7,000**	125	126	121
Methoxychlor	**4,000**	**4,000**	**4,000**	**4,000**	**4,000**	**4,000**
Toluene	**100,000**	**100,000**	**100,000**	1,900	2,150	1,930

Bold: Action Level is capped at a concentration of 100 times the MADL

Table 18: Action Levels for Stormwater Pollutants at UICs with 7 Feet Separation Distance

	Average Scenario			Reasonable Maximum Scenario		
Pollutant (µg/L)	**Qfc**	**Qff**	**QTg**	**Qfc**	**Qff**	**QTg**
Benzo(a)pyrene	**200**	**200**	**200**	**200**	**200**	**200**
Naphthalene	**620**	**620**	**620**	**620**	**620**	**620**
PCP	**100**	**100**	**100**	**100**	**100**	**100**
Di-(2-ethylhexyl) phthalate	**600**	**600**	**600**	**600**	**600**	**600**
2,4-D	**7,000**	**7,000**	**7,000**	126	126	187
Methoxychlor	**4,000**	**4,000**	**4,000**	**4,000**	**4,000**	**4,000**
Toluene	**100,000**	**100,000**	**100,000**	1,930	2,320	10,590

Bold: Action Level is capped at a concentration of 100 times the MADL

Metals: Action levels were not determined for metals. Instead, the time before the metal concentration would breakthrough at concentrations above the MADL was estimated. Breakthrough time was estimated instead of an action level because metals do not degrade (i.e., they are persistent) and will breakthrough given sufficient time. For the average scenario, the average metal concentrations were estimated using data from the City's Year 1 and 2 UIC stormwater discharge monitoring program. This average concentration was used as the influent stormwater concentration and for the reasonable maximum scenario, the 90% UCL concentration calculated from the Year 1 and 2 monitoring data was used as the influent stormwater concentration. Assuming breakthrough occurs, the maximum copper or lead concentration predicted at the water table in both the average and reasonable maximum scenarios was below the MADL for all three geologic units evaluated and for both the 5 foot and 7 foot separation distances. These results demonstrate that metals concentrations in stormwater discharges to City-owned UICs are not reasonably likely to adversely impact groundwater quality.

To estimate the time it would take for the observed stormwater discharge metal concentrations to reach groundwater, the number of days calculated in the fate and transport analysis was divided by the number of days per year stormwater flows into the UICs (12.86). Tables 19 and 20 present the time in years until the maximum metals concentration (still at concentrations below applicable MADLs) is observed at the water table.

Table 19: Time for Copper and Lead Entering UICs with 5 Feet Separation Distance to Reach Their Maximum Concentration at the Water Table (Years)

	Average Scenario			Reasonable Maximum Scenario		
Pollutant	**Qfc**	**Qff**	**QTg**	**Qfc**	**Qff**	**QTg**
Copper	47,000	75,000	460,000	4,500	13,000	45,000
Lead	620,000	1,000,000	6,000,000	90,000	250,000	850,000

Table 20: Time for Copper and Lead Entering UICs with 7 Feet Separation Distance to Reach Their Maximum Concentration at the Water Table (Years)

	Average Scenario			Reasonable Maximum Scenario		
Pollutant	**Qfc**	**Qff**	**QTg**	**Qfc**	**Qff**	**QTg**
Copper	65,000	115,000	620,000	6,000	18,000	630,000
Lead	850,000	1,500,000	8,500,000	125,000	375,000	1,200,000

8 Findings and Recommendations

8.1 Uncertainty Analyses

The separation distance analyses presented in this technical memorandum were performed using conservative assumptions due to the uncertainties associated with each of the input parameters. Table 21 presents a summary of the uncertainty associated with each of the key parameters used in the analyses presented in this document. This table demonstrates the compounding conservatism that is introduced to the reasonable maximum scenarios. Therefore, the reasonable maximum action level values should be used with caution, since it is unlikely that all the conservative assumptions would be applicable at a given UIC. The reasonable maximum should be considered as a hypothetical "upper bound".

The average scenario also contains several conservative assumptions; however, it is considered to be the more representative scenario. The average scenario should be used to determine if groundwater quality is reasonably likely to be adversely affected in accordance with OAR 340-040. Stormwater entering City UICs at concentrations below the action levels presented in Tables 17 and 18, is not expected to reach or impact groundwater at concentrations above the pollutants' respective MADLs, if the separation distance of 5 feet or greater is present. It should be noted that pollutant concentrations measured by the UIC monitoring program in Years 1 and 2 are all less than their respective MADLs with the exception of lead, pentachlorophenol, and DEHP. Pentachlorophenol is the only pollutant in stormwater discharge to City-owned UICs whose annual mean concentration has exceeded the MADL in selected UICs. The annual average pentachlorophenol concentrations in Years 1 and 2 are less than 3 μg/L, significantly less than the 100 μg/L action level set for a 5 foot or 7 foot separation distance. It should be noted that the "action level" was reasonably capped at 100 times the MADL and not set because of predicted adverse impacts to groundwater.

8.2 Findings

City of Portland WPCF permit compliance is based on pollutant concentrations detected at the point stormwater enters the top of the UIC (i.e., end-of pipe) and does not account for the treatment/removal (i.e., attenuation) of pollutants by subsurface soils between the point of discharge and seasonal high groundwater. Using the soil and chemical input parameters and the one-dimensional pollutant fate and transport equation presented in Section 5, it was determined:

- Representative pollutants measured in stormwater discharges to City-owned UICs would be attenuated during unsaturated zone transport with vertical separation distances of $\geq$ 5 feet in the three geologic units in which City-owned UICs are completed.
- Pollutant MADL exceedences (i.e., Year 1 and Year 2 MADL exceedances) measured at the end of pipe (i.e., compliance point) are not reasonably likely to reach groundwater under either average or reasonable maximum scenario conditions if a separation

distance ≥ 5 feet is present (Note: minimum protective separation distances of less than 5 feet were not determined. Category 3 UICs with separation distances of less than 5 feet were identified for corrective action in the *UICMP Annual Report: Year 2* (BES, 2007b)).

- As was expected, based on the literature review, the unsaturated soils have the capacity to treat the types of pollutants and the low concentrations of pollutants that enter the UICs via urban stormwater. Pollutants are treated in the unsaturated zone by filtration, sorption and biodegradation processes. In addition, it is likely that the treatment capacity of the unsaturated zone around the UICs is enhanced by the organic carbon found in stormwater which continues to be added to the unsaturated zone.
- Stormwater concentrations at 100 times the MADLs are not reasonably likely to adversely impact groundwater quality in accordance with OAR 340-040 under the average scenario. These values are identified as "action levels" (i.e., screening levels) to identify when further evaluation, response action, or corrective actions may be required under the permit. It should be noted that observed stormwater discharge concentrations are well below these action levels.
- The results of the analyses presented in this document are consistent with DEQ's review of regional groundwater quality data that did not indicate adverse impacts to groundwater quality from UICs (DEQ, 2005).
- The results of the fate and transport evaluation demonstrate that the overarching goal of the permit to protect the highest beneficial use of groundwater, while allowing underground injection of urban stormwater from city rights-of-way, is attained even in the event of reduced separation distances and/or low level exceedences of the permit MADLs.

The evaluations presented in this document used site-specific information, where available, to assess if groundwater quality is protected in accordance with OAR 340-040. The analyses were performed in accordance with *UICER 6 – Groundwater Protectiveness Demonstration*, included in Appendix H of the UICMP (BES, 2006a) and with DEQ input.

8.3 Use of Findings

The analyses presented in this technical memorandum will be:

- Incorporated in the Generic Groundwater Protectiveness tool currently being prepared, with DEQ input, for DEQ review and approval. This tool will be used to assist the City and DEQ in evaluating the fate and transport of pollutants discharged to the City's UICs and in developing a consistent, streamlined decision-making process for evaluating when response and corrective actions are needed.

- Used in a future technical memorandum to document that a Groundwater Protectiveness Demonstration (i.e., risk assessment) is an appropriate corrective action response for selected Category 3 UICs and that expected stormwater discharges to these UICs are protective of beneficial uses of groundwater and public health and the environment as required by OAR 340-040.

Table 21: Summary of Fate and Transport Analyses Uncertainty

Parameter	Symbol	Units	Analyses Sensitivity	Average	Reasonable Maximum	Level of Confidence	Uncertainty
Separation Distance	L	m	Moderate	Conservative	Conservative	High	Based on Portland Specific groundwater elevation data developed by USGS. Separation distances used are depths to "seasonal" high groundwater. The mean depth to groundwater is 3 feet lower in most areas. Water levels fluctuate seasonally and would be lower approximately 11 months of the year.
Porosity	η	(-)	Moderate	Conservative	Conservative	Moderate	Values used are in low range of soil porosity and therefore conservative in that it increases pore water velocities and decreases travel times. Values selected based on best professional judgement.
Soil Moisture Content	Θ	(-)	High	Conservative	Concervative	Low	Porosity was used in the advection dispersion equation to err on the conservative side as the moisture conect will cycle between nearly saturated and irriducible water content due to the variable timing of rainstorms capable of producing enough stormwater to flow to the UICs.
Soil Bulk Density	ρ_b	g/cm^3	Low	Conservative	Conservative	High	Based on literature values and best professional judgement.
Fraction Organic Carbon	f_{oc}	(-)	High	Reasonable	Conservative	Moderate	Estimates based on the low range of TOC in stormwater reported by EPA (11-50 ppm) and available local stormwater TOC data (including limited UIC TOC monitoring).
Organic Carbon Partitioning Coefficient	K_{oc}	L/kg	Moderate	Reasonable	Conservative	Moderate	Selection of Koc values considered local pH and and dissolved oxygen conditions. PCP values specifically chosen based on its pH dependance.
Degradation Rate Constant (pollutant specific)	k	d^{-1}	High	Reasonable	Conservative	Moderate	Values uses are based on peer reviewed literature for degradation in low concentration environments where available. For PCP, a the degradation rate was conservatively selected as 10 percent of literature values.

Table 21: Summary of Fate and Transport Analyses Uncertainty

Parameter	Symbol	Units	Analyses Sensitivity	Average	Reasonable Maximum	Level of Confidence	Uncertainty
Pore Water Velocity	V	m/day	High	Reasonable	Conservative	Moderate	Derived from local and site specific data. Average case used the mean calculated velocity using borehole infiltration analyses of Portland sump capacity tests and RM case based on 90th UCL of the results of this anlyses.
Pollutant Concentration	C_0	µg/L	Moderate	Reasonable	Conservative	High	Data from Portland's UIC monitoring program. UICs representative of Portland's system are collected from each location five times per year. Data from 2 years of monitoring were used. Available data shows a narrow concentration range for most pollutants. Mean concentration used for Average scenarion and 90th UCL for the RM scenario.
Distribution Coefficient	K_d	(-)	Moderate	Reasonable	Conservative	High	For organics, the distribution coefficient was calculated by multiplying the foc by the Koc. To be conservative, the lowest-reported Koc value from the literature was used for the reasonable maximum scenario. For metals, the distribution coefficient was estimated from equations in Bricker (1998) using site specific information. To be conservative, the 10th percentile value from the literature was used for the reasonable maximum scenario.
Hydraulic Conductivity	K	m/day	High	Reasonable	Conservative	Moderate	Calculated from over 100 BES UIC sump capacity tests using the pump-in test calculation. Use mean for Average scenario and 90th UCL for RM scenario.
Dispsersion Coefficent	α	m	Moderate	Conservative	Conservative	Moderate	Use a dispersivity of L/20, or 0.05. According to tracer tests in the unsaturated zone and literature review by SSPA (2008); the dispersivity in the unsaturated zone is closer to 0.01. However, since there is an influx of water from the UICs, an average between the unsaturated condition and saturated condition was used.

9 Works Cited

Alexander, M., Wagenet, R. J., Baveye, P.C., Gannon, J.T., Mingelgrin, U. and Tan, Y. (1991). Movement of Bacteria through Soil and Aquifer Sand. EPA 600/2-91/010.

Allison, J.D., and Allison, T.L. (2005). Partition Coefficients for Metals in Surface Water, Soil, and Waste. U.S. EPA, Athens, GA. EPA/600/R-05-074.

Anderson, M. P., and Woessner, W. W. (1992). *Applied Groundwater Modeling: Simulation of Flow and Advective Transport.* Academic Press: San Diego, California, 381 pp.

Aronson, D., Citra, M., Shuler, K., Printup, H., and Howard, P.H. (1999). Aerobic Biodegradation of Organic Chemicals in Environmental Media: A Summary of Field and Laboratory Studies, Final Report. U.S. EPA.

Ashok, B.T., Saxena, S., Singh, K.P., and Musarrat, J. (1995). Short communication: Biodegradation of polycyclic aromatic hydrocarbons in soil around Mathura oil refinery. *World J. Microbiol. Biotechnol*. 11, 691-692.

Azadpour-Keeley, A., Faulkner, B. R., and Chen, J. (2003). Movement and Longevity of Viruses in the Subsurface. EPA/540/S-03/500, April 2003.

BES (2006a). *Underground Injection Control Management Plan*. Prepared by: City of Portland Bureau of Environmental Services, December.

BES (2006b). *Corrective Action Plan*. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2006c). *Stormwater Discharge Monitoring Annual Report: Year 1 – October 2005 to May 2006*. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2006d). *Systemwide Assessment*. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2006e). *UIC Management Plan Annual Report: Year 1*. Prepared by: City of Portland Bureau of Environmental Services, December.

BES (2006f). *Systemwide Assessment Follow-up Actions*. Prepared by: City of Portland Bureau of Environmental Services, December.

BES (2006g). *Stormwater Discharge Monitoring Plan*. Prepared by: City of Portland Bureau of Environmental Services, February.

BES (2007a). *Stormwater Discharge Monitoring Annual Report: Year 2 – October 2006 to May 2007*. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2007b). *UIC Management Plan Annual Report: Year 2*. Prepared by: City of Portland Bureau of Environmental Services, November.

Bossart, I.D., and Bartha, R. (1986). Structure-biodegradability relationships of polycyclic aromatic hydrocarbons in soil. *Bull. Environ. Contam. Toxicol*. 37, 490-495.

Bouma, J., Ziebell, W.A., Walker, W.G., Olcutt, P.G., McCoy, E., and Hole, F.D. (1972). "Soil Absorption of Septic Tank Effluent", Extension Circular No. 20, University of Wisconsin, Madison.

Bricker, O. P. (1998). An Overview of the Factors Involved in Evaluating the Geochemical Effects of Highway Runoff on the Environment, USGS.

Caldwell, E.L., and Parr, L.W. (1937). Groundwater pollution and the bored hole latrine. *J. Infectious Diseases* 61,148-183.

Cantor, L.W., and Knox, R.C. (1985). Groundwater Pollution from Septic Tank Systems. In *Septic Tank System Effects on Ground Water Quality*. Lewis Publishers, Inc., pp. 333.

Carmichael, L.M., and Pfaender, F.K. (1997). Polynuclear aromatic hydrocarbon metabolism in soils: Relationship to soil characteristics and preexposure. *Environ. Toxicol. Chem*. 16, 666-675.

Cave, B., and Kolsky, P. (1999). WELL Study, Groundwater, latrines and health, Task No:163. Prepared for Well Water and Environmental Health at London and Loughborough.

Chinalia, F.A., and Killham, K.S. (2006). 2,4-Dichlorophenoxyacetic acid (2,4-D) biodegradation in river sediments of Northeast-Scotland and its effect on the microbial communities (PLFA and DGGE): *Chemosphere,* 64, 1675-1683.

Coover, M.P., and Sims, R.C. (1987). The effect of temperature on polycyclic aromatic hydrocarbon persistence in an unacclimated agricultural soil. *Hazard. Waste & Hazard. Mater.* 4, 69-82.

Davis, J.W., and Madsen, S. (1996). Factors affecting the biodegradation of toluene in soil: *Chemosphere*, 33, 107-130.

DEQ (1998). Guidance for Conduct of Deterministic Human Health Risk Assessments.

DEQ (2005). Fact Sheet and Class V Underground Injection Control (UIC) WPCF Permit Evaluation, Permit Number 102830. Date Permit Issued: June 1, 2005.

DEQ (2007). Environmental Cleanup and Tanks Program: Risk-based Concentrations for Individual Chemicals. March 20, 2007 revision.

DEQ (2007). Oregon Department of Environmental Quality Risk-Based Decision Making. July 4, 2007 revision.

DEQ (2008). E-mail comments from Henning Larsen/DEQ to Rodney Struck/BES regarding the Category 4 Corrective Action Groundwater Protectiveness Demonstration.

Deschenes, L., Lafrance, P., Villeneuve, J.P., and Samson, R. (1996). Adding sodium dodecyl sulfate and Pseudomonas aeruginosa UG2 biosurfactants inhibits polycyclic aromatic hydrocarbon biodegradation in a weathered creosote-contaminated soil. *Appl. Microbiol. Biotechnol*. 46, 638-646.

Department of Local Government & Planning (2004). On-Site Sewerage Facilities: Guidelines for Vertical and Horizontal Separation Distance, Queensland, Australia. January 2004.

Dorfler, U., Haala, R., Matthies, M., and Scheunert, I. (1996). Mineralization kinetics of chemicals in soils in relation to environmental conditions. *Ecotoxicol. Environ. Safety*. 34, 216-222.

Efroymson, R.A., and Alexander, M. (1994). Biodegradation in soil of hydrophobic pollutants in nonaqueous-phase liquids (NAPLs). *Environ. Toxicol. Chem*. 13, 405-411.

Ellis, B., Harold, P., and Kronberg, H. (1991). Bioremediation of a creosote contaminated site. *Environ. Technol*. 12, 447-459.

Engstrom, A.M. (2004). Characterizing Water Quality of Urban Stormwater Runoff: Interactions of Heavy Metals and Solids in Seattle Residential Catchments, University of Washington.

EPA (1980). Design Manual - Onsite Wastewater Treatment and Disposal Systems, EPA 625/1-80-012. U.S.EPA, Washington D.C.

EPA (1996). Soil Screening Guidance: Technical Background Document. Office of Solid Waste and Emergency Response, Washington, DC. May. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/index.htm

EPA (1999). The Class V Underground Injection Control Study. EPA 816-R-014c, Volume 3 Storm Water Drainage Wells, September 1999.

EPA (2001). Fact Sheet: Correcting the Henry's Law Constant for Soil Temperature.

EPA (2004). 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).

EPA (2007). Human Health Medium-Specific Screening Values. http://www.epa.gov/Region6/6pd/rcra_c/pd-n/screenvalues.xls

EPA (2008a). National Primary Drinking Water Standards. Available online at: http://www.epa.gov/safewater/contaminants/index.html. Downloaded by GSI on 21 January 2008.

EPA (2008b). 2,4-D RED Facts. Available online at: http://www.epa.gov/OGWDW/dwh/t-soc/24d-fs.htm.

EPA (2008c). Technical Fact Sheet on 2,4-D. Available online at: http://www.epa.gov/OGWDW/dwh/t-soc/24-d.htm.

EPA (2008d). Technical Fact Sheet on Toluene. Available online at: http://www.epa.gov/OGWDW/dwh/t-voc/toluene.htm.

EPA (2008e). Technical Fact Sheet on methoxychlor. Available online at: http://www.epa.gov/OGWDW/dwh/t-soc/methoxyc.htm.

Fairbanks, B.C., O'Connor, G. A., and Smith, S. E. (1985). Fate of di-2-(ethylhexyl)phthalate in three sludge-amended New Mexico soils. *J. Environ. Qual*. 14, 479-483.

Fan, S., and Scow, K. M. (1993). Biodegradation of trichloroethylene and toluene by indigenous microbial populations in soil. *Appl. Environ. Microbiol*. 59, 1911-1918.

Faulkner, B. R., Lyon, W. G., Khan, F. A., and Chattopadhyay, S. (2002). Predicting Attenuation of Viruses during Percolation in Soils. EPA 600/R-02/051a and b.

Fetter, C. W. (1994). *Applied Hydrogeology*. 3rd Ed. Prentice Hall: Upper Saddle River, New Jersey. 691 pp.

Flemming, J.T., Sanseverino, J., and Saylor, G. S. (1993). Quantitative relationship between naphthalene catabolic gene frequency and expression in predicting PAH degradation in soils at town gas manufacturing sites. *Environ. Sci. Technol.* 27, 1068-1074.

Fogel, S., Lancione, R., Sewall, A., and Boethling, R. S. (1982). Enhanced biodegradation of methoxychlor in soil under enhanced environmental conditions. *Appl. Environ. Microbiol.* 44, 113-120.

Fogel, S., Findlay, M., Scholl, C., and Warminsky, M. (1995). Biodegradation and bioavailability of bis(2-ethylhexyl)phthalate in soil. In: *Intrinsic Biorem.* 3rd. Ed. Hinchee, R.E., et. al. (Eds). Battelle Press: Columbus, OH. pp. 315-322.

Freeze, A., and Cherry, J. A. (1979). *Groundwater.* Prentice Hall: Englewood Cliffs, N.J. 604pp.

Fuller, M.E., Mu, D. Y., and Scow, K. M. (1995). Biodegradation of trichloroethylene and toluene by indigenousmicrobial populations in unsaturated sediments. *Microb. Ecol.* 29.

Gelhar, L. W., Mantoglu, A., Welty, C. , and Rehfeldt, K. R. (1985). A Review of Field-Scale Physical Solute Transport Processes in Saturated and Unsaturated Porous Media. EPRI EA-4190, Project 2485-5, Final Report, Electric Power Research Institute.

Gelhar, L.W., Welty, C., and Rehfeldt, K.R. (1992). A critical review of data on field-scale dispersion in aquifers. *Water Resources Research* 28: 1955-1974.

Grosser, R.J., Warshawsky, D., and Vestal, J.R. (1991). Indigenous and enhanced mineralization of pyrene, benzo(a)pyrene, and carbazole in soils. *Appl. Environ. Microbiol.* 57, 3462-3469.

Grosser, R.J., Warshawsky, D., and Vestal, J.R. (1995). Mineralization of polycyclic and N-heterocyclic aromatic compounds in hydrocarbon-contaminated soils. *Environ. Toxicol. Chem*. 14, 375-382.

GSI (2008). Category 4 UIC Corrective Actions Groundwater Protectiveness Demonstration. Prepared for: City of Portland Bureau of Environmental Services.

Hagedorn, C., McCoy, E.L., and Rahe, T.M. (1981). The potential for ground water contamination from septic effluents. *J. Environmental Quality* 10, 1-8.

Hansel, M.J., and Machmeier, R.E. (1980). "Onsite Wastewater Treatment on Problem Soils", *Journal of Water Pollution Control Federation* 52(3), 548-558.

Hartford, S.V., and McFarland, W.D. (1989). Lithology, Thickness, and Extent of the Hydrogeologic Units Underlying the East Portland Basin Area, Oregon, U.S. Geological Survey Water-Resources Investigation Report 88-4110, 23p.

Hornsby, A.G., Wachope, R. D., and Herner, A.E. (1996). Pesticide Properties in the Environment, Springer.

Howard, P.H., Boethling, R.S., Jarvis, W.F. , Meylan, M.W., Michalenco, E.M., Editors. (1991). *Handbook of Environmental Degradation Rates.* Lewis Publishers, Inc., Chelsea, Michigan, U.S.A.

HYDRA (2008). Rainfall at Kelly School Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov./non-usgs/bes/

Jin, Y., Streck, T., and Jury, W.A. (1994). Transport and biodegradation of toluene in unsaturated soil. *J. Contam. Hydrol*. 17, 111-127.

Jury, W. A., Winer, A. M., Spencer, W. F., Focht, D. D. (1987) Transport and transformations of organic chemicals in the soil-air water ecosystem. *Rev. Environ. Contam. Toxicol.* 99, 120-164.

Kaufman, D. D. (1976). Soil degradation and persistence. In: A Literature Survey of Benchmark Pesticides. pp. 19-71. The George Washington University Medical Center, Dept. of Medical and Public Affairs, Science Communication Division, Washington DC.

Kayhanian, M., Suverkropp, C., Ruby, A., and Tsay, K. (2007). Characterization and prediction of highway runoff constituent event mean concentration. *Journal of Environmental Management* 85, 279-295.

Keck, J., Sims, R.C., Coover, M., Park, K., and Symons, B. (1989). Evidence for cooxidation of polynuclear aromatic hydrocarbons in soil. *Wat. Res*. 23, 1467-1476.

Keswick, B.H., Gerba, C.P., Seco, S.L., and Cech, I. (1982). Survival of entetic viruses and indicator bacteria in ground water*. J. Environ. Sci. Health*. 17 (6), 903-912.

Kjeldsen, P., Dalager, A., and Broholm, K. (1997). Attenuation of methane and nonmethane organic compounds in landfill gas affected soils*. J. Air & Waste Manage. Assoc*. 47, 1268-1275.

Langmuir, D.L., Chrostowski, P., Chaney, R.L., and Vigneault, B. (2004). Issue paper on the environmental chemistry of metals. US-EPA Risk Assessment Forum: Papers Addressing Scientific Issues in the Risk Assessment of Metals.

Laxen, D.P.H, and Harrison, R.M. (1977). The highway as a source of water pollution: An appraisal with the heavy metal lead. *Water Research* 11.

Lewis, W. J., et. al., (1980). The risk of groundwater pollution by on-site sanitation in developing countries: a literature review, International Reference Centre for Wastes Disposal.

Maag, J., and Loekke, H. (1990). Landfarming of DEHP contaminated soil. In: *Contaminated Soil* '90. F. Arendt, et. al. (Eds.). pp. 975-982.

Mackay, D., Sharpe, S., Cahill, T., Gouin, T., Cousins, I., and Toose, L. (2001). Assessing the Environmental Persistence of a Variety of Chemical Substances Including Metals. CEMC Report No. 200104. Trent University, Peterborough, Ontario.

Mackay, D. (2006). *Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals*, CRC Press.

Madin, I. (1990). Earthquake Hazard Geology Maps of the Portland Metropolitan Area, Oregon. Open File Report: 0-90-2.

Mayer, F.L., and Sanders, H.O. (1973). Toxicology of phthalic acid esters in aquatic organisms. *Environ. Health Prospect*. 3, 153-157.

McCall, P. J., Vrona, S.A., and Kelley, S.S. (1981). Fate of uniformly carbon-14 ring labeled 2,4,5-trichlorophenoxyacetic acid and 2,4 dichlorophenoxyacetic acid. J. *Agric. Food Chem*. 29, 100-107.

McFeters, G. A., Bossonnette, G.K., Jezeski, J.J., Thomson, C.A., and Stuart, D.G. (1974). Comparitive survival of indicator bacteria and enteric pathogens in well water. *Applied Microbiology*. 27(5), 823-829.

McNabb, J.F., Smith, B.H., and Wilson, J.T. (1981). Biodegradation of toluene and chlorobenzene in soil and groundwater. 81st Annual Meeting of the Amer. Society for Microbiology. Dallas, TX. March 1-6. 213 pp.

Mihelcic, J.R., and Luthy, R.G. (1988). Microbial degradation of acenaphthalene and naphthalene under denitrification conditions in soil-water systems. *Appl. Environ. Microbiol.* 54, 1188-1198.

Mu, D.Y., and Scow, K.M. (1994). Effect of trichloroethylene (TCE) and toluene concentrations on TCE and toluene biodegradation and the population density of TCE and toluene degraders in soil. *Appl. Environ. Microbiol*. 60, 2661-2665.

Mueller, J.G., Middaugh, D.P., Lantz, S.E., and Chapman, P.J. (1991). Biodegradation of creosote and pentachlorophenol in contaminated groundwater: Chemical and biological assessment. *Appl. Environ. Microbiol*. 57, 1277-1285.

Nash, R. G. (1983). Determining environmental fate of pesticides with microagroecosystems. *Res. Rev*. 85, 199-215.

Neville, C. J., and Vlassopoulos, D. (2008). Peer Review of UIC Category 4 Groundwater Protectiveness Demonstration. S.S. Papadopulos, Inc. Prepared for City of Portland Bureau of Environmental Services.

Park, K.S., Simms, R.C., Dupont, R.R., Doucette, W.J., and Matthews, J.E. (1990). Fate of PAH compounds in two soil types: Influence of volatilization, abiotic loss and biological activity. *Environ. Toxicol. Chem*. 9, 187-195.

Pitt, R. (1998). Epidemiology and Stormwater Management. In Stormwater Quality Management. CRC/Lewis Publishers. New York, NY.

Pitt, R., Maestre, A., and Morquecho, R. (2004). The National Stormwater Quality Database (NSQD, version 1.1): Department of Civil and Environmental Engineering University of Alabama, AL http://unix. eng. ua. edu/rpitt/research/ms4/paper/recentpaper. html, February.

Pott, B.M., and Henrysson, T. (1995). Ex situ bioremediation of polycyclic aromatic hydrocarbons in laboratory systems. In: Intrinsic Biorem. [Pap. Int. In Situ On-Site Bioreclam. Symp.]. 3rd. Hinchee R.E. et. al. (Eds). Battelle Press: Columbus, OH. pp. 39-44.

Ruedel, H., Schmid, T.S., Koerdel, W., and Klein, W. (1993). Degradation of pesticides in soil: Comparison of laboratory experiments in a biometer system and outdoor lysimeter experiments. *Sci. Total Environ*. 132, 181-200.

Scheunert, I., Vockel, D., Schmitzer, J., and Korte, F. (1987). Biomineralization rates of 14C-labelled organic chemicals in aerobic and anaerobic suspended soil. *Chemosphere.* 16, 1031-1041.

Schmidt, K. (1985). Results of Dry Well Monitoring Project for a Commercial Site in Phoenix Urban Area. Phoenix AZ: Maricopa association of Governments.

Schmitzer, J.L., Scheunert, I., and Korte, F. (1988). Fate of bis(2-ethylhexyl) [14C]phthalate in laboratory and outdoor soil-plant systems. *J. Agric. Food Chem*. 36, 210-215.

Schueler, T. (1999). Microbes and urban watersheds: Concentrations, sources and pathways. *Watershed Protection Techniques*. 3(1), 554-565.

Shanker, R., Ramakrishna, C., and Seth, P.K. (1985). Degradation of some phthalic acid esters in soil. *Environ. Pollut*. 39, 1-7.

Smith, M.J. (1997). Bioavailability and biodegradation of polycyclic aromatic hydrocarbons in soils. *FEMS Microbiol. Lett.* 152, 141-147.

Stephens, D. B. (1996). *Unsaturated Zone Hydrology*. Lewis Publishers, Boca Raton: Florida, 347 pp.

Swindoll, C.M., Aelion, C.M., and Pfaender, F.K. (1988). Influence of inorganic and organic nutrients on aerobic biodegradation and on the adaptation response of subsurface microbial communities. *Appl. Environ. Microbiol*. 54, 212-217.

Trimble, D.E. (1963). Geology of Portland Oregon and adjacent areas, U.S. Geological Survey Bulletin 1119. 119 p.

Toraeng, L., Nyholm, N., and Albrechtsen, H.G. (2003). Shifts in biodegradation kinetics of the herbicides MCPP and 2,4-D at low concentrations in aerobic aquifer materials. *Environmental Science and Technology* 37, 3090-3103.

USDI (1993). *Drainage Manual: A Water Resources Technical Publication*. US Department of the Interior-Bureau of Reclamation.

USGS (1996a). Description of the Groundwater Flow System in the Portland Basin, Oregon and Washington. USGS Water Supply Paper 2470-A. United States Government Printing Office, Washington, 56 p.

USGS (1996b). Simulation Analysis of the Groundwater Flow System in the Portland Basin, Oregon and Washington. USGS Water Supply Paper 2470-B. United States Government Printing Office, Washington.

USGS (1998a). Geologic Framework of the Willamette Lowland Aquifer System, Washington and Oregon. Regional Aquifer System Analysis – Pugent Willamette Lowland. USGS Professional Paper 1424-A. United States Government Printing Office, Washington, 32 pp.

USGS (1998b). Use of a Ground-Water Flow Model with Particle Tracking to Evaluate Ground-Water Vulnerability, Clark County, Washington. Water Supply Paper 2488. United States Government Printing Office. Washington.

USGS (2008). Estimation of Depth to Groundwater and Configuration of the Water Table in the Portland, Oregon Area - Colleague Review Draft (dated April 24, 2007). It should be noted that the information presented in the USGS report is draft and subject to change after USGS publication of the document.

Venkatraman, S.N., Kosson, D.S., and Schuring, J.R. (1998). Transport and biological fate of toluene in low permeability soils. *GWMR*. 18, 105-113.

Washington Department of Ecology (2006). Guidance for UIC Wells that Manage Stormwater. Water Quality Program, Publication 05-10-067.

Watts, R. J. (1998). *Hazardous Wastes: Sources, Pathways, Receptors*. John Wiley and Sons, New York: New York.

Wild, S.R., and Jones, K.C. (1993). Biological and abiotic losses of polynuclear aromatic hydrocarbons (PAHs) from soils freshly amended with sewage sludge. *Environ Toxicol. Chem*. 12, 5-12.

Wilhelm, S. R., Schiff, S.L., and Robertson, W.D. (1994). Chemical fate and transport in a domestic septic system: Unsaturated and saturated zone geochemistry. *Environmental Technology and Chemistry* 13(2), 193-203.

Wilson, J.T., Enfield, C.G., Dunlap, W.J., Cosby, R.L., Foster, D.A., and Baskin, L.B. (1981). Transport and fate of selected organic pollutants in a sandy soil. *J. Environ. Qual*. 10, 501-506.

Wischmann, H., and Steinhart, H. (1997). The formation of PAH oxidation products in soils and soil/compost mixtures. *Chemosphere*. 35, 1681-1698.

World Health Organization (2006). Overview of reywater management: Health considerations. WHO-EM/CEH/125/E.

Yeager, J. G., and O'Brien, R.T. (1979). Entervirus inactivation in Soil, *Appl. Environ. Microbiol*. 38, 694-701.

Ziebell, W.A., Nero, D.H., Deininger, J.F., and McCoy, E. (1974). Use of Bacteria in Assessing Waste Treatment and Soil Disposal Systems. Home Sewage treatment, *American Society of Agricultural Engineers Publication Proc-175*, St. Joseph, MI, p.58.

Appendix A.1
Qfc - Coarse Grained Facies of the UG
Separation Distance > 5 Feet

	Parameter	Symbol	Units	Metals				PAHs			
				Copper		Lead		Benzo(a)pyrene		Naphthalene	
				Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
	Concentration	C_0	mg/L	0.00245 [1]	0.01446 [2]	0.00256 [3]	0.01998 [4]				
	Infiltration Time	t	d	600,000 [5]	55,000 [5]	7,900,000 [5]	1,150,000 [5]	12.86 [6]	12.86 [6]	12.86 [6]	12.86 [7]
Chemical Properties	First-Order Rate Constant	k	d^{-1}					1.30E-03 [8]	2.60E-04 [9]	7.50E-02 [8]	2.50E-02 [9]
	Half-Life	h	d					533 [12]	2666 [12]	9 [12]	28 [12]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]
	Fraction Organic Carbon	f_{oc}	-					0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg					282,185 [16]	282,185 [16, 17]	1,300 [16]	830 [18]
	Distribution Coefficient	K_d	L/kg	76,163 [26]	17,255 [27]	1,001,923 [26]	343,064 [27]	5,093 [28]	2,283 [28]	23.5 [28]	6.7 [28]
	Pore Water Velocity	v	m/d	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]
Calculations	Retardation Factor	R	-	419,190	94,970	5,514,431	1,888,172	28,032	12,566	130	38.0
	Dispersion Coefficient	D	m^2/d	8.01E-02	1.88E-01	7.99E-02	1.88E-01	7.99E-02	1.88E-01	7.99E-02	1.88E-01
	Normalized Dispersion	D'	m^2/d	1.91E-07	1.98E-06	1.45E-08	9.95E-08	2.85E-06	1.50E-05	6.14E-04	4.95E-03
	Normalized Velocity	v'	m/d	2.51E-06	2.60E-05	1.91E-07	1.31E-06	3.75E-05	1.97E-04	8.08E-03	6.51E-02
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.64E-08	2.07E-08	5.76E-04	6.59E-04
	A_1	-	-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.88E-03	-1.60E-04	-1.08E-01	-1.54E-02
	A_2	-	-	2.89E-02	1.33E-01	2.12E-02	2.04E-02	1.26E+02	5.47E+01	7.96E+00	1.35E+00
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.98E-01	1.00E+00	8.98E-01	9.85E-01
	$erfc(A_2)$	-	-	9.67E-01	8.51E-01	9.76E-01	9.77E-01	0.00E+00	0.00E+00	0.00E+00	5.64E-02
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.01E+01	2.00E+01
	B_2	-	-	4.47E+00	4.47E+00	4.47E+00	4.47E+00	1.26E+02	5.49E+01	9.15E+00	4.67E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.86E+08	4.85E+08	5.40E+08	4.93E+08
	$erfc(B_2)$	-	-	2.54E-10	2.49E-10	2.54E-10	2.54E-10	0.00E+00	0.00E+00	0.00E+00	3.82E-11
	Concentration	C	mg/L	1.34E-03	7.02E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.31E-02
Action Level [34]	Concentration	C	mg/L					0.02	0.02	0.62	0.62
Regulatory Standards	EPA MCLs		mg/L	1.30E+00 [31]		1.50E-02 [31]		2.00E-04 [31]		6.20E-03 [32]	
	MADLs		mg/L	1.30E+00 [33]		5.00E-02 [33]		2.00E-04 [33]		NA	

	Parameter	Symbol	Units	SVOCs				Pesticides/Herbicides				VOCs	
				PCP		di-(2-ethylhexyl) phthalate		2,4-D		Methoxychlor		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	Separation Distance	y	m	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
	Concentration	C_0	mg/L										
	Infiltration Time	t	d	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [6]	12.86 [6]	1.15 [7]	12.86 [6]	12.86 [6]	12.86 [6]	1.61 [7]
Chemical Properties	First-Order Rate Constant	k	d^{-1}	2.21E-02 [10]	1.39E-02 [11]	1.50E-02 [8]	1.00E-02 [9]	5.30E-03 [8]	2.20E-03 [9]	1.10E-02 [8]	4.40E-03 [9]	3.30E-01 [8]	8.20E-02 [9]
	Half-Life	h	d	31 [12]	50 [12]	46 [12]	69 [12]	131 [12]	315 [12]	63 [12]	158 [12]	2 [12]	8 [12]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]
	Fraction Organic Carbon	f_{oc}	-	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg	877 [19]	703 [19]	12,200 [16]	12,200 [16, 17]	201 [20]	20 [21]	97,700 [22]	9,700 [23]	182 [24]	37 [25]
	Distribution Coefficient	K_d	L/kg	15.8 [28]	5.7 [28]	220.2 [28]	98.7 [28]	3.6 [28]	0.159 [28]	1,763 [28]	78.5 [28]	3.3 [28]	0.30 [28]
	Pore Water Velocity	v	m/d	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]
Calculations	Retardation Factor	R	-	88.1	32.3	1,213	544	21.0	1.9	9,706	433	19.1	2.6
	Dispersion Coefficient	D	m^2/d	7.99E-02	1.88E-01	7.99E-02	1.88E-01	7.99E-02	1.88E-01	7.99E-02	1.88E-01	7.99E-02	1.88E-01
	Normalized Dispersion	D'	m^2/d	9.06E-04	5.82E-03	6.59E-05	3.45E-04	3.81E-03	1.00E-01	8.23E-06	4.34E-04	4.19E-03	7.10E-02
	Normalized Velocity	v'	m/d	1.19E-02	7.66E-02	8.67E-04	4.54E-03	5.01E-02	1.32E+00	1.08E-04	5.71E-03	5.51E-02	9.34E-01
	Normalized Degradation	k'	d^{-1}	2.51E-04	4.30E-04	1.24E-05	1.84E-05	2.52E-04	1.17E-03	1.13E-06	1.02E-05	1.73E-02	3.10E-02
	A_1	-	-	-3.19E-02	-8.54E-03	-2.17E-02	-6.14E-03	-7.66E-03	-1.35E-03	-1.59E-02	-2.70E-03	-4.66E-01	-5.03E-02
	A_2	-	-	6.33E+00	9.77E-01	2.59E+01	1.10E+01	1.98E+00	1.78E-03	7.38E+01	9.68E+00	1.68E+00	1.27E-02
	e^{A1}	-	-	9.69E-01	9.91E-01	9.79E-01	9.94E-01	9.92E-01	9.99E-01	9.84E-01	9.97E-01	6.27E-01	9.51E-01
	$erfc(A_2)$	-	-	0.00E+00	1.67E-01	0.00E+00	0.00E+00	5.13E-03	9.98E-01	0.00E+00	0.00E+00	1.77E-02	9.86E-01
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.05E+01	2.01E+01
	B_2	-	-	7.75E+00	4.58E+00	2.63E+01	1.18E+01	4.89E+00	4.47E+00	7.39E+01	1.07E+01	4.87E+00	4.48E+00
	e^{B1}	-	-	5.01E+08	4.89E+08	4.96E+08	4.88E+08	4.89E+08	4.86E+08	4.93E+08	4.86E+08	7.73E+08	5.10E+08
	$erfc(B_2)$	-	-	0.00E+00	9.39E-11	0.00E+00	0.00E+00	4.57E-12	2.53E-10	0.00E+00	0.00E+00	5.52E-12	2.29E-10
	Concentration	C	mg/L	0.00E+00	1.06E-02	0.00E+00	0.00E+00	2.56E-02	7.00E-02	0.00E+00	0.00E+00	7.67E-01	1.00E+00
Action Level [34]	Concentration	C	mg/L	0.10	0.10	0.60	0.60	7.0	0.125	4.0	4.0	100.0	1.90
Regulatory Standards	EPA MCLs		mg/L	1.00E-03 [31]		4.10E-03 [31]		7.00E-02 [31]		4.00E-02 [31]		1.00E+00 [31]	
	MADLs		mg/L	1.00E-03 [33]		6.00E-03		7.00E-02 [33]		NA [33]		1.00E+00 [33]	

NOTES

[1] Average total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
[2] 90% UCL of total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
[3] Average total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
[4] 90% UCL of total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
[5] Infiltration time is the time at which the maximum metals concentration occurs at a point immediately above the water table.
[6] Infiltration time is the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate exceeds 0.04 inches/hour. Because most Category 3 UICs are located in southeast Portland, precipitation was obtained from two raingages located in southeast portland: the Kelly School Raingage (HYDRA, 2008a) and Holgate Raingage (HYRDRA, 2008b). Precipitation data from 1999 to 2007 was used in the analysis, and results from the Holgate and Kelly School Raingages were averaged together using the geometric mean.
[7] Infiltration time is shorter than 12.86 days because the maximum pollutant concentration immediately above the water table occurred prior to the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC.
[8] Median biodegradation rate from a review of scientific literature (see text for references).
[9] 25th percentile biodegradation rate from a review of scientific literature (see text for references).
[10] 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).
[11] 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).
[12] 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.
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[33] Maximum Allowable Discharge Limits (MADLs) from the Water Pollution Control Facilities (WPCF) Permit issued by DEQ to BES in 2005

[34] The action level is the influent concentration that will cause the MADL to be exceeded at a point immediately above the water table in the unsaturated zone. If this concentration was greater than 100 times the MADL, then the action level was set at 100 time the MADL.

ABBREVIATIONS

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SVOCs = Semi-Volatile Organic Compounds
VOCs = Volatile Organic Compounds
PCP = Pentachlorophenol
USGS =United States Geological Survey
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REFERENCES

Bricker, O. P., 1998, An Overview of the Factors Involved in Evaluating the Geochemical Effects of Highway Runoff on the Environment, USGS.
DeAngelo, E. M., and K. R. Reddy, 2000. Aerobic and anaerobic transformations of pentachlorophenol in wetland soils. *Soil Science of America Journal*. 64, pp. 933 - 943.
DOGAMI, 1990. Earthquake hazard geology maps of the Portland metropolitan area, Oregon. Open File Report 0-90-2.
EPA, 1996. Soil Screening Guidance: Technical Background Document. Office of Solid Waste and Emergency Response, Washington, DC. May. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/index.htm
EPA, 2003. National Primary Drinking Water Standards. Office of Water, June 2003. Available online at: www.epa.gov/safewater.
EPA, 2008a. 2,4-D RED Facts. Available online at: http://www.epa.gov/oppsrrd1/REDs/factsheets/24d_fs.htm. Downloaded by GSI on 10 March 2008.
EPA, 2008b. Technical Factsheet on: 2,4-D. Available online at: http://www.epa.gov/OGWDW/dwh/t-soc/24-d.htm. Downloaded by GSI on 15 April 2008.
EPA, 2008c. Technical Factsheet on: Toluene. Available online at: http://www.epa.gov/safewater/dwh/t-voc/toluene.html. Downloaded by GSI on 15 April 2008.
EPA, 2008d. Technical Factsheet on: Methoxychlor. Available online at: http://www.epa.gov/safewater/dwh/t-soc/methoxyc.htm. Downloaded by GSI on 15 April 2008.
Fetter, 1994. Applied Hydrogeology. 3rd Ed. Prentice-Hall, Upper Saddle River, New Jersey: 691 pp.
Freeze and Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, New Jersey: 604 pp.
Green, G. L. 1983. Soil Survey of Multnomah County, Oregon. United States Department of Agriculture – Soil Conservation Service. 225 pp.
HYDRA, 2008a. Rainfall at the Kelly School Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.
HYDRA, 2008b. Rainfall at the Holgate Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.
Schmidt, L. M., J. J. Delfino, J. F. Preston, and G. St Laurent, 1999. Biodegradation of low aqueous concentration pentachlorophenol (PCP) contaminated groundwater. *Chemosphere*. 38, pp. 2897 - 2912.
Watts, R. J. 1998. Hazardous Wastes: Sources, Pathways, Receptors. John Wiley & Sons, Inc., New York: 764 pp.
USDI, 1993. Drainage Manual: A Water Resources Technical Publication. Bureau of Reclamation, 321 pp.

Appendix A.2

Qfc - Coarse Grained Facies of the UG

Separation Distance > 7 Feet

	Parameter	Symbol	Units	Metals				PAHs				SVOCs				Pesticides/Herbicides				VOCs	
				Copper		Lead		Benzo(a)pyrene		Naphthalene		PCP		di-(2-ethylhexyl) phthalate		2,4-D		Methoxychlor		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	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13
	Concentration	C_0	mg/L	0.00245 [1]	0.01446 [2]	0.00256 [3]	0.01998 [4]														
	Infiltration Time	t	d	850,000 [5]	81,000 [5]	11,000,000 [5]	1,620,000 [5]	12.86 [6]	12.86 [6]	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [6]	12.86 [6]	1.61 [7]	12.86 [6]	12.86 [6]	12.86 [6]	2.26 [7]
Chemical Properties	First-Order Rate Constant	k	d^{-1}					1.30E-03 [8]	2.60E-04 [9]	7.50E-02 [8]	2.50E-02 [9]	2.21E-02 [10]	1.39E-02 [11]	1.50E-02 [8]	1.00E-02 [9]	5.10E-03 [8]	2.20E-03 [9]	1.10E-02 [8]	4.40E-03 [9]	3.30E-01 [8]	8.20E-02 [9]
	Half-Life	h	d					533 [12]	2666 [12]	9 [12]	28 [12]	31 [12]	50 [12]	46 [12]	69 [12]	136 [12]	315 [12]	63 [12]	158 [12]	2 [12]	8 [12]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]
	Soil Moisture Content	θ	-	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]
	Fraction Organic Carbon	f_{oc}	-					0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg					282,185 [16]	282,185 [16, 17]	1,300 [16]	830 [18]	877 [19]	703 [19]	12,200 [16]	12,200 [16, 17]	201 [20]	20 [21]	97,700 [22]	9,700 [23]	182 [24]	37 [25]
	Distribution Coefficient	K_d	L/kg	76,163 [26]	17,255 [27]	1,001,923 [26]	343,064 [27]	5,093 [28]	2,283 [28]	23.5 [28]	6.7 [28]	15.8 [28]	5.7 [28]	220.2 [28]	98.7 [28]	3.6 [28]	0.159 [28]	1,763 [28]	78.5 [28]	3.3 [28]	0.30 [28]
	Pore Water Velocity	v	m/d	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]	1.051 [29]	2.473 [30]
Calculations	Retardation Factor	R	-	419,190	94,970	5,514,431	1,888,172	28,032	12,566	130	38.0	88.1	32.3	1,213	544	21.0	1.9	9,706	433	19.1	2.6
	Dispersion Coefficient	D	m^2/d	1.12E-01	2.64E-01	1.12E-01	5.28E-01	1.12E-01	2.64E-01	1.12E-01	2.64E-01	1.12E-01	2.64E-01	1.12E-01	2.64E-01	1.12E-01	2.64E-01	1.12E-01	2.64E-01	1.12E-01	2.64E-01
	Normalized Dispersion	D'	m^2/d	2.67E-07	2.78E-06	2.03E-08	2.79E-07	4.00E-06	2.10E-05	8.62E-04	6.95E-03	1.27E-03	8.17E-03	9.24E-05	4.85E-04	5.34E-03	1.41E-01	1.16E-05	6.09E-04	5.88E-03	9.96E-02
	Normalized Velocity	v'	m/d	2.51E-06	2.60E-05	1.91E-07	1.31E-06	3.75E-05	1.97E-04	8.08E-03	6.51E-02	1.19E-02	7.66E-02	8.67E-04	4.54E-03	5.01E-02	1.32E+00	1.08E-04	5.71E-03	5.51E-02	9.34E-01
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.64E-08	2.07E-08	5.76E-04	6.59E-04	2.51E-04	4.30E-04	1.24E-05	1.84E-05	2.43E-04	1.17E-03	1.13E-06	1.02E-05	1.73E-02	3.10E-02
	A_1	-	-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.64E-03	-2.24E-04	-1.51E-01	-2.15E-02	-4.48E-02	-1.20E-02	-3.04E-02	-8.62E-03	-1.03E-02	-1.90E-03	-2.23E-02	-3.80E-03	-6.49E-01	-7.05E-02
	A_2	-	-	2.48E-03	2.56E-02	3.91E-02	8.72E-03	1.49E+02	6.48E+01	9.63E+00	2.16E+00	7.74E+00	1.77E+00	3.08E+01	1.31E+01	2.84E+00	7.42E-03	8.75E+01	1.16E+01	2.51E+00	8.03E-03
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.97E-01	1.00E+00	8.60E-01	9.79E-01	9.56E-01	9.88E-01	9.70E-01	9.91E-01	9.90E-01	9.98E-01	9.78E-01	9.96E-01	5.23E-01	9.32E-01
	$erfc(A_2)$	-	-	9.97E-01	9.71E-01	9.56E-01	9.90E-01	0.00E+00	0.00E+00	0.00E+00	2.21E-03	0.00E+00	1.23E-02	0.00E+00	0.00E+00	5.89E-05	9.92E-01	0.00E+00	0.00E+00	3.89E-04	9.91E-01
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	1.00E+01	2.00E+01	2.00E+01	2.02E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.06E+01	2.01E+01
	B_2	-	-	4.47E+00	4.47E+00	4.47E+00	3.16E+00	1.49E+02	6.50E+01	1.06E+01	4.97E+00	8.94E+00	4.81E+00	3.11E+01	1.39E+01	5.30E+00	4.47E+00	8.76E+01	1.25E+01	5.25E+00	4.49E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	2.20E+04	4.86E+08	4.85E+08	5.64E+08	4.96E+08	5.07E+08	4.91E+08	5.00E+08	4.89E+08	4.90E+08	4.86E+08	4.96E+08	4.87E+08	9.28E+08	5.21E+08
	$erfc(B_2)$	-	-	2.54E-10	2.54E-10	2.54E-10	7.74E-06	0.00E+00	0.00E+00	0.00E+00	2.03E-12	0.00E+00	1.00E-11	0.00E+00	0.00E+00	6.62E-14	2.53E-10	0.00E+00	0.00E+00	1.10E-13	2.20E-10
	Concentration	C	mg/L	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.83E-04	0.00E+00	8.52E-04	0.00E+00	0.00E+00	3.18E-04	7.00E-02	0.00E+00	0.00E+00	1.53E-02	1.00E+00
Action Level [34]	Concentration	C	mg/L					0.02	0.02	0.62	0.62	0.10	0.10	0.60	0.60	7.0	0.126	4.0	4.0	100.0	1.93
Regulatory Standards	EPA MCLs	C	mg/L	1.30E+00 [31]		1.50E-02 [31]		2.00E-04 [31]		6.20E-03 [32]		1.00E-03 [31]		4.10E-03 [31]		7.00E-02 [31]		4.00E-02 [31]		1.00E+00 [31]	
	MADLs	C	mg/L	1.30E+00 [33]		5.00E-02 [33]		2.00E-04 [33]		NA [33]		1.00E-03 [33]		6.00E-03 [33]		7.00E-02 [33]		NA [33]		1.00E+00 [33]	

NOTES

[1] Average total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.

[2] 90% UCL of total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.

[3] Average total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.

[4] 90% UCL of total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.

[5] Infiltration time is the time at which the maximum metals concentration occurs at a point immediately above the water table.

[6] Infiltration time is the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate exceeds 0.04 inches/hour. Because most Category 3 UICs are located in southeast Portland, precipitation was obtained from two raingages located in southeast portland: the Kelly School Raingage (HYDRA, 2008a) and Holgate Raingage (HYRDRA, 2008b). Precipitation data from 1999 to 2007 was used in the analysis, and results from the Holgate and Kelly School Raingages were averaged together using the geometric mean.

[7] Infiltration time is shorter than 12.86 days because the maximum pollutant concentration immediately above the water table occurred prior to the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC.

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

[9] 25th percentile biodegradation rate from a review of scientific literature (see text for references).

[10] 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).

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TOC = Total Organic Carbon
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m = meters
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mg/L = milligrams per liter
L/kg = Liters per kilogram

REFERENCES

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DeAngelo, E. M., and K. R. Reddy, 2000. Aerobic and anaerobic transformations of pentachlorophenol in wetland soils. *Soil Science of America Journal*. 64, pp. 933 - 943.
DOGAMI, 1990. Earthquake hazard geology maps of the Portland metropolitan area, Oregon. Open File Report 0-90-2.
EPA, 1996. Soil Screening Guidance: Technical Background Document. Office of Solid Waste and Emergency Response, Washington, DC. May. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/index.htm
EPA, 2003. National Primary Drinking Water Standards. Office of Water, June 2003. Available online at: www.epa.gov/safewater.
EPA, 2008a. 2,4-D RED Facts. Available online at: http://www.epa.gov/oppsrrd1/REDs/factsheets/24d_fs.htm. Downloaded by GSI on 10 March 2008.
EPA, 2008b. Technical Factsheet on: 2,4-D. Available online at: http://www.epa.gov/OGWDW/dwh/t-soc/24-d.htm. Downloaded by GSI on 15 April 2008.
EPA, 2008c. Technical Factsheet on: Toluene. Available online at: http://www.epa.gov/safewater/dwh/t-voc/toluene.html. Downloaded by GSI on 15 April 2008.
EPA, 2008d. Technical Factsheet on: Methoxychlor. Available online at: http://www.epa.gov/safewater/dwh/t-soc/methoxyc.htm. Downloaded by GSI on 15 April 2008.
Fetter, 1994. Applied Hydrogeology. 3rd Ed. Prentice-Hall, Upper Saddle River, New Jersey: 691 pp.
Freeze and Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, New Jersey: 604 pp.
Green, G. L. 1983. Soil Survey of Multnomah County, Oregon. United States Department of Agriculture – Soil Conservation Service. 225 pp.
HYDRA, 2008a. Rainfall at the Kelly School Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.
HYDRA, 2008b. Rainfall at the Holgate Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.
Schmidt, L. M., J. J. Delfino, J. F. Preston, and G. St Laurent, 1999. Biodegradation of low aqueous concentration pentachlorophenol (PCP) contaminated groundwater. *Chemosphere*. 38, pp. 2897 - 2912.
Watts, R. J. 1998. Hazardous Wastes: Sources, Pathways, Receptors. John Wiley & Sons, Inc., New York: 764 pp.
USDI, 1993. Drainage Manual: A Water Resources Technical Publication. Bureau of Reclamation, 321 pp.

Appendix A.3
Category 3 UICs: Qff - Fine Grained Facies of the UG
Separation Distance > 5 Feet

Metals

	Parameter	Symbol	Units	Copper – Average Scenario	Copper – Reasonable Maximum Scenario	Lead – Average Scenario	Lead – Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	1.52	1.52	1.52	1.52
	Concentration	C_0	mg/L	0.00245 [1]	0.01446 [2]	0.00256 [3]	0.01998 [4]
	Infiltration Time	t	d	1,000,000 [5]	170,000 [5]	14,000,000 [5]	3,400,000 [5]
Chemical Properties	First-Order Rate Constant	k	d^{-1}				
	Half-Life	h	d				
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]
	Soil Moisture Content	θ	-	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]
	Soil Bulk density	ρ_b	g/cm^3	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]
	Fraction Organic Carbon	f_{oc}	-				
	Organic Carbon Partition Coefficient	K_{oc}	L/kg				
	Distribution Coefficient	K_d	L/kg	76,163 [26]	17,255 [27]	1,001,923 [26]	343,064 [27]
	Pore Water Velocity	v	m/d	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]
Calculations	Retardation Factor	R	-	336,388	76,211	4,425,161	1,515,200
	Dispersion Coefficient	D	m^2/d	3.61E-02	5.09E-02	3.60E-02	5.09E-02
	Normalized Dispersion	D'	m^2/d	1.07E-07	6.68E-07	8.14E-09	3.36E-08
	Normalized Velocity	v'	m/d	1.41E-06	8.79E-06	1.07E-07	4.42E-07
	Normalized Degradation	k'	d^{-1}	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
	A_2	-	-	1.75E-01	3.78E-02	3.02E-02	2.45E-02
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00
	erfc(A_2)	-	-	8.04E-01	9.57E-01	9.66E-01	9.72E-01
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01
	B_2	-	-	4.48E+00	4.47E+00	4.47E+00	4.47E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08
	erfc(B_2)	-	-	2.46E-10	2.54E-10	2.54E-10	2.54E-10
	Concentration	C	mg/L	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Action Level [33]	Concentration	C	mg/L				
Regulatory Standards	EPA MCLs	C	mg/L	1.30E+00 [31]		1.50E-02 [31]	
	MADLs	C	mg/L	1.30E+00 [32]		5.00E-02 [32]	

PAHs

	Parameter	Symbol	Units	Benzo(a)pyrene – Average Scenario	Benzo(a)pyrene – Reasonable Maximum Scenario	Naphthalene – Average Scenario	Naphthalene – Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	1.52	1.52	1.52	1.52
	Concentration	C_0	mg/L				
	Infiltration Time	t	d	12.86 [6]	12.86 [6]	12.86 [6]	12.86 [7]
Chemical Properties	First-Order Rate Constant	k	d^{-1}	1.30E-03 [8]	2.60E-04 [9]	7.50E-02 [8]	2.50E-02 [9]
	Half-Life	h	d	533 [12]	2666 [12]	9 [12]	28 [12]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]
	Soil Moisture Content	θ	-	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]
	Soil Bulk density	ρ_b	g/cm^3	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]
	Fraction Organic Carbon	f_{oc}	-	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg	282,185 [16]	282,185 [16,17]	1,300 [16]	830 [18]
	Distribution Coefficient	K_d	L/kg	5,093 [28]	2,283 [28]	23.5 [28]	6.7 [28]
	Pore Water Velocity	v	m/d	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]
Calculations	Retardation Factor	R	-	22,495	10,084	105	30.7
	Dispersion Coefficient	D	m^2/d	3.60E-02	5.09E-02	3.60E-02	5.09E-02
	Normalized Dispersion	D'	m^2/d	1.60E-06	5.05E-06	3.44E-04	1.66E-03
	Normalized Velocity	v'	m/d	2.11E-05	6.64E-05	4.53E-03	2.19E-02
	Normalized Degradation	k'	d^{-1}	5.78E-08	2.58E-08	7.17E-04	8.15E-04
	A_1	-	-	-4.17E-03	-5.90E-04	-2.38E-01	-5.66E-02
	A_2	-	-	1.67E+02	9.43E+01	1.10E+01	4.23E+00
	e^{A1}	-	-	9.96E-01	9.99E-01	7.88E-01	9.45E-01
	erfc(A_2)	-	-	0.00E+00	0.00E+00	0.00E+00	2.14E-09
	B_1	-	-	2.00E+01	2.00E+01	2.02E+01	2.01E+01
	B_2	-	-	1.68E+02	9.44E+01	1.19E+01	6.17E+00
	e^{B1}	-	-	4.87E+08	4.85E+08	6.15E+08	5.13E+08
	erfc(B_2)	-	-	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Concentration	C	mg/L	0.00E+00	0.00E+00	0.00E+00	6.27E-10
Action Level [33]	Concentration	C	mg/L	0.02	0.02	0.62	0.62
Regulatory Standards	EPA MCLs	C	mg/L	2.00E-04 [31]		6.20E-03 [31]	
	MADLs	C	mg/L	2.00E-04 [32]		NA [32]	

SVOCs

	Parameter	Symbol	Units	PCP – Average Scenario	PCP – Reasonable Maximum Scenario	di-(2-ethylhexyl) phthalate – Average Scenario	di-(2-ethylhexyl) phthalate – Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	1.52	1.52	1.52	1.52
	Concentration	C_0	mg/L				
	Infiltration Time	t	d	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [6]
Chemical Properties	First-Order Rate Constant	k	d^{-1}	2.21E-02 [10]	1.39E-02 [11]	1.50E-02 [8]	1.00E-02 [9]
	Half-Life	h	d	31 [12]	50 [12]	46 [12]	69 [12]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]
	Soil Moisture Content	θ	-	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]
	Soil Bulk density	ρ_b	g/cm^3	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]
	Fraction Organic Carbon	f_{oc}	-	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg	877 [19]	703 [19]	12,200 [16]	12,200 [16,17]
	Distribution Coefficient	K_d	L/kg	15.8 [28]	5.7 [28]	220.2 [28]	98.7 [28]
	Pore Water Velocity	v	m/d	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]
Calculations	Retardation Factor	R	-	70.9	26.1	973	437
	Dispersion Coefficient	D	m^2/d	3.60E-02	5.09E-02	3.60E-02	5.09E-02
	Normalized Dispersion	D'	m^2/d	5.08E-04	1.95E-03	3.70E-05	1.17E-04
	Normalized Velocity	v'	m/d	6.68E-03	2.57E-02	4.87E-04	1.53E-03
	Normalized Degradation	k'	d^{-1}	3.12E-04	5.32E-04	1.54E-05	2.29E-05
	A_1	-	-	-7.06E-02	-3.15E-02	-4.80E-02	-2.27E-02
	A_2	-	-	8.87E+00	3.75E+00	3.47E+01	1.94E+01
	e^{A1}	-	-	9.32E-01	9.69E-01	9.53E-01	9.78E-01
	erfc(A_2)	-	-	0.00E+00	1.09E-07	0.00E+00	0.00E+00
	B_1	-	-	2.01E+01	2.00E+01	2.00E+01	2.00E+01
	B_2	-	-	9.94E+00	5.84E+00	3.50E+01	1.99E+01
	e^{B1}	-	-	5.21E+08	5.01E+08	5.09E+08	4.96E+08
	erfc(B_2)	-	-	0.00E+00	1.11E-16	0.00E+00	0.00E+00
	Concentration	C	mg/L	0.00E+00	8.08E-09	0.00E+00	0.00E+00
Action Level [33]	Concentration	C	mg/L	0.10	0.10	0.60	0.60
Regulatory Standards	EPA MCLs	C	mg/L	1.00E-03 [31]		4.10E-03 [31]	
	MADLs	C	mg/L	1.00E-03 [32]		6.00E-03 [32]	

Pesticides/Herbicides and VOCs

	Parameter	Symbol	Units	2,4-D – Average Scenario	2,4-D – Reasonable Maximum Scenario	Methoxychlor – Average Scenario	Methoxychlor – Reasonable Maximum Scenario	Toluene (VOCs) – Average Scenario	Toluene (VOCs) – Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	1.52	1.52	1.52	1.52	1.52	1.52
	Concentration	C_0	mg/L						
	Infiltration Time	t	d	12.86 [6]	3.85 [7]	12.86 [6]	12.86 [6]	12.86 [6]	5.17 [7]
Chemical Properties	First-Order Rate Constant	k	d^{-1}	5.10E-03 [8]	2.20E-03 [9]	1.10E-02 [8]	4.40E-03 [9]	3.30E-01 [8]	8.20E-02 [9]
	Half-Life	h	d	136 [12]	315 [12]	63 [12]	158 [12]	2 [12]	8 [12]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]
	Soil Moisture Content	θ	-	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]
	Soil Bulk density	ρ_b	g/cm^3	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]
	Fraction Organic Carbon	f_{oc}	-	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg	201 [20]	20 [21]	97,700 [22]	9,700 [23]	182 [24]	37 [25]
	Distribution Coefficient	K_d	L/kg	3.6 [28]	0.159 [28]	1,763 [28]	78.5 [28]	3.3 [28]	0.30 [28]
	Pore Water Velocity	v	m/d	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]
Calculations	Retardation Factor	R	-	17.0	1.7	7,789	348	15.5	2.3
	Dispersion Coefficient	D	m^2/d	3.60E-02	5.09E-02	3.60E-02	5.09E-02	3.60E-02	5.09E-02
	Normalized Dispersion	D'	m^2/d	2.11E-03	2.99E-02	4.63E-06	1.46E-04	2.32E-03	2.19E-02
	Normalized Velocity	v'	m/d	2.78E-02	3.94E-01	6.09E-05	1.93E-03	3.06E-02	2.89E-01
	Normalized Degradation	k'	d^{-1}	2.99E-04	1.29E-03	1.41E-06	1.27E-05	2.13E-02	3.53E-02
	A_1	-	-	-1.63E-02	-4.99E-03	-3.52E-02	-9.98E-03	-1.01E+00	-1.84E-01
	A_2	-	-	3.52E+00	3.26E-03	9.85E+01	1.72E+01	3.15E+00	1.19E-03
	e^{A1}	-	-	9.84E-01	9.95E-01	9.65E-01	9.90E-01	3.65E-01	8.32E-01
	erfc(A_2)	-	-	6.28E-07	9.96E-01	0.00E+00	0.00E+00	8.65E-06	9.99E-01
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.10E+01	2.02E+01
	B_2	-	-	5.70E+00	4.47E+00	9.86E+01	1.78E+01	5.65E+00	4.51E+00
	e^{B1}	-	-	4.93E+08	4.88E+08	5.03E+08	4.90E+08	1.33E+09	5.83E+08
	erfc(B_2)	-	-	7.77E-16	2.51E-10	0.00E+00	0.00E+00	1.33E-15	1.74E-10
	Concentration	C	mg/L	3.50E-06	7.00E-02	0.00E+00	0.00E+00	2.46E-04	1.00E+00
Action Level [33]	Concentration	C	mg/L	7.0	0.126	4.0	4.0	100.0	2.15
Regulatory Standards	EPA MCLs	C	mg/L	7.00E-02 [31]		4.00E-02 [31]		1.00E+00 [31]	
	MADLs	C	mg/L	7.00E-02 [32]		NA [32]		1.00E+00 [32]	

NOTES

[1] Average total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.

[2] 90% UCL of total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.

[3] Average total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.

[4] 90% UCL of total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.

[5] Infiltration time is the time at which the maximum metals concentration occurs at a point immediately above the water table.

[6] Infiltration time is the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate exceeds 0.04 inches/hour. Because most Category 3 UICs are located in southeast Portland, precipitation was obtained from two raingages located in southeast portland: the Kelly School Raingage (HYDRA, 2008a) and Holgate Raingage (HYRDRA, 2008b). Precipitation data from 1999 to 2007 was used in the analysis, and results from the Holgate and Kelly School Raingages were averaged together using the geometric mean.

[7] Infiltration time is shorter than 12.86 days because the maximum pollutant concentration immediately above the water table occurred prior to the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC.

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

[9] 25th percentile biodegradation rate from a review of scientific literature (see text for references).

[10] 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).

[11] 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).

[12] 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.

[13] DOGAMI (1990) identifies the coarse grained facies (Qfc) as a gravel with a silt and sand matrix. Therefore, average porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.

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

[15] Estimate of f_{oc} based on loading of TOC in stormwater; see text for description and Attachment A.5 for calculations.

[16] Calculated from the equation of Griffin (1985), which relates K_{oc} to either water solubility or K_{ow}, as presented in Fetter (1994). The Griffin (1985) equation calculated a lower (i.e., more conservative) K_{oc} than the equations reported in EPA (1996).

[17] 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 from K_{ow}.

[18] 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.

[19] 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 twelve USGS wells screened at or near the water table in Portland on the east side of the Willamette River from 1997 to 2007. The average groundwater pH at the wells is 6.4, and was used for the "Average Scenario". This pH is consistent with shallow soil pH in Multnomah County (Green, 1983). The PCP organic carbon partitioning coefficient when pH = 6.4 is 877 L/kg [EPA (1996) – Appendix L: Koc Values for Ionizing Organics as a Function of pH]. Because PCP is more mobile at higher pH, Koc for the "Reasonable Maximum Scenario" is based on the average maximum groundwater pH at the USGS wells (i.e., 6.6). This pH is consistent with shallow soil pH in Multnomah County (Green, 1983). The PCP organic carbon partitioning coefficient when pH = 6.6 is 704 L/kg.

[20] Calculated from equation (71) in EPA (1996), which relates K_{oc} to K_{ow} for chlorinated pesticides. K_{ow} was taken from EPA (2008a).

[21] The lowest K_{oc} reported for 2,4-D in EPA (2008b). The range of K_{oc} is 19.6 to 109.1 L/kg.

[22] Calculated from equations in EPA (1996) relating K_{oc} to K_{ow}. Fetter (1994) did not provide a K_{oc} for this compound.

[23] The lowest K_{oc} reported for Methoxychlor in EPA (2008d). The range of Koc was 9,700 to 100,000 L/kg.

[24] Calculated from equations in EPA (1996) relating K_{oc} to K_{ow}. The EPA (1996) equation calculated a lower (i.e., more conservative) K_{oc} than the equations presented in Fetter (1994) for this compound.

[25] The lowest K_{oc} reported for Toluene in EPA (2008c). The range of K_{oc} was 37 - 178 L/kg.

[26] Median K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998).

[27] 10th percentile of K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998).

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

[29] The median hydraulic conductivity calculated using the pump-in method at over 100 UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.

[30] The 90% UCL from over 100 hydraulic conductivity measurements from pump-in tests. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.

[31] EPA MCLs from EPA (2003).

[32] EPA Region 6 Human Health Medium-Specific Screening Levels (updated 3/2008)

[33] Maximum Allowable Discharge Limits (MADLs) from the Water Pollution Control Facilities (WPCF) Permit issued by DEQ to BES in 2005

[34] The action level is the influent concentration that will cause the MADL to be exceeded at a point immediately above the water table in the unsaturated zone. If this concentration was greater than 100 times the MADL, then the action level was set at 100 time the MADL.

ABBREVIATIONS

PAHs = Polynuclear Aromatic Hydrocarb	USGS =United States Geological Survey	UIC = Underground Injection Control	Qfc = Quaternary coarse-grained facies	m = meters	L/kg = Liters per kilogram
SVOCs = Semi-Volatile Organic Compoun	EPA = Environmental Protection Agency	EPA = Environmental Protection Agency	TOC = Total Organic Carbon	m/d = meters per day	
VOCs = Volatile Organic Compounds	DOGAMI = Department of Geology and Mineral Industries	MCL = Maximum Contaminant Level	d = days	m^2/d = square meters per day	
PCP = Pentachlorophenol		UCL = Upper Confidence Level	g/cm^3 = grams per cubic centimeter	mg/L = milligrams per liter	

REFERENCES

Bricker, O. P., 1998, An Overview of the Factors Involved in Evaluating the Geochemical Effects of Highway Runoff on the Environment, USGS.

DeAngelo, E. M., and K. R. Reddy, 2000. Aerobic and anaerobic transformations of pentachlorophenol in wetland soils. *Soil Science of America Journal*. 64, pp. 933 - 943.

DOGAMI, 1990. Earthquake hazard geology maps of the Portland metropolitan area, Oregon. Open File Report 0-90-2.

EPA, 1996. Soil Screening Guidance: Technical Background Document. Office of Solid Waste and Emergency Response, Washington, DC. May. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/index.htm

EPA, 2003. National Primary Drinking Water Standards. Office of Water, June 2003. Available online at: www.epa.gov/safewater.

EPA, 2008a. 2,4-D RED Facts. Available online at: http://www.epa.gov/oppsrrd1/REDs/factsheets/24d_fs.htm. Downloaded by GSI on 10 March 2008.

EPA, 2008b. Technical Factsheet on: 2,4-D. Available online at: http://www.epa.gov/OGWDW/dwh/t-soc/24-d.htm. Downloaded by GSI on 15 April 2008.

EPA, 2008c. Technical Factsheet on: Toluene. Available online at: http://www.epa.gov/safewater/dwh/t-voc/toluene.html. Downloaded by GSI on 15 April 2008.

EPA, 2008d. Technical Factsheet on: Methoxychlor. Available online at: http://www.epa.gov/safewater/dwh/t-soc/methoxyc.htm. Downloaded by GSI on 15 April 2008.

Fetter, 1994. Applied Hydrogeology. 3rd Ed. Prentice-Hall, Upper Saddle River, New Jersey: 691 pp.

Freeze and Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, New Jersey: 604 pp.

Green, G. L. 1983. Soil Survey of Multnomah County, Oregon. United States Department of Agriculture – Soil Conservation Service. 225 pp.

HYDRA, 2008a. Rainfall at the Kelly School Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.

HYDRA, 2008b. Rainfall at the Holgate Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.

Schmidt, L. M., J. J. Delfino, J. F. Preston, and G. St Laurent, 1999. Biodegradation of low aqueous concentration pentachlorophenol (PCP) contaminated groundwater. *Chemosphere*. 38, pp. 2897 - 2912.

Watts, R. J. 1998. Hazardous Wastes: Sources, Pathways, Receptors. John Wiley & Sons, Inc., New York: 764 pp.

USDI, 1993. Drainage Manual: A Water Resources Technical Publication. Bureau of Reclamation, 321 pp.

Appendix A.4

Category 3 UICs: Qff - Fine Grained Facies of the UG

Separation Distance > 7 Feet

	Parameter	Symbol	Units	Metals				PAHs				SVOCs				Pesticides/Herbicides				VOCs	
				Copper		Lead		Benzo(a)pyrene		Naphthalene		PCP		di-(2-ethylhexyl) phthalate		2,4-D		Methoxychlor		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	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13
	Concentration	C_0	mg/L	0.00245 [1]	0.01446 [2]	0.00256 [3]	0.01998 [4]														
	Infiltration Time	t	d	1,500,000 [5]	240,000 [5]	19,000,000 [5]	4,800,000 [5]	12.86 [6]	12.86 [6]	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [6]	12.86 [6]	5.41 [7]	12.86 [6]	12.86 [6]	12.86 [6]	7.2 [7]
Chemical Properties	First-Order Rate Constant	k	d^{-1}					1.30E-03 [8]	2.60E-04 [9]	7.50E-02 [8]	2.50E-02 [9]	2.21E-02 [10]	1.39E-02 [11]	1.50E-02 [8]	1.00E-02 [9]	5.10E-03 [8]	2.20E-03 [9]	1.10E-02 [8]	4.40E-03 [9]	3.30E-01 [8]	8.20E-02 [9]
	Half-Life	h	d					533 [12]	2666 [12]	9 [12]	28 [12]	31 [12]	50 [12]	46 [12]	69 [12]	136 [12]	315 [12]	63 [12]	158 [12]	2 [12]	8 [12]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]	0.375 [13]
	Soil Moisture Content	θ	-	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]	0.31 [9]	0.31 [10]
	Soil Bulk density	ρ_b	g/cm^3	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]	1.66 [14]
	Fraction Organic Carbon	f_{oc}	-					0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg					282,185 [16]	282,185 [16,17]	1,300 [16]	830 [18]	877 [19]	703 [19]	12,200 [16]	12,200 [16,17]	201 [20]	20 [21]	97,700 [22]	9,700 [23]	182 [24]	37 [25]
	Distribution Coefficient	K_d	L/kg	76,163 [26]	17,255 [27]	1,001,923 [26]	343,064 [27]	5,093 [28]	2,283 [28]	23.5 [28]	6.7 [28]	15.8 [28]	5.7 [28]	220.2 [28]	98.7 [28]	3.6 [28]	0.159 [28]	1,763 [28]	78.5 [28]	3.3 [28]	0.30 [28]
	Pore Water Velocity	v	m/d	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]	0.474 [29]	0.67 [30]
Calculations	Retardation Factor	R	-	336,388	76,211	4,425,161	1,515,200	22,495	10,084	105	30.7	70.9	26.1	973	437	17.0	1.7	7,789	348	15.5	2.3
	Dispersion Coefficient	D	m^2/d	5.06E-02	7.15E-02	5.06E-02	7.15E-02	5.06E-02	7.15E-02	5.06E-02	7.15E-02	5.06E-02	7.15E-02	5.06E-02	7.15E-02	5.06E-02	7.15E-02	5.06E-02	7.15E-02	5.06E-02	7.15E-02
	Normalized Dispersion	D'	m^2/d	1.50E-07	9.38E-07	1.14E-08	4.72E-08	2.25E-06	7.09E-06	4.83E-04	2.33E-03	7.13E-04	2.74E-03	5.19E-05	1.64E-04	2.97E-03	4.20E-02	6.49E-06	2.06E-04	3.26E-03	3.08E-02
	Normalized Velocity	v'	m/d	1.41E-06	8.79E-06	1.07E-07	4.42E-07	2.11E-05	6.64E-05	4.53E-03	2.19E-02	6.68E-03	2.57E-02	4.87E-04	1.53E-03	2.78E-02	3.94E-01	6.09E-05	1.93E-03	3.06E-02	2.89E-01
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.78E-08	2.58E-08	7.17E-04	8.15E-04	3.12E-04	5.32E-04	1.54E-05	2.29E-05	2.99E-04	1.29E-03	1.41E-06	1.27E-05	2.13E-02	3.53E-02
	A_1	-	-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-5.85E-03	-8.28E-04	-3.32E-01	-7.93E-02	-9.90E-02	-4.42E-02	-6.73E-02	-3.18E-02	-2.29E-02	-7.00E-03	-4.94E-02	-1.40E-02	-1.39E+00	-2.58E-01
	A_2	-	-	2.09E-02	2.48E-02	1.06E-01	1.16E-02	1.98E+02	1.12E+02	1.31E+01	5.34E+00	1.07E+01	4.80E+00	4.12E+01	2.30E+01	4.54E+00	2.94E-04	1.17E+02	2.05E+01	4.12E+00	2.68E-03
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.94E-01	9.99E-01	7.17E-01	9.24E-01	9.06E-01	9.57E-01	9.35E-01	9.69E-01	9.77E-01	9.93E-01	9.52E-01	9.86E-01	2.49E-01	7.73E-01
	$erfc(A_2)$	-	-	9.76E-01	9.72E-01	8.81E-01	9.87E-01	0.00E+00	0.00E+00	0.00E+00	4.15E-14	0.00E+00	1.10E-11	0.00E+00	0.00E+00	1.31E-10	1.00E+00	0.00E+00	0.00E+00	5.83E-09	9.97E-01
	B_1	-	-	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.03E+01	2.01E+01	2.01E+01	2.00E+01	2.01E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.14E+01	2.03E+01
	B_2	-	-	4.47E+00	4.47E+00	4.47E+00	4.47E+00	1.98E+02	1.12E+02	1.39E+01	6.98E+00	1.16E+01	6.57E+00	4.14E+01	2.35E+01	6.38E+00	4.47E+00	1.17E+02	2.10E+01	6.30E+00	4.53E+00
	e^{B1}	-	-	4.85E+08	4.85E+08	4.85E+08	4.85E+08	4.88E+08	4.86E+08	6.76E+08	5.25E+08	5.36E+08	5.07E+08	5.19E+08	5.01E+08	4.96E+08	4.89E+08	5.10E+08	4.92E+08	1.95E+09	6.28E+08
	$erfc(B_2)$	-	-	2.54E-10	2.54E-10	2.51E-10	2.54E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-10	0.00E+00	0.00E+00	0.00E+00	1.50E-10
	Concentration	C	mg/L	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.19E-14	0.00E+00	5.24E-13	0.00E+00	0.00E+00	4.50E-10	7.00E-02	0.00E+00	0.00E+00	7.27E-08	1.00E+00
Action Level [34]	Concentration	C	mg/L					0.02	0.02	0.62	0.62	0.10	0.10	0.60	0.60	7.0	0.126	4.0	4.0	100.0	2.32
Regulatory Standards	EPA MCLs	C	mg/L	1.30E+00 [31]		1.50E-02 [31]		2.00E-04 [31]		6.20E-03 [32]		1.00E-03 [31]		4.10E-03 [31]		7.00E-02 [31]		4.00E-02 [31]		1.00E+00 [31]	
	MADLs	C	mg/L	1.30E+00 [33]		5.00E-02 [33]		2.00E-04 [33]		NA [33]		1.00E-03 [33]		6.00E-03 [33]		7.00E-02 [33]		NA [33]		1.00E+00 [33]	

NOTES

1 Average total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
2 90% UCL of total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
3 Average total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
4 90% UCL of total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
5 Infiltration time is the time at which the maximum metals concentration occurs at a point immediately above the water table.
6 Infiltration time is the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate exceeds 0.04 inches/hour. Because most Category 3 UICs are located in southeast Portland, precipitation was obtained from two raingages located in southeast portland: the Kelly School Raingage (HYDRA, 2008a) and Holgate Raingage (HYRDRA, 2008b). Precipitation data from 1999 to 2007 was used in the analysis, and results from the Holgate and Kelly School Raingages were averaged together using the geometric mean.
7 Infiltration time is shorter than 12.86 days because the maximum pollutant concentration immediately above the water table occurred prior to the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC.
8 Median biodegradation rate from a review of scientific literature (see text for references).
9 25th percentile biodegradation rate from a review of scientific literature (see text for references).
10 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).
11 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).
12 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.
13 DOGAMI (1990) identifies the coarse grained facies (Qfc) as a gravel with a silt and sand matrix. Therefore, average porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.
14 Calculated by formula 8.26 in Freeze and Cherry (1979): $p_b = 2.65(1-\eta)$.
15 Estimate of f_{oc} based on loading of TOC in stormwater; see text for description and Attachment A.5 for calculations.
16 Calculated from the equation of Griffin (1985), which relates K_{oc} to either water solubility or K_{ow}, as presented in Fetter (1994). The Griffin (1985) equation calculated a lower (i.e., more conservative) K_{oc} than the equations reported in EPA (1996).
17 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 from K_{ow}.
18 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.

[19] 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 twelve USGS wells screened at or near the water table in Portland on the east side of the Willamette River from 1997 to 2007. The average groundwater pH at the wells is 6.4, and was used for the "Average Scenario". This pH is consistent with shallow soil pH in Multnomah County (Green, 1983). The PCP organic carbon partitioning coefficient when pH = 6.4 is 877 L/kg [EPA (1996) – Appendix L: Koc Values for Ionizing Organics as a Function of pH]. Because PCP is more mobile at higher pH, Koc for the "Reasonable Maximum Scenario" is based on the average maximum groundwater pH at the USGS wells (i.e., 6.6). This pH is consistent with shallow soil pH in Multnomah County (Green, 1983). The PCP organic carbon partitioning coefficient when pH = 6.6 is 704 L/kg.

[20] Calculated from equation (71) in EPA (1996), which relates K_{oc} to K_{ow} for chlorinated pesticides. K_{ow} was taken from EPA (2008a).

[21] The lowest K_{oc} reported for 2,4-D in EPA (2008b). The range of K_{oc} is 19.6 to 109.1 L/kg.

[22] Calculated from equations in EPA (1996) relating K_{oc} to K_{ow}. Fetter (1994) did not provide a K_{oc} for this compound.

[23] The lowest K_{oc} reported for Methoxychlor in EPA (2008d). The range of Koc was 9,700 to 100,000 L/kg.

[24] Calculated from equations in EPA (1996) relating K_{oc} to K_{ow}. The EPA (1996) equation calculated a lower (i.e., more conservative) K_{oc} than the equations presented in Fetter (1994) for this compound.

[25] The lowest K_{oc} reported for Toluene in EPA (2008c). The range of K_{oc} was 37 - 178 L/kg.

[26] Median K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998).

[27] 10th percentile of K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998).

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

[29] The median hydraulic conductivity calculated using the pump-in method at over 100 UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.

[30] The 90% UCL from over 100 hydraulic conductivity measurements from pump-in tests. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.

[31] EPA MCLs from EPA (2003).

[32] EPA Region 6 Human Health Medium-Specific Screening Levels (updated 3/2008)

[33] Maximum Allowable Discharge Limits (MADLs) from the Water Pollution Control Facilities (WPCF) Permit issued by DEQ to BES in 2005

[34] The action level is the influent concentration that will cause the MADL to be exceeded at a point immediately above the water table in the unsaturated zone. If this concentration was greater than 100 times the MADL, then the action level was set at 100 time the MADL.

ABBREVIATIONS

PAHs = Polynuclear Aromatic Hydrocarb	USGS = United States Geological Survey	UIC = Underground Injection Control	Qfc = Quaternary coarse-grained facies	m = meters	L/kg = Liters per kilogram
SVOCs = Semi-Volatile Organic Compoun	EPA = Environmental Protection Agency	EPA = Environmental Protection Agency	TOC = Total Organic Carbon	m/d = meters per day	
VOCs = Volatile Organic Compounds	DOGAMI = Department of Geology and Mineral Industries	MCL = Maximum Contaminant Level	d = days	m^2/d = square meters per day	
PCP = Pentachlorophenol		UCL = Upper Confidence Level	g/cm^3 = grams per cubic centimeter	mg/L = milligrams per liter	

REFERENCES

Bricker, O. P., 1998, An Overview of the Factors Involved in Evaluating the Geochemical Effects of Highway Runoff on the Environment, USGS.
DeAngelo, E. M., and K. R. Reddy, 2000. Aerobic and anaerobic transformations of pentachlorophenol in wetland soils. *Soil Science of America Journal*. 64, pp. 933 - 943.
DOGAMI, 1990. Earthquake hazard geology maps of the Portland metropolitan area, Oregon. Open File Report 0-90-2.
EPA, 1996. Soil Screening Guidance: Technical Background Document. Office of Solid Waste and Emergency Response, Washington, DC. May. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/index.htm
EPA, 2003. National Primary Drinking Water Standards. Office of Water, June 2003. Available online at: www.epa.gov/safewater.
EPA, 2008a. 2,4-D RED Facts. Available online at: http://www.epa.gov/oppsrrd1/REDs/factsheets/24d_fs.htm. Downloaded by GSI on 10 March 2008.
EPA, 2008b. Technical Factsheet on: 2,4-D. Available online at: http://www.epa.gov/OGWDW/dwh/t-soc/24-d.htm. Downloaded by GSI on 15 April 2008.
EPA, 2008c. Technical Factsheet on: Toluene. Available online at: http://www.epa.gov/safewater/dwh/t-voc/toluene.html. Downloaded by GSI on 15 April 2008.
EPA, 2008d. Technical Factsheet on: Methoxychlor. Available online at: http://www.epa.gov/safewater/dwh/t-soc/methoxyc.htm. Downloaded by GSI on 15 April 2008.
Fetter, 1994. Applied Hydrogeology. 3rd Ed. Prentice-Hall, Upper Saddle River, New Jersey: 691 pp.
Freeze and Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, New Jersey: 604 pp.
Green, G. L. 1983. Soil Survey of Multnomah County, Oregon. United States Department of Agriculture – Soil Conservation Service. 225 pp.
HYDRA, 2008a. Rainfall at the Kelly School Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.
HYDRA, 2008b. Rainfall at the Holgate Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.
Schmidt, L. M., J. J. Delfino, J. F. Preston, and G. St Laurent, 1999. Biodegradation of low aqueous concentration pentachlorophenol (PCP) contaminated groundwater. *Chemosphere*. 38, pp. 2897 - 2912.
Watts, R. J. 1998. Hazardous Wastes: Sources, Pathways, Receptors. John Wiley & Sons, Inc., New York: 764 pp.
USDI, 1993. Drainage Manual: A Water Resources Technical Publication. Bureau of Reclamation, 321 pp.

Appendix A.5
Category 3 UICs: QTg - Troutdale Gravels
Separation Distance > 5 Feet

	Parameter	Symbol	Units	Metals				PAHs				SVOCs				Pesticides/Herbicides				VOCs	
				Copper		Lead		Benzo(a)pyrene		Naphthalene		PCP		di-(2-ethylhexyl) phthalate		2,4-D		Methoxychlor		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	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
	Concentration	C_0	mg/L	0.00245 [1]	0.01446 [2]	0.00256 [3]	0.01998 [4]														
	Infiltration Time	t	d	6,000,000 [5]	580,000 [5]	79,000,000 [5]	11,000,000 [5]	12.86 [6]	12.86 [6]	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [6]	12.86 [6]	11.47 [7]	12.86 [6]	12.86 [6]	12.86 [6]	12.86 [7]
Chemical Properties	First-Order Rate Constant	k	d^{-1}					1.30E-03 [8]	2.60E-04 [9]	7.50E-02 [8]	2.50E-02 [9]	2.21E-02 [10]	1.39E-02 [11]	1.50E-02 [8]	1.00E-02 [9]	5.10E-03 [8]	2.20E-03 [9]	1.10E-02 [8]	4.40E-03 [9]	3.30E-01 [8]	8.20E-02 [9]
	Half-Life	h	d					533 [12]	2666 [12]	9 [12]	28 [12]	31 [12]	50 [12]	46 [12]	69 [12]	136 [12]	315 [12]	63 [12]	158 [12]	2 [12]	8 [12]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]
	Soil Moisture Content	θ	-	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]
	Fraction Organic Carbon	f_{oc}	-					0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg					282,185 [16]	282,185 [16, 17]	1,300 [16]	830 [18]	877 [19]	703 [19]	12,200 [16]	12,200 [16, 17]	201 [20]	20 [21]	97,700 [22]	9,700 [23]	182 [24]	37 [25]
	Distribution Coefficient	K_d	L/kg	76,163 [26]	17,255 [27]	1,001,923 [26]	343,064 [27]	5,093 [28]	2,283 [28]	23.5 [28]	6.7 [28]	15.8 [28]	5.7 [28]	220.2 [28]	98.7 [28]	3.6 [28]	0.159 [28]	1,763 [28]	78.5 [28]	3.3 [28]	0.30 [28]
	Pore Water Velocity	v	m/d	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]
Calculations	Retardation Factor	R	-	419,190	94,970	5,514,431	1,888,172	28,032	12,566	130	38.0	88.1	32.3	1,213	544	21.0	1.9	9,706	433	19.1	2.6
	Dispersion Coefficient	D	m^2/d	8.01E-03	3.76E-02	8.01E-03	3.76E-02	8.01E-03	3.76E-02	8.01E-03	3.76E-02	8.01E-03	3.76E-02	8.01E-03	3.76E-02	8.01E-03	3.76E-02	8.01E-03	3.76E-02	8.01E-03	3.76E-02
	Normalized Dispersion	D'	m^2/d	1.91E-08	3.96E-07	1.45E-09	1.99E-08	2.86E-07	2.99E-06	6.15E-05	9.90E-04	9.09E-05	1.16E-03	6.60E-06	6.91E-05	3.82E-04	2.01E-02	8.25E-07	8.68E-05	4.20E-04	1.42E-02
	Normalized Velocity	v'	m/d	2.51E-07	2.60E-06	1.91E-08	1.31E-07	3.75E-06	1.97E-05	8.08E-04	6.51E-03	1.19E-03	7.66E-03	8.67E-05	4.54E-04	5.01E-03	1.32E-01	1.08E-05	5.71E-04	5.51E-03	9.34E-02
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.64E-08	2.07E-08	5.76E-04	6.59E-04	2.51E-04	4.30E-04	1.24E-05	1.84E-05	2.43E-04	1.17E-03	1.13E-06	1.02E-05	1.73E-02	3.10E-02
	A_1	-	-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.88E-02	-1.60E-03	-1.03E+00	-1.51E-01	-3.15E-01	-8.47E-02	-2.15E-01	-6.11E-02	-7.37E-02	-1.35E-02	-1.58E-01	-2.70E-02	-3.99E+00	-4.81E-01
	A_2	-	-	2.89E-02	1.01E-02	2.70E-02	8.47E-02	3.98E+02	1.23E+02	2.69E+01	6.35E+00	2.21E+01	5.80E+00	8.26E+01	2.54E+01	1.04E+01	1.34E-03	2.34E+02	2.26E+01	9.70E+00	2.38E-01
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.81E-01	9.98E-01	3.56E-01	8.60E-01	7.29E-01	9.19E-01	8.06E-01	9.41E-01	9.29E-01	9.87E-01	8.54E-01	9.73E-01	1.85E-02	6.18E-01
	erfc(A_2)	-	-	9.67E-01	9.89E-01	9.70E-01	9.05E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.22E-16	0.00E+00	0.00E+00	0.00E+00	9.98E-01	0.00E+00	0.00E+00	0.00E+00	7.37E-01
	B_1	-	-	2.00E+01	1.00E+01	2.00E+01	1.00E+01	2.00E+01	1.00E+01	2.10E+01	1.02E+01	2.03E+01	1.01E+01	2.02E+01	1.01E+01	2.01E+01	1.00E+01	2.02E+01	1.00E+01	2.40E+01	1.05E+01
	B_2	-	-	4.47E+00	3.16E+00	4.47E+00	3.16E+00	3.98E+02	1.23E+02	2.73E+01	7.12E+00	2.25E+01	6.62E+00	8.28E+01	2.56E+01	1.13E+01	3.17E+00	2.34E+02	2.29E+01	1.10E+01	3.32E+00
	e^{B1}	-	-	4.85E+08	2.20E+04	4.85E+08	2.20E+04	4.94E+08	2.21E+04	1.36E+09	2.56E+04	6.65E+08	2.40E+04	6.02E+08	2.34E+04	5.22E+08	2.23E+04	5.68E+08	2.26E+04	2.62E+10	3.56E+04
	erfc(B_2)	-	-	2.54E-10	7.74E-06	2.54E-10	7.69E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.53E-06	0.00E+00	0.00E+00	0.00E+00	2.67E-06
	Concentration	C	mg/L	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-17	0.00E+00	0.00E+00	0.00E+00	7.00E-02	0.00E+00	0.00E+00	0.00E+00	5.31E-01
Action Level [34]	Concentration	C	mg/L					0.02	0.02	0.62	0.62	0.10	0.10	0.60	0.60	7.0	0.121	4.0	4.0	100.0	1.93
Regulatory Standards	EPA MCLs	C	mg/L	1.30E+00 [31]		1.50E-02 [31]		2.00E-04 [31]		6.20E-03 [32]		1.00E-03 [31]		4.10E-03 [31]		7.00E-02 [31]		4.00E-02 [31]		1.00E+00 [31]	
	MADLs	C	mg/L	1.30E+00 [33]		5.00E-02 [33]		2.00E-04 [33]		NA [33]		1.00E-03 [33]		6.00E-03 [33]		7.00E-02 [33]		NA [33]		1.00E+00 [33]	

NOTES

1 Average total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
2 90% UCL of total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
3 Average total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
4 90% UCL of total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
5 Infiltration time is the time at which the maximum metals concentration occurs at a point immediately above the water table.
6 Infiltration time is the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate exceeds 0.04 inches/hour. Because most Category 3 UICs are located in southeast Portland, precipitation was obtained from two raingages located in southeast portland: the Kelly School Raingage (HYDRA, 2008a) and Holgate Raingage (HYRDRA, 2008b). Precipitation data from 1999 to 2007 was used in the analysis, and results from the Holgate and Kelly School Raingages were averaged together using the geometric mean.
7 Infiltration time is shorter than 12.86 days because the maximum pollutant concentration immediately above the water table occurred prior to the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC.
8 Median biodegradation rate from a review of scientific literature (see text for references).
9 25th percentile biodegradation rate from a review of scientific literature (see text for references).
10 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).
11 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).
12 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.
13 DOGAMI (1990) identifies the coarse grained facies (Qfc) as a gravel with a silt and sand matrix. Therefore, average porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.
14 Calculated by formula 8.26 in Freeze and Cherry (1979): $p_b = 2.65(1-\eta)$.

[15] Estimate of f_{oc} based on loading of TOC in stormwater; see text for description and Attachment A.5 for calculations.
[16] Calculated from the equation of Griffin (1985), which relates K_{oc} to either water solubility or K_{ow}, as presented in Fetter (1994). The Griffin (1985) equation calculated a lower (i.e., more conservative) K_{oc} than the equations reported in EPA (1996).
[17] 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 from K_{ow}.
[18] 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.
[19] 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 twelve USGS wells screened at or near the water table in Portland on the east side of the Willamette River from 1997 to 2007. The average groundwater pH at the wells is 6.4, and was used for the "Average Scenario". This pH is consistent with shallow soil pH in Multnomah County (Green, 1983). The PCP organic carbon partitioning coefficient when pH = 6.4 is 877 L/kg [EPA (1996) – Appendix L: Koc Values for Ionizing Organics as a Function of pH]. Because PCP is more mobile at higher pH, Koc for the "Reasonable Maximum Scenario" is based on the average maximum groundwater pH at the USGS wells (i.e., 6.6). This pH is consistent with shallow soil pH in Multnomah County (Green, 1983). The PCP organic carbon partitioning coefficient when pH = 6.6 is 704 L/kg.
[20] Calculated from equation (71) in EPA (1996), which relates K_{oc} to K_{ow} for chlorinated pesticides. K_{ow} was taken from EPA (2008a).
[21] The lowest K_{oc} reported for 2,4-D in EPA (2008b). The range of K_{oc} is 19.6 to 109.1 L/kg.
[22] Calculated from equations in EPA (1996) relating K_{oc} to K_{ow}. Fetter (1994) did not provide a K_{oc} for this compound.
[23] The lowest K_{oc} reported for Methoxychlor in EPA (2008d). The range of Koc was 9,700 to 100,000 L/kg.
[24] Calculated from equations in EPA (1996) relating K_{oc} to K_{ow}. The EPA (1996) equation calculated a lower (i.e., more conservative) K_{oc} than the equations presented in Fetter (1994) for this compound.
[25] The lowest K_{oc} reported for Toluene in EPA (2008c). The range of K_{oc} was 37 - 178 L/kg.
[26] Median K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998).
[27] 10th percentile of K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998).
[28] K_d calculated from the following equation: $Kd = (f_{oc})(K_{oc})$ (e.g., Watts, pg. 279, 1998).
[29] The median hydraulic conductivity calculated using the pump-in method at over 100 UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.
[30] The 90% UCL from over 100 hydraulic conductivity measurements from pump-in tests. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.
[31] EPA MCLs from EPA (2003).
[32] EPA Region 6 Human Health Medium-Specific Screening Levels (updated 3/2008)
[33] Maximum Allowable Discharge Limits (MADLs) from the Water Pollution Control Facilities (WPCF) Permit issued by DEQ to BES in 2005
[34] The action level is the influent concentration that will cause the MADL to be exceeded at a point immediately above the water table in the unsaturated zone. If this concentration was greater than 100 times the MADL, then the action level was set at 100 time the MADL.

ABBREVIATIONS

PAHs = Polynuclear Aromatic Hydrocarbons
SVOCs = Semi-Volatile Organic Compounds
VOCs = Volatile Organic Compounds
PCP = Pentachlorophenol
USGS = United States Geological Survey
EPA = Environmental Protection Agency
DOGAMI = Department of Geology and Mineral Industries
UIC = Underground Injection Control
EPA = Environmental Protection Agency
MCL = Maximum Contaminant Level
UCL = Upper Confidence Level
Qfc = Quaternary coarse-grained facies
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
L/kg = Liters per kilogram

REFERENCES

Bricker, O. P., 1998, An Overview of the Factors Involved in Evaluating the Geochemical Effects of Highway Runoff on the Environment, USGS.
DeAngelo, E. M., and K. R. Reddy, 2000. Aerobic and anaerobic transformations of pentachlorophenol in wetland soils. *Soil Science of America Journal*. 64, pp. 933 - 943.
DOGAMI, 1990. Earthquake hazard geology maps of the Portland metropolitan area, Oregon. Open File Report 0-90-2.
EPA, 1996. Soil Screening Guidance: Technical Background Document. Office of Solid Waste and Emergency Response, Washington, DC. May. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/index.htm
EPA, 2003. National Primary Drinking Water Standards. Office of Water, June 2003. Available online at: www.epa.gov/safewater.
EPA, 2008a. 2,4-D RED Facts. Available online at: http://www.epa.gov/oppsrrd1/REDs/factsheets/24d_fs.htm. Downloaded by GSI on 10 March 2008.
EPA, 2008b. Technical Factsheet on: 2,4-D. Available online at: http://www.epa.gov/OGWDW/dwh/t-soc/24-d.htm. Downloaded by GSI on 15 April 2008.
EPA, 2008c. Technical Factsheet on: Toluene. Available online at: http://www.epa.gov/safewater/dwh/t-voc/toluene.html. Downloaded by GSI on 15 April 2008.
EPA, 2008d. Technical Factsheet on: Methoxychlor. Available online at: http://www.epa.gov/safewater/dwh/t-soc/methoxyc.htm. Downloaded by GSI on 15 April 2008.
Fetter, 1994. Applied Hydrogeology. 3rd Ed. Prentice-Hall, Upper Saddle River, New Jersey: 691 pp.
Freeze and Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, New Jersey: 604 pp.
Green, G. L. 1983. Soil Survey of Multnomah County, Oregon. United States Department of Agriculture – Soil Conservation Service. 225 pp.
HYDRA, 2008a. Rainfall at the Kelly School Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.
HYDRA, 2008b. Rainfall at the Holgate Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.
Schmidt, L. M., J. J. Delfino, J. F. Preston, and G. St Laurent, 1999. Biodegradation of low aqueous concentration pentachlorophenol (PCP) contaminated groundwater. *Chemosphere*. 38, pp. 2897 - 2912.
Watts, R. J. 1998. Hazardous Wastes: Sources, Pathways, Receptors. John Wiley & Sons, Inc., New York: 764 pp.
USDI, 1993. Drainage Manual: A Water Resources Technical Publication. Bureau of Reclamation, 321 pp.

Appendix A.6
Category 3 UICs: QTg - Troutdale Gravels
Separation Distance > 7 Feet

	Parameter	Symbol	Units	Metals				PAHs				SVOCs				Pesticides/Herbicides				VOCs	
				Copper		Lead		Benzo(a)pyrene		Naphthalene		PCP		di-(2-ethylhexyl) phthalate		2,4-D		Methoxychlor		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	Average Scenario	Reasonable Maximum Scenario
UIC Properties	Separation Distance	y	m	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13
	Concentration	C_0	mg/L	0.00245 [1]	0.01446 [2]	0.00256 [3]	0.01998 [4]														
	Infiltration Time	t	d	8,000,000 [5]	810,000 [5]	110,000,000 [5]	16,000,000 [5]	12.86 [6]	12.86 [6]	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [6]	12.86 [6]	12.86 [7]	12.86 [6]	12.86 [6]	12.86 [6]	12.86 [7]
Chemical Properties	First-Order Rate Constant	k	d^{-1}					1.30E-03 [8]	2.60E-04 [9]	7.50E-02 [8]	2.50E-02 [9]	2.21E-02 [10]	1.39E-02 [11]	1.50E-02 [8]	1.00E-02 [9]	5.10E-03 [8]	2.20E-03 [9]	1.10E-02 [8]	4.40E-03 [9]	3.30E-01 [8]	8.20E-02 [9]
	Half-Life	h	d					533 [12]	2666 [12]	9 [12]	28 [12]	31 [12]	50 [12]	46 [12]	69 [12]	136 [12]	315 [12]	63 [12]	158 [12]	2 [12]	8 [12]
Physical and Chemical Soil Properties	Soil Porosity	η	-	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]	0.325 [13]
	Soil Moisture Content	θ	-	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]	0.28 [9]	0.28 [10]
	Soil Bulk density	ρ_b	g/cm^3	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]	1.79 [14]
	Fraction Organic Carbon	f_{oc}	-					0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]	0.018 [15]	0.008 [15]
	Organic Carbon Partition Coefficient	K_{oc}	L/kg					282,185 [16]	282,185 [16,17]	1,300 [16]	830 [18]	877 [19]	703 [19]	12,200 [16]	12,200 [16,17]	201 [20]	20 [21]	97,700 [22]	9,700 [23]	182 [24]	37 [25]
	Distribution Coefficient	K_d	L/kg	76,163 [26]	17,255 [27]	1,001,923 [26]	343,064 [27]	5,093 [28]	2,283 [28]	23.5 [28]	6.7 [28]	15.8 [28]	5.7 [28]	220.2 [28]	98.7 [28]	3.6 [28]	0.159 [28]	1,763 [28]	78.5 [28]	3.3 [28]	0.30 [28]
	Pore Water Velocity	v	m/d	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]	0.1051 [29]	0.2473 [30]
Calculations	Retardation Factor	R	-	419,190	94,970	5,514,431	1,888,172	28,032	12,566	130	38.0	88.1	32.3	1,213	544	21.0	1.9	9,706	433	19.1	2.6
	Dispersion Coefficient	D	m^2/d	1.12E-02	5.28E-02	1.12E-02	5.28E-02	1.12E-02	5.28E-02	1.12E-02	5.28E-02	1.12E-02	5.28E-02	1.12E-02	5.28E-02	1.12E-02	5.28E-02	1.12E-02	5.28E-02	1.12E-02	5.28E-02
	Normalized Dispersion	D'	m^2/d	2.67E-08	5.56E-07	2.03E-09	2.79E-08	4.00E-07	4.20E-06	8.62E-05	1.39E-03	1.27E-04	1.63E-03	9.24E-06	9.69E-05	5.34E-04	2.82E-02	1.16E-06	1.22E-04	5.88E-04	1.99E-02
	Normalized Velocity	v'	m/d	2.51E-07	2.60E-06	1.91E-08	1.31E-07	3.75E-06	1.97E-05	8.08E-04	6.51E-03	1.19E-03	7.66E-03	8.67E-05	4.54E-04	5.01E-03	1.32E-01	1.08E-05	5.71E-04	5.51E-03	9.34E-02
	Normalized Degradation	k'	d^{-1}	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.64E-08	2.07E-08	5.76E-04	6.59E-04	2.51E-04	4.30E-04	1.24E-05	1.84E-05	2.43E-04	1.17E-03	1.13E-06	1.02E-05	1.73E-02	3.10E-02
	A_1	-	-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.64E-02	-2.24E-03	-1.42E+00	-2.11E-01	-4.39E-01	-1.19E-01	-3.00E-01	-8.55E-02	-1.03E-01	-1.89E-02	-2.21E-01	-3.78E-02	-5.30E+00	-6.63E-01
	A_2	-	-	1.38E-01	1.81E-02	3.91E-02	2.84E-02	4.70E+02	1.45E+02	3.19E+01	7.65E+00	2.62E+01	7.01E+00	9.78E+01	3.01E+01	1.25E+01	3.56E-01	2.77E+02	2.69E+01	1.16E+01	7.63E-01
	e^{A1}	-	-	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.74E-01	9.98E-01	2.41E-01	8.10E-01	6.45E-01	8.88E-01	7.41E-01	9.18E-01	9.02E-01	9.81E-01	8.02E-01	9.63E-01	5.01E-03	5.15E-01
	$erfc(A_2)$	-	-	8.45E-01	9.80E-01	9.56E-01	9.68E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.14E-01	0.00E+00	0.00E+00	0.00E+00	2.80E-01
	B_1	-	-	2.00E+01	1.00E+01	2.00E+01	1.00E+01	2.00E+01	1.00E+01	2.14E+01	1.02E+01	2.04E+01	1.01E+01	2.03E+01	1.01E+01	2.01E+01	1.00E+01	2.02E+01	1.00E+01	2.53E+01	1.07E+01
	B_2	-	-	4.47E+00	3.16E+00	4.47E+00	3.16E+00	4.70E+02	1.45E+02	3.22E+01	8.31E+00	2.66E+01	7.71E+00	9.79E+01	3.03E+01	1.33E+01	3.19E+00	2.77E+02	2.70E+01	1.29E+01	3.45E+00
	e^{B1}	-	-	4.85E+08	2.20E+04	4.85E+08	2.20E+04	4.98E+08	2.21E+04	2.01E+09	2.72E+04	7.53E+08	2.48E+04	6.55E+08	2.40E+04	5.38E+08	2.24E+04	6.05E+08	2.29E+04	9.68E+10	4.28E+04
	$erfc(B_2)$	-	-	2.49E-10	7.74E-06	2.54E-10	7.74E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.52E-06	0.00E+00	0.00E+00	0.00E+00	1.06E-06
	Concentration	C	mg/L	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-02	0.00E+00	0.00E+00	0.00E+00	1.00E+00
Action Level [34]	Concentration	C	mg/L					0.02	0.02	0.62	0.62	0.10	0.10	0.60	0.60	7.0	0.187	4.0	4.0	100.0	10.59
Regulatory Standards	EPA MCLs	C	mg/L	1.30E+00 [31]		1.50E-02 [31]		2.00E-04 [31]		6.20E-03 [32]		1.00E-03 [31]		4.10E-03 [31]		7.00E-02 [31]		4.00E-02 [31]		1.00E+00 [31]	
	MADLs	C	mg/L	1.30E+00 [33]		5.00E-02 [33]		2.00E-04 [33]		NA [33]		1.00E-03 [33]		6.00E-03 [33]		7.00E-02 [33]		NA [33]		1.00E+00 [33]	

NOTES

[1] Average total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
[2] 90% UCL of total copper concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
[3] Average total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
[4] 90% UCL of total lead concentration in stormwater measured during Year 1 and Year 2 Stormwater Monitoring.
[5] Infiltration time is the time at which the maximum metals concentration occurs at a point immediately above the water table.
[6] Infiltration time is the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC. Stormwater infiltration occurs when the precipitation rate exceeds 0.04 inches/hour. Because most Category 3 UICs are located in southeast Portland, precipitation was obtained from two raingages located in southeast portland: the Kelly School Raingage (HYDRA, 2008a) and Holgate Raingage (HYRDRA, 2008b). Precipitation data from 1999 to 2007 was used in the analysis, and results from the Holgate and Kelly School Raingages were averaged together using the geometric mean.
[7] Infiltration time is shorter than 12.86 days because the maximum pollutant concentration immediately above the water table occurred prior to the number of days during the water year (i.e., October through May) that stormwater infiltrates into the UIC.
[8] Median biodegradation rate from a review of scientific literature (see text for references).
[9] 25th percentile biodegradation rate from a review of scientific literature (see text for references).
[10] 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).
[11] 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).
[12] 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.
[13] DOGAMI (1990) identifies the coarse grained facies (Qfc) as a gravel with a silt and sand matrix. Therefore, average porosity of a gravel from Freeze and Cherry (1979), page 37, Table 2.4 is used in this analysis.
[14] Calculated by formula 8.26 in Freeze and Cherry (1979): $p_b = 2.65(1-\eta)$.

[15] Estimate of f_{oc} based on loading of TOC in stormwater; see text for description and Attachment A.5 for calculations.
[16] Calculated from the equation of Griffin (1985), which relates K_{oc} to either water solubility or K_{ow}, as presented in Fetter (1994). The Griffin (1985) equation calculated a lower (i.e., more conservative) K_{oc} than the equations reported in EPA (1996).
[17] 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 from K_{ow}.
[18] 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.
[19] 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 twelve USGS wells screened at or near the water table in Portland on the east side of the Willamette River from 1997 to 2007. The average groundwater pH at the wells is 6.4, and was used for the "Average Scenario". This pH is consistent with shallow soil pH in Multnomah County (Green, 1983). The PCP organic carbon partitioning coefficient when pH = 6.4 is 877 L/kg [EPA (1996) – Appendix L: Koc Values for Ionizing Organics as a Function of pH]. Because PCP is more mobile at higher pH, Koc for the "Reasonable Maximum Scenario" is based on the average maximum groundwater pH at the USGS wells (i.e., 6.6). This pH is consistent with shallow soil pH in Multnomah County (Green, 1983). The PCP organic carbon partitioning coefficient when pH = 6.6 is 704 L/kg.
[20] Calculated from equation (71) in EPA (1996), which relates K_{oc} to K_{ow} for chlorinated pesticides. K_{ow} was taken from EPA (2008a).
[21] The lowest K_{oc} reported for 2,4-D in EPA (2008b). The range of K_{oc} is 19.6 to 109.1 L/kg.
[22] Calculated from equations in EPA (1996) relating K_{oc} to K_{ow}. Fetter (1994) did not provide a K_{oc} for this compound.
[23] The lowest K_{oc} reported for Methoxychlor in EPA (2008d). The range of Koc was 9,700 to 100,000 L/kg.
[24] Calculated from equations in EPA (1996) relating K_{oc} to K_{ow}. The EPA (1996) equation calculated a lower (i.e., more conservative) K_{oc} than the equations presented in Fetter (1994) for this compound.
[25] The lowest K_{oc} reported for Toluene in EPA (2008c). The range of K_{oc} was 37 - 178 L/kg.
[26] Median K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998).
[27] 10th percentile of K_d for copper or lead, calculated using site-specific data and an equation from Brickner (1998).
[28] K_d calculated from the following equation: $Kd = (f_{oc})(K_{oc})$ (e.g., Watts, pg. 279, 1998).
[29] The median hydraulic conductivity calculated using the pump-in method at over 100 UICs. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.
[30] The 90% UCL from over 100 hydraulic conductivity measurements from pump-in tests. The pump-in method is outlined in USDI (pgs. 83 - 95, 1993), and is discussed in more detail in the text.
[31] EPA MCLs from EPA (2003).
[32] EPA Region 6 Human Health Medium-Specific Screening Levels (updated 3/2008)
[33] Maximum Allowable Discharge Limits (MADLs) from the Water Pollution Control Facilities (WPCF) Permit issued by DEQ to BES in 2005
[34] The action level is the influent concentration that will cause the MADL to be exceeded at a point immediately above the water table in the unsaturated zone. If this concentration was greater than 100 times the MADL, then the action level was set at 100 time the MADL.

ABBREVIATIONS

PAHs = Polynuclear Aromatic Hydrocarbons
SVOCs = Semi-Volatile Organic Compounds
VOCs = Volatile Organic Compounds
PCP = Pentachlorophenol
USGS = United States Geological Survey
EPA = Environmental Protection Agency
DOGAMI = Department of Geology and Mineral Industries
UIC = Underground Injection Control
EPA = Environmental Protection Agency
MCL = Maximum Contaminant Level
UCL = Upper Confidence Level
Qfc = Quaternary coarse-grained facies
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
L/kg = Liters per kilogram

REFERENCES

Bricker, O. P., 1998, An Overview of the Factors Involved in Evaluating the Geochemical Effects of Highway Runoff on the Environment, USGS.
DeAngelo, E. M., and K. R. Reddy, 2000. Aerobic and anaerobic transformations of pentachlorophenol in wetland soils. *Soil Science of America Journal*. 64, pp. 933 - 943.
DOGAMI, 1990. Earthquake hazard geology maps of the Portland metropolitan area, Oregon. Open File Report 0-90-2.
EPA, 1996. Soil Screening Guidance: Technical Background Document. Office of Solid Waste and Emergency Response, Washington, DC. May. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/index.htm
EPA, 2003. National Primary Drinking Water Standards. Office of Water, June 2003. Available online at: www.epa.gov/safewater.
EPA, 2008a. 2,4-D RED Facts. Available online at: http://www.epa.gov/oppsrrd1/REDs/factsheets/24d_fs.htm. Downloaded by GSI on 10 March 2008.
EPA, 2008b. Technical Factsheet on: 2,4-D. Available online at: http://www.epa.gov/OGWDW/dwh/t-soc/24-d.htm. Downloaded by GSI on 15 April 2008.
EPA, 2008c. Technical Factsheet on: Toluene. Available online at: http://www.epa.gov/safewater/dwh/t-voc/toluene.html. Downloaded by GSI on 15 April 2008.
EPA, 2008d. Technical Factsheet on: Methoxychlor. Available online at: http://www.epa.gov/safewater/dwh/t-soc/methoxyc.htm. Downloaded by GSI on 15 April 2008.
Fetter, 1994. Applied Hydrogeology. 3rd Ed. Prentice-Hall, Upper Saddle River, New Jersey: 691 pp.
Freeze and Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, New Jersey: 604 pp.
Green, G. L. 1983. Soil Survey of Multnomah County, Oregon. United States Department of Agriculture – Soil Conservation Service. 225 pp.
HYDRA, 2008a. Rainfall at the Kelly School Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.
HYDRA, 2008b. Rainfall at the Holgate Raingage. City of Portland HYDRA Rainfall Network. Available online at: http://or.water.usgs.gov/non-usgs/bes/. Downloaded by GSI on 10 March 2008.
Schmidt, L. M., J. J. Delfino, J. F. Preston, and G. St Laurent, 1999. Biodegradation of low aqueous concentration pentachlorophenol (PCP) contaminated groundwater. *Chemosphere*. 38, pp. 2897 - 2912.
Watts, R. J. 1998. Hazardous Wastes: Sources, Pathways, Receptors. John Wiley & Sons, Inc., New York: 764 pp.
USDI, 1993. Drainage Manual: A Water Resources Technical Publication. Bureau of Reclamation, 321 pp.

Appendix C

DEQ Approval Letter
Evaluation of Vertical Separation Distance

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Oregon
Theodore Kulongoski, Governor

Department of Environmental Quality
Northwest Region Portland Office
2020 SW 4th Avenue, Suite 400
Portland, OR 97201-4987
(503) 229-5263
FAX (503) 229-6957
TTY (503) 229-5471

June 5, 2008

Ms. Mary Stephens
Bureau of Environmental Services
City of Portland
1120 SW Fifth Avenue, Room 1000
Portland, OR 97204

Re: Approval of *Evaluation of Vertical Separation Distance, Groundwater Protectiveness Demonstration* model

Dear Ms. Stephens:

The Department of Environmental Quality (DEQ) has received and reviewed *Evaluation of Vertical Separation Distance, Groundwater Protectiveness Demonstration* model, prepared by GSI Water Solutions, Inc. for the City of Portland (City) and dated May 27, 2008. The model was developed, in consultation with DEQ, to provide a screening tool in order to determine if pollutant levels in stormwater pose an adverse risk to groundwater quality for Underground Injection Control (UIC) systems that have a separation distance of 5 to 10 feet between the bottom of the UIC and the seasonally high water table.

DEQ reviewed the model in context of the following regulatory criteria:

- OAR 340-040-0020(2): Anti-degradation policy
- OAR 340-040-0020(3): Protect beneficial uses of groundwater
- OAR 340-040-0020(4) and (5): Groundwater quality parameters
- OAR 340-04-0020(8): Focus on adverse impacts
- OAR 340-04-0020(11): Meet highest and best practicable method of protection
- OAR 340-040-0030(2): Likely adverse impact to groundwater determination
- OAR 340-040-0030(3)(b): Meet naturally existing background groundwater quality conditions, unless a concentration limit variance is granted by permit. (This criterion applies at the water table, not the discharge point into the UIC.)

DEQ issued a Water Pollution Control Facility (WPCF) permit to the City for its UIC activities to manage stormwater. The permit sets two conditions for separation distance:

1. UICs greater than 5 feet deep must have a separation distance of 10 feet from the bottom of the UIC and the seasonally high water table.
2. UICs with a depth of 5 feet or less must have a separation distance of 5 feet between the bottom of the UIC and the seasonally high water table.

As a permit condition, the City conducted a system-wide assessment of its UICs. This assessment identified UICs that did not meet the separation distance criteria. These UICs are classified as Category

3 non-compliant UICs by the permit. The permit allows the City a maximum of 3 Capital Improvement Project cycles to correct Category 3 non-compliant UICs or demonstrate the reduced separation distance does not pose a likely adverse impact to groundwater. A capital Improvement Project cycle extends from July 1 to June 30 of each year.

The *Evaluation of Vertical Separation Distance, Groundwater Protectiveness Demonstration* model was develop by the City to demonstrate Category 3 UICs with a separation distance between 5 and 10 feet from groundwater do not pose a likely adverse impact to groundwater quality. DEQ met with the City and its consultant to review and provide comments as the model was developed. The *Evaluation of Vertical Separation Distance, Groundwater Protectiveness Demonstration* model, dated May 27, 2008 reflects the outcome of these meeting and incorporated DEQ's comments and recommendations.

DEQ finds the model meets the regulatory criteria as described above and can be used address Category 3 non-compliant UICs that have a separation distance between 5 and 10 feet. DEQ approves the use of *Evaluation of Vertical Separation Distance, Groundwater Protectiveness Demonstration* model for the Category 3 non-compliant UICs with separation distances between 5 and 10 feet from the seasonal high water table. Category 3 non-compliant UICs with less than 5 feet separation must have increased separation distance or be closed in accordance with permit conditions.

If you have any questions regarding this letter, please contact me at 503-229-5886.

Sincerely,

Rodney Weick

Rodney Weick
Stormwater and Underground Injection Control Manager
DEQ Northwest Region

Cc: Rod Struck, BES
Heidi Blischke, GSI Water Solutions

Appendix D

Groundwater Protectiveness Demonstration for UICs with < 5 Feet Separation Distance

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Appendix D

Groundwater Protectiveness Demonstration for UICs with < 5 Feet of Separation Distance

This appendix documents the basis and technical approach used to develop the groundwater protectiveness demonstration (GWPD) for Underground Injection Control (UIC) systems in the City of Portland (City) that have a separation distance of < 5 feet. The results of these analyses are presented in Section 9 of this *Decision Making Framework for Groundwater Protectiveness Decisions (*Framework) report.

The purpose of this analysis is to determine whether domestic and public water wells located within permit UIC setbacks (i.e., Category 2 and Category 3 UICs, both non-compliant due to inadequate vertical separation distances) are protected pending the completion of required corrective actions. City-owned UICs with vertical separation distances of < 5 feet are not compliant with permit conditions and corrective action is required and will be implemented in accordance with the *Corrective Action Plan* (CAP; BES, 2006a), as discussed in Section 2 of the Framework report.

"Worst Case"

"Worst case", as used in this document means a hypothetical scenario developed to analyze potential risks to groundwater. The assumptions used in this scenario include:

- UICs with < 5 feet of vertical separation distance are considered to discharge directly to groundwater. (This is conservative because separation distances are estimated based on seasonal high groundwater levels, and UICs have up to 3 feet of additional separation distance for most of the year).
- Stormwater pollutant concentrations are discharged at concentrations up to the 95th UCL on the 95th percentile value for the reasonable maximum scenario.

The conservatism in these "worse case" conditions is compounded by the use of conservative assumptions in input parameter values for the reasonable maximum scenario (as described in Sections 9 and 10 of this Framework report). The combination of the conservative assumptions in this analysis become an unlikely scenario. "Worst case" as used in this document does not include consideration of spills to UICs.

This GWPD was performed to assess the likelihood of stormwater pollutants entering City-owned UICs to impact nearby groundwater wells (domestic or public) at concentrations greater than or equal to maximum allowable discharge limits (MADLs), or other risk-based standards protective of human health. The results of the GWPD are used to determine if groundwater is protected in accordance with Oregon Administrative Rules (OAR) 340-040 and potential groundwater users are protected pending completion of the required corrective actions. The results will also assist the City's Bureau of Environmental Services (BES) prioritize corrective actions required under the permit. The analyses presented in this Appendix are "worst case" in that it is assumed that stormwater pollutants are discharged directly into groundwater; this is not the case. These UICs have < 5 feet of vertical separation to seasonal high groundwater.

This GWPD evaluates groundwater protectiveness at UICs with < 5 feet of separation distance, and consists of:

- Discussion of the BIOSCREEN analytical model used to perform the GWPD (Section D1);
- Documentation of input parameters used in the BIOSCREEN model (Section D2); and
- Results of BIOSCREEN modeling (Section D3).

D1 BIOSCREEN

The GWPD for UICs with < 5 feet of separation distance was performed using BIOSCREEN (EPA, 1996), an analytical model developed by the Environmental Protection Agency (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 (e.g., EPA, 1996):

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

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 (unitless)
k = first order degradation rate constant (T^{-1})
Y = source width (L)
Z = source depth (L).

BIOSCREEN is based on the following assumptions:

- A simple groundwater flow regime is present (i.e., homogeneous and isotropic aquifer, no pumping, vertical gradients are insignificant, etc.).
- Adsorption follows a linear isotherm and is a reversible process.
- Groundwater velocity is sufficiently fast enough so that molecular diffusion can be ignored.

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 parameters. For example, velocity can be input directly, or can be calculated from the site-specific parameters hydraulic conductivity, effective porosity, and hydraulic gradient. Source characteristics include source thickness, width, and concentration. BIOSCREEN simulates declining source concentrations with time based on source half life (not used in this GWPD) or soluble mass (used in this GWPD).

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}).

The GWPD is conservative because:

- Pollutant attenuation in the unsaturated zone and dilution into the groundwater is not included in the analysis. Previous GWPDs (*i.e.*, GSI, 2008a; GSI, 2008b) have demonstrated that significant pollutant attenuation occurs in the unsaturated zone, even at short (*i.e.*, 5 feet) separation distances, dilution accounts for a minimum reduction factor of 78 percent or a 4.5 fold reduction in stormwater discharge concentrations; and
- The BIOSCREEN simulations use conservative values for input parameters based on conservative assumptions, as discussed in the Vertical Separation Distance GWPD (GSI, 2008a).

D2 INPUT PARAMETERS

This GWPD uses similar input parameters as the Category 4 UIC GWPD (GSI, 2008b) and Vertical Separation Distance GWPD (GSI, 2008a) because attenuation is simulated for the same pollutants in the same aquifer. Input parameters were selected using Portland specific information when possible. However, because pollutant attenuation occurs under saturated conditions (instead of unsaturated conditions) and the direction of pollutant migration is horizontal (instead of vertical), the input parameters were slightly modified for this GWPD for UICs with vertical separation distances of < 5 feet.

This section documents the input parameters for the GWPD for UICs with < 5 feet of separation distance and discusses how/if these input parameters were modified from the previous GWPDs (*i.e.*, GSI, 2008a; GSI, 2008b). As for the unsaturated GWPD Tool, the input parameters for this GWPD are representative of the most conservative hydrogeologic unit [i.e., coarse-grained facies (Qfc) of the unconsolidated gravels (UG)].

D2.1 Seepage Velocity

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

$$v = \frac{K}{\eta_e} \nabla h \qquad (2)$$

Where:

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

Table D1 summarizes the input parameters used to calculate seepage velocity for the average and reasonable maximum scenarios. A discussion of the parameters follows:

- **Horizontal hydraulic conductivity (K).** The horizontal hydraulic conductivity was calculated from 64 pump-in tests at UICs completed in the Qfc of the UG. The method for calculating horizontal hydraulic conductivity was discussed in the *Evaluation of Separation Distance – Groundwater Protectiveness Demonstration* (GSI, 2008a). Because this Category 2 UIC GWPD uses horizontal hydraulic conductivity instead of vertical hydraulic conductivity, the hydraulic conductivity in this GWPD is larger than the hydraulic conductivity used in the Category 4 UIC GWPD and Vertical Separation Distance GWPD (GSI, 2008b; GSI 2008a).

- **Horizontal hydraulic gradient (∇h).** The horizontal hydraulic gradient used in this GWPD was taken from the conservative edge of the range of Portland specific hydraulic gradients given in DEQ's *Fact Sheet and Class V Underground Injection Control (UIC) Permit Evaluation, Permit* Number 102830 (2005). Because this Category 2 UIC GWPD uses horizontal hydraulic gradient instead of vertical hydraulic gradient, the hydraulic gradient in this GWPD is smaller than the hydraulic gradient used in the Category 4 UIC GWPD and Vertical Separation Distance GWPD (GSI, 2008b; GSI 2008a).

- **Effective porosity (η_e).** Effective porosity was estimated using Portland specific data for the UG (USGS, 1998). The effective porosity used in this GWPD is the same as the effective porosity used in the Category 4 UIC GWPD and Vertical Separation Distance GWPD (GSI, 2008b; GSI 2008a).

Table D1: Seepage Velocity Calculations for BIOSCREEN Input

Scenario	K (m/day)	η_e (dimensionless)	∇h (dimensionless)	v (m/day)	v (ft/yr)
Average Scenario	105	0.31	0.0002	0.075	89.9
Reasonable Maximum Scenario	247	0.31	0.0002	0.159	190

NOTES
K = hydraulic conductivity
η_e = effective porosity
∇h = hydraulic gradient
v = velocity
m = meters
yr = year
ft = feet

As shown in Table D1, a velocity of 0.075 meters/day (89.9 feet/year) is used in the average scenario, and a velocity of 0.159 meters/day (190 feet/year) is used in the reasonable maximum scenario of this GWPD.

D2.2 Dispersion

Dispersion is the spreading of a contaminant plume caused by pore water mixing. The dispersion coefficient, *D*, is defined as (e.g., Fetter, 1994):

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

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 (e.g., Gelhar, et. al., 1992):

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

where:

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

Dispersivity used in this GWPD is based on the BIOSCREEN length scale of transport for each simulation. The longitudinal dispersivity is calculated from equation (4). Transverse dispersivity and vertical dispersivity used in this GWPD were 10 percent of horizontal dispersivity.

Because dispersivity under saturated conditions is greater than dispersivity under unsaturated conditions (e.g., Gelhar et al., 1985), this GWPD uses a larger dispersivity than the dispersivity used in the Category 4 UIC GWPD and Vertical Separation Distance GWPD.

D2.3 Adsorption

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

$$R = 1 + \frac{(\rho_b)(K_{oc})(f_{oc})}{\eta} \tag{5}$$

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).

Retardation in the Qfc of the UG was calculated using equation (5) for pentachlorophenol (PCP), toluene, and 2,4-dichlorophenoxyacetic acid (2,4-D) in the Vertical Separation Distance GWPD (GSI, 2008a). An in-depth discussion of the bulk density, organic carbon partitioning coefficient, fraction organic carbon, and total porosity used in the calculation is provided in the Vertical Separation Distance GWPD (GSI, 2008a). This GWPD demonstration uses the same retardation factors, as summarized in Table D2.

Table D2: Retardation Calculations for BIOSCREEN Input

Pollutant	Scenario	ρ_b (g/cm^3)	K_{oc} (L/kg)	f_{oc} (-)	η (-)	R (-)
PCP	Average Scenario	1.79	877	0.018	0.325	88.1
	Reasonable Maximum Scenario	1.79	703	0.008	0.325	32.3
Toluene	Average Scenario	1.79	182	0.018	0.325	19.1
	Reasonable Maximum Scenario	1.79	37	0.008	0.325	2.6
2,4-D	Average Scenario	1.79	201	0.018	0.325	21.0
	Reasonable Maximum Scenario	1.79	20	0.008	0.325	1.9

NOTES

ρ_b = bulk density

K_{oc} = organic carbon partitioning coefficient

η = porosity

g = gram

kg = kilogram

(-) indicates dimensionless

R = retardation factor

f_{oc} = fraction organic carbon

PCP = pentachlorophenol

2,4-D = 2,4-dichlorophenoxyacetic acid

cm^3 = cubic centimeters

D2.4 Biodegradation

Biodegradation for the pollutants evaluated in this GWPD was calculated for PCP in GSI (2008b), and for toluene and 2,4-D in GSI (2008a). An in-depth discussion of the bulk density, organic carbon partitioning coefficient, fraction organic carbon, and total porosity used in the calculation is provided in GSI (2008a) and GSI (2008b). This GWPD demonstration uses the same biodegradation rates, as summarized in Table D3.

Table D3: Biodegradation Rates for BIOSCREEN Input

Pollutant	Scenario	Half-Life (days)	Biodegradation Rate Constant ($days^{-1}$)
PCP	Average Scenario	31	0.0221
	Reasonable Maximum Scenario	50	0.0139
Toluene	Average Scenario	2	0.330
	Reasonable Maximum Scenario	8	0.082
2,4-D	Average Scenario	131	0.0053
	Reasonable Maximum Scenario	315	0.0022

NOTES
PCP = pentachlorophenol
2,4-D= 2,4-dichlorophenoxyacetic acid

D2.5 Soluble Mass

The theoretical soluble mass in the source (*i.e.*, stormwater) is input into BIOSCREEN so that the mass loading during the fate and transport simulation does not exceed the mass of the source. This method for controlling source concentration is much more robust than using a constant source for the source term in equation (1), which would significantly overestimate mass loading.

Between 1999 and 2007, analyses of City stormwater data >0.04 inches/year indicate that stormwater infiltration occurs an average of 12.86 days per year (GSI, 2008a). The maximum amount of mass (i.e., soluble mass) loaded at a given UIC was calculated by the following formula:

$$M_x = (V_{sw})(C_x) \tag{6}$$

Where:

- M = soluble mass of pollutant x (M)
- V_{sw} = volume of stormwater that infiltrated at the UIC (L^3)
- C_x = 95% upper confidence limit (UCL) concentration (mean or 95th percentile) of pollutant x in stormwater for Years 1-3 (M/L^3)

Table D4 shows calculations for soluble masses for PCP, toluene, and 2,4-D used in this GWPD. The pollutant concentration in stormwater for the average scenario was taken from the 95th UCL on the mean for Years 1 through 3 sampling. The pollutant concentration in stormwater for the reasonable maximum scenario was taken from the 95th UCL on the 95 percentile for Years 1 through 3 sampling. The volume of stormwater infiltrated into the UIC (V_{sw}) was calculated using the following formula from BES (2007):

$$V_{sw} = (\text{Average Impervious Area per UIC})(\text{Long - Term Precipitation Rate})(1 - \text{Evaporative Loss Factor}) \tag{7}$$

Equation (7) calculates an average infiltration volume for UICs on the east side of the Willamette River in the City of Portland. The average impervious area per UIC was taken from Table 7-4 of BES (2007), long term precipitation rate was taken from Table 5-7 of BES (2007), and the evaporation loss factor was taken from Table 7-5 of BES (2007).

Table D4: Soluble Mass Calculations for BIOSCREEN Input

Pollutant	V_{sw} (L)	Scenario	Concentration (mg/L)	Soluble Mass (mg)	Soluble Mass (kg)
PCP	492,437	Average	0.00060	295	0.000295
		Reasonable Maximum	0.00262	1290	0.00129
Toluene	492,437	Average	0.00205	1,009	0.001009
		Reasonable Maximum	0.00808	3979	0.003979
2,4-D	492,437	Average	0.00068	334	0.000334
		Reasonable Maximum	0.00658	3240	0.00324

NOTES

V_{sw} = stormwater volume
mg = milligram
L = liters
kg = kilogram
PCP = pentachlorophenol
2,4-D = 2,4-dichlorophenoxyacetic acid

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

D2.6 Discretization

BIOSCREEN requires specification of transport time, 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 D5.

Table D5: BIOSCREEN Discretization

Parameter	Value	Rationale
Modeled Area Length	1 – 100 feet	Varies depending on distance that pollutants migrate
Modeled Area Width	4 feet	Diameter of a UIC
Modeled Area Thickness	10 feet	No significant vertical gradients
Transport Time	1 year	Consistent with mass loading calculation

NOTES
UIC = underground injection control

D2.7 Pollutants

BIOSCREEN (EPA, 1996), a saturated flow solute transport model, was selected to estimate the attenuation distances for selected pollutants: PCP, 2,4-D, and toluene. These pollutants were chosen based on previous applications of the GWPD Tool to the following nine pollutants (see Sections 5 and 8 of the Framework report):

- Copper
- Lead
- Benzo(a)pyrene
- Naphthalene
- PCP
- DEHP
- 2,4-D
- Methoxychlor, and
- Toluene.

These nine pollutants were chosen, based on the pollutant selection criteria presented in Section 4 of the Framework Report. Of these nine pollutants, PCP, 2,4-D, and toluene exhibited the least amount of attenuation during pollutant fate and transport (i.e., were the most mobile) due to the lower retardation and biodegradation rates associated with these three pollutants. Therefore, BIOSCREEN was applied only to PCP, 2,4-D, and toluene.

D3 ASSUMPTIONS

The GWPD Tool evaluated the fate and transport of pollutants in the vadose zone and indicated that subsurface soils in the Portland area are highly effective in reducing pollutant concentrations between the point of discharge and the point stormwater infiltrates into groundwater. In this Appendix, the theoretical fate and transport of pollutants in groundwater are evaluated for UICs with < 5 feet of vertical separation distance. The evaluation assesses the distance that a pollutant that is directly discharged into groundwater (*i.e.*, "worst case") will travel prior to being attenuated to concentrations below analytical laboratory MRLs, or to zero.

The following are assumptions used in considering the fate and transport of pollutants in groundwater:

- Stormwater discharges directly into groundwater, even though many of the UICs with < 5 feet of separation distance may have 5 or more feet of separation for much of the year.
- Pollutant attenuation in the unsaturated zone is not considered. Separation distances are based on seasonal high groundwater levels. As previously discussed in this document, seasonal high groundwater levels are expected to occur < 15 % of the year.
- Stormwater pollutant concentrations are conservatively assumed to continuously discharge to UICs at 95th UCL on the mean and 95th UCL on the 95th percentile concentrations.
- An average scenario and reasonable maximum scenario were simulated to assess a conservative range of pollutant fate and transport distances in groundwater. The stormwater discharge input concentrations used for the average scenario was 95% UCL on the mean, while the 95% UCL on the 95 percentile value was used for the reasonable maximum scenario (see Section 4.3 of the Framework report).
- No dilution is considered.
- The aquifer is homogeneous and isotropic, no pumping is occurring, and vertical gradients are insignificant.
- Adsorption follows a linear isotherm and is a reversible processes.
- Groundwater velocity is sufficiently fast so that molecular diffusion can be ignored.

D4 RESULTS

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

D4.1 PCP Fate and Transport

Results of the BIOSCREEN fate and transport simulations for PCP are shown in Figures D1 and D2 (average scenario) and Figures D3 and D4 (reasonable maximum scenario). The BIOSCREEN simulations indicate that after one year of fate and transport:

- PCP concentrations are below the MADL or EPA maximum concentration limit (MCL) for public drinking water supplies at the point stormwater enters the UIC under the average scenario.
- PCP will be attenuated to an estimated concentration of 0 at a distance between 1 foot from the UIC (average scenario) and 6 feet from the UIC (reasonable maximum scenario).
- Exceedence of the EPA MCL for PCP is restricted to within one foot of the UIC for the reasonable maximum scenario.

Figure D1: Input Parameters for PCP Fate and Transport – Average Scenario

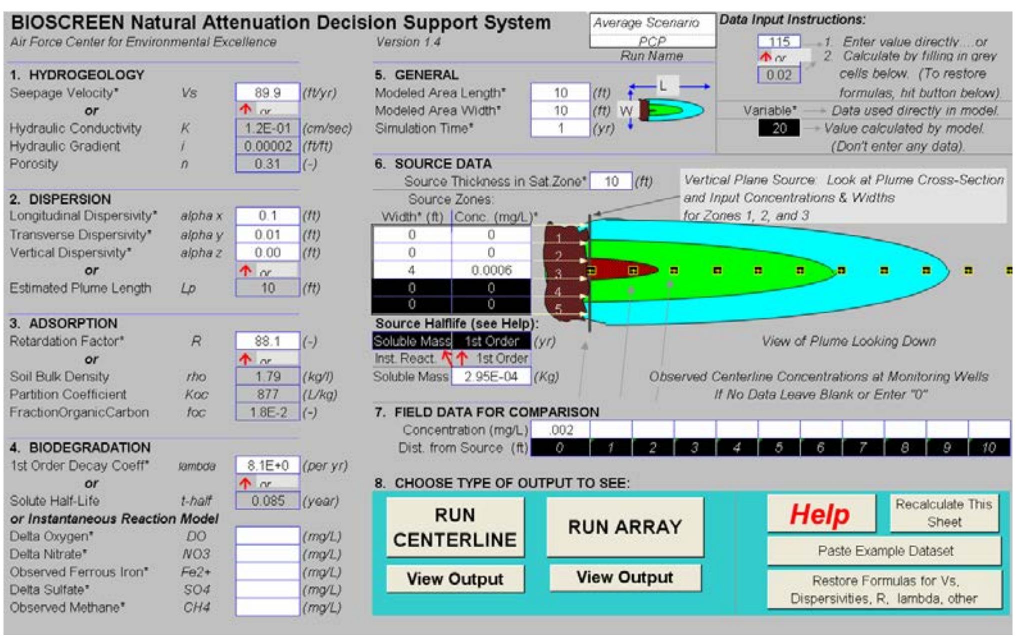


Figure D2: BIOSCREEN Output for PCP Fate and Transport – Average Scenario

SIMULATION OF PCP TRANSPORT IN GROUNDWATER

	Distance from Source (ft)										
TYPE OF MODEL	0	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
No Degradation	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1st Order Decay	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
95% UCL on Mean	6.00E-04										

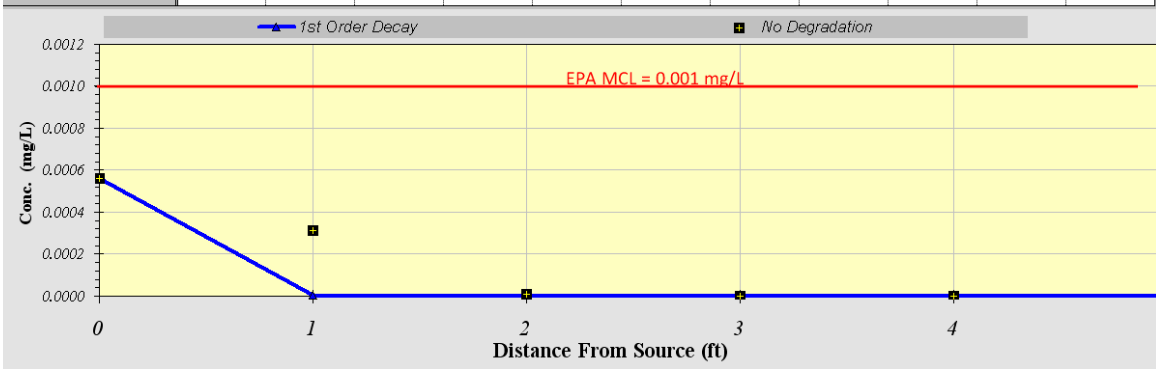


Figure D3: Input Parameters for PCP Fate and Transport – Reasonable Maximum Scenario

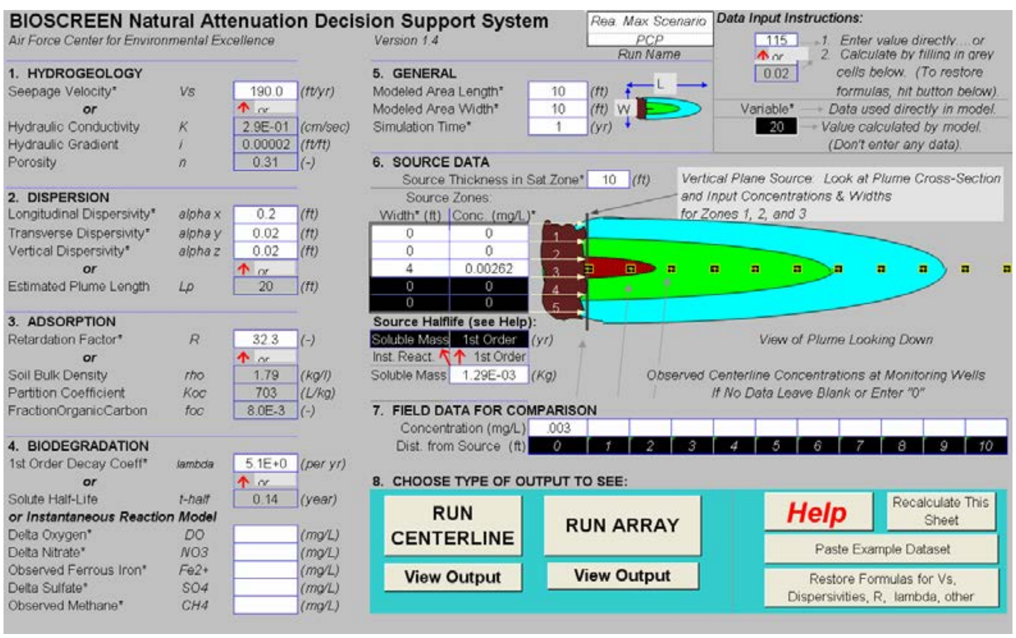
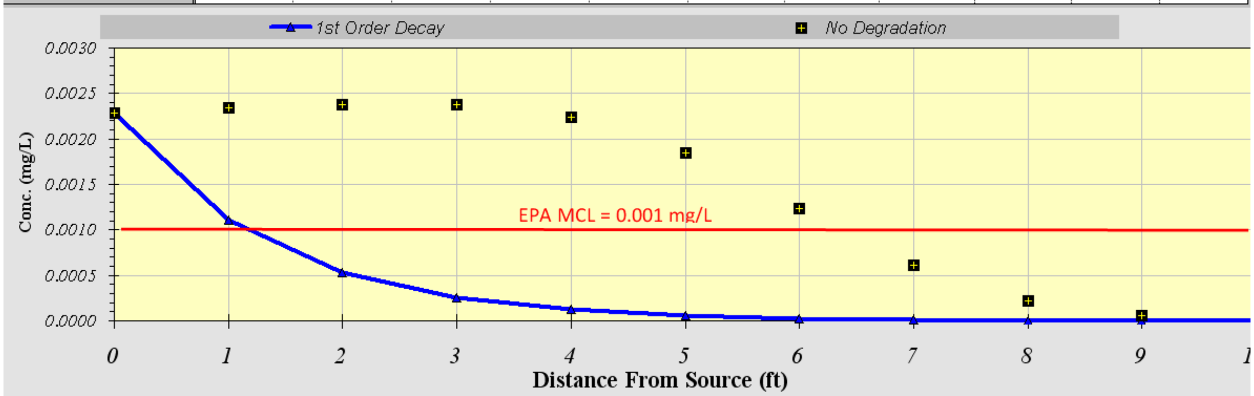


Figure D4: BIOSCREEN Output for PCP Fate and Transport – Reasonable Maximum Scenario

SIMULATION OF PCP TRANSPORT IN GROUNDWATER

	Distance from Source (ft)										
TYPE OF MODEL	0	1	2	3	4	5	6	7	8	9	10
No Degradation	0.0023	0.0023	0.0024	0.0024	0.0022	0.0018	0.0012	0.0006	0.0002	0.0001	0.0000
1st Order Decay	0.0023	0.0011	0.0005	0.0003	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
95% UCL on 95%	0.0026										



D4.2 Toluene Fate and Transport

Results of the BIOSCREEN fate and transport simulations for toluene are shown in Figures D5 and D6 for the average scenario and Figures D7 and D8 for the reasonable maximum scenario. The MADL and EPA MCL for toluene are significantly higher than the toluene concentrations detected in by the City's UIC stormwater discharge monitoring program and the input concentration used for the BIOSCREEN simulation. Therefore, the toluene concentrations are plotted on a log axis in Figures D5 through D8 to facilitate comparison of BIOSCREEN results and the MADL. The BIOSCREEN simulations indicate that after one year of fate and transport:

- Toluene concentrations are well below (*i.e.*, at least 100x < the EPA MCL) the MADL and EPA MCL at the point stormwater enters the UIC under the average and reasonable maximum scenarios.
- Toluene will be attenuated to the laboratory method reporting limit of 0.5 µg/L in a distance of < 1 foot from the UIC for the average scenario and within 22 feet from the UIC for the reasonable maximum scenario. The MRL for toluene in water using EPA Method 8260B was specified in the *Stormwater Discharge Monitoring Plan* (SDMP; BES, 2006b).
- The Toluene MADL or EPA MCL are not exceeded in groundwater.

Figure D5: Input Parameters for Toluene Fate and Transport – Average Scenario

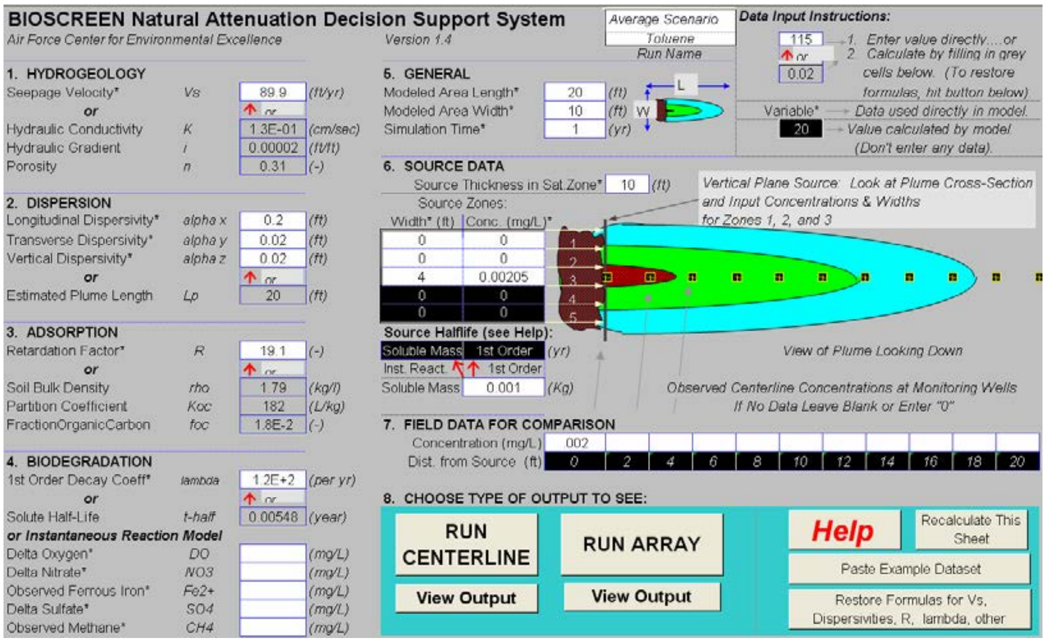


Figure D6: BIOSCREEN Output for Toluene Fate and Transport – Average Scenario

SIMULATION OF TOLUNE TRANSPORT IN GROUNDWATER

Distance from Source (ft)

TYPE OF MODEL	0	2	4	6	8	10	12	14	16	18	20
No Degradation	1.92E-03	1.93E-03	1.41E-03	3.55E-04	1.68E-05	1.17E-07	1.09E-10	1.28E-14	2.25E-19	0.00E+00	0.00E+00
1st Order Decay	1.92E-03	2.54E-11	3.36E-19	4.36E-27	5.60E-35	7.20E-43	9.23E-51	1.18E-58	1.51E-66	0.00E+00	0.00E+00
95% UCL on mean	2.05E-03										

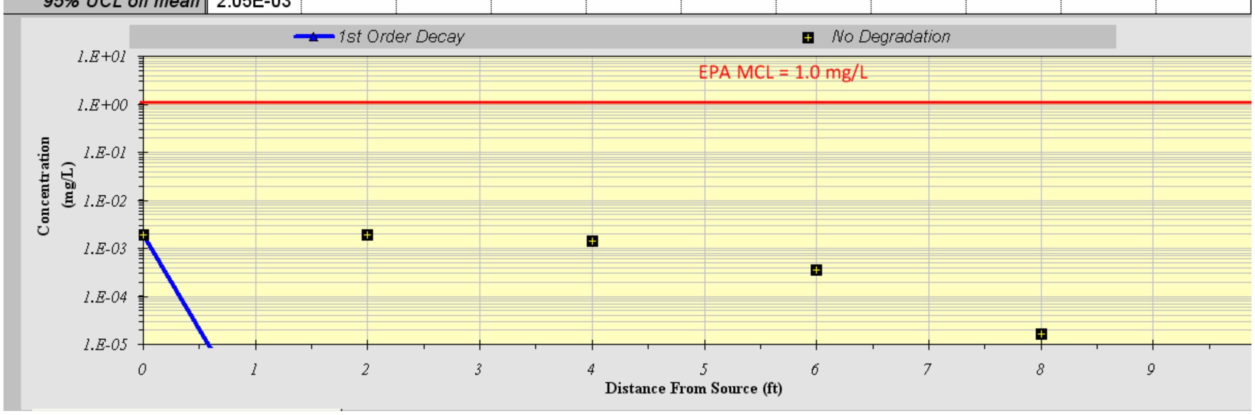


Figure D7: Input Parameters for Toluene Fate and Transport – Reasonable Maximum Scenario

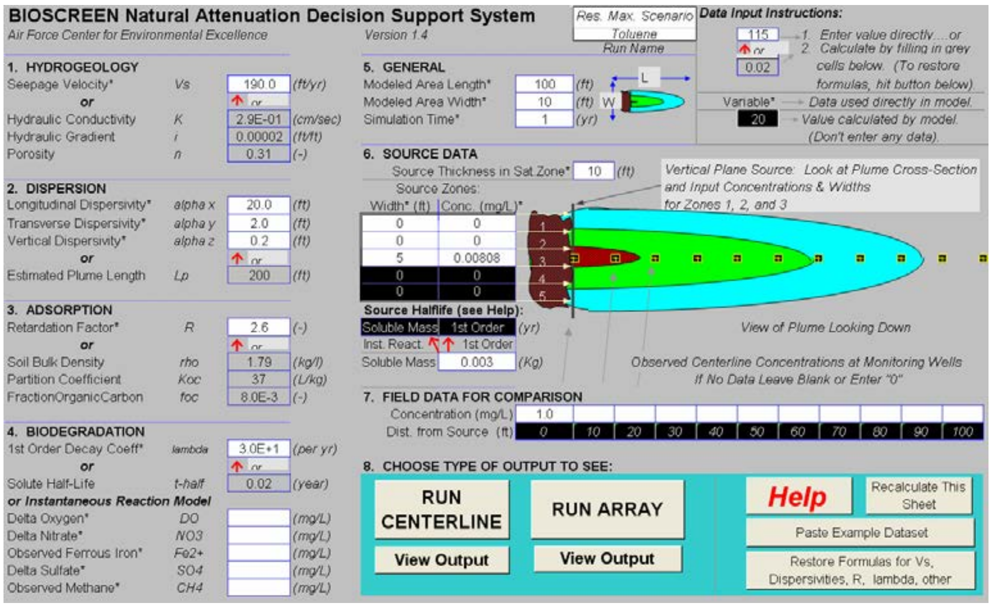
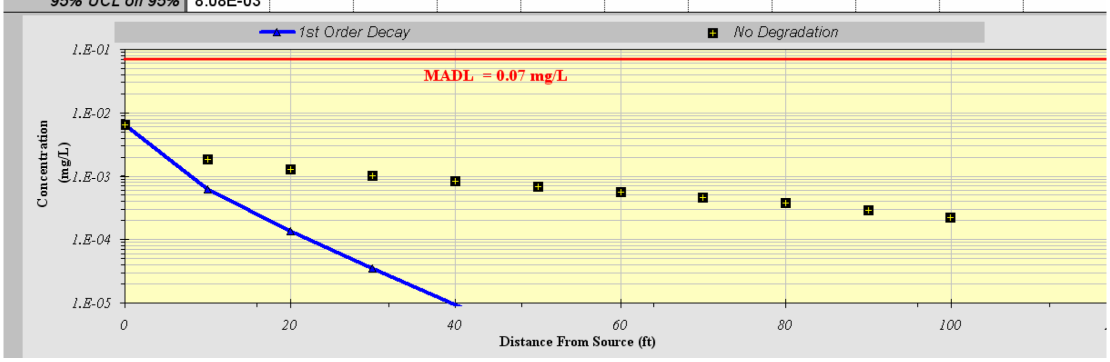


Figure D8: BIOSCREEN Output for Toluene Fate and Transport – Reasonable Maximum Scenario

SIMULATION OF TOLUNE TRANSPORT IN GROUNDWATER

TYPE OF MODEL	Distance from Source (ft) 0	10	20	30	40	50	60	70	80	90	100
No Degradation	6.56E-03	1.82E-03	1.28E-03	1.01E-03	8.30E-04	6.88E-04	5.70E-04	4.68E-04	3.72E-04	2.89E-04	2.20E-04
1st Order Decay	6.56E-03	6.23E-04	1.38E-04	3.48E-05	9.26E-06	2.53E-06	7.03E-07	1.98E-07	5.49E-08	1.53E-08	4.26E-09
95% UCL on 95%	8.08E-03										



D4.3 2,4-D Fate and Transport

Results of the BIOSCREEN fate and transport simulations for 2,4-D are shown in Figures D9 and D10 (average scenario) and Figures D11 and D12 (reasonable maximum scenario). The BIOSCREEN simulations indicate that after one year of fate and transport:

- 2,4-D concentrations are well below (*i.e.*, are less 100x < the MADL) the MADL and EPA MCL at the point stormwater enters the UIC under the average and reasonable maximum scenarios.
- 2,4-D will be attenuated to the laboratory MRL of 0.1 µg/L in a distance of about 4 feet from the UIC for the average scenario and about 75 feet from the UIC for the reasonable maximum scenario. The MRL for 2,4-D was specified in the SDMP (BES, 2006b).
- The 2,4-D MADL or EPA MCL are not exceeded in groundwater.

Figure D9: Input Parameters for 2,4-D Fate and Transport – Average Scenario

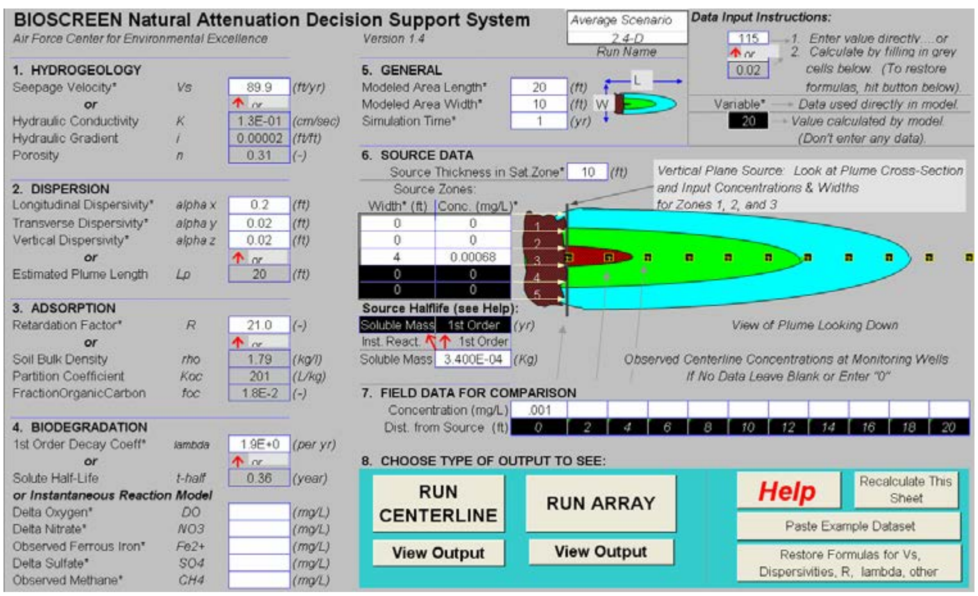


Figure D10: BIOSCREEN Output for 2,4-D Fate and Transport – Average Scenario

SIMULATION OF 2,4-D TRANSPORT IN GROUNDWATER

Distance from Source (ft)

TYPE OF MODEL	0	2	4	6	8	10	12	14	16	18	20
No Degradation	6.38E-04	6.31E-04	3.96E-04	6.42E-05	1.52E-06	4.21E-09	1.24E-12	3.74E-17	0.00E+00	0.00E+00	0.00E+00
1st Order Decay	6.38E-04	2.82E-04	9.91E-05	1.23E-05	2.62E-07	6.86E-10	1.96E-13	5.82E-18	0.00E+00	0.00E+00	0.00E+00
95% UCL on the mean	6.800E-04										

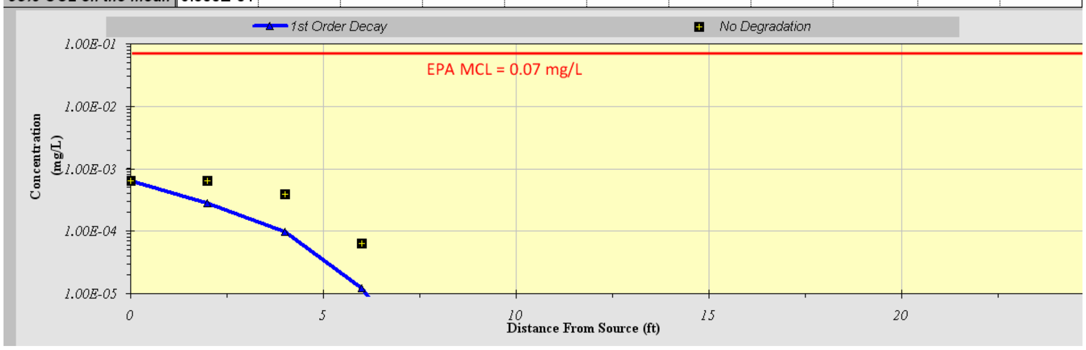


Figure D11: Input Parameters for 2,4-D Fate and Transport – Reasonable Maximum Scenario

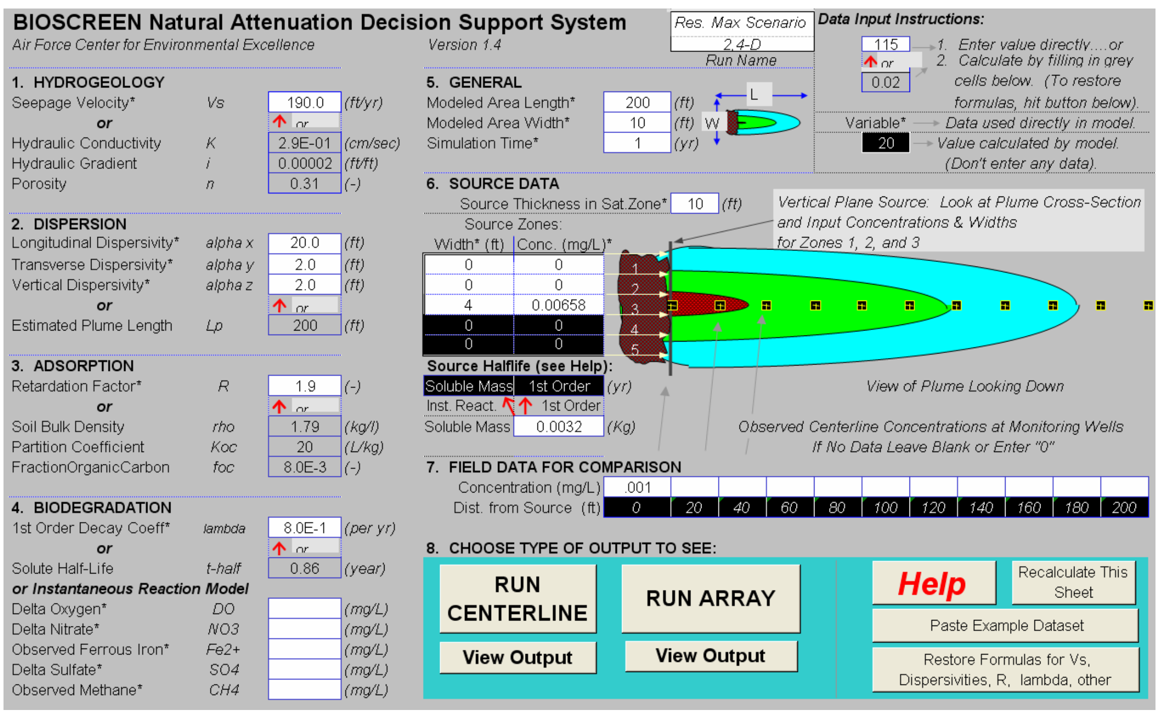
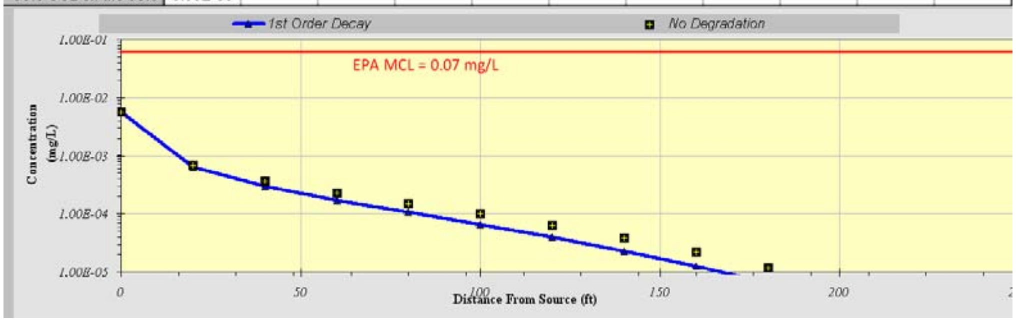


Figure D12: BIOSCREEN Output for 2,4-D Fate and Transport – Reasonable Maximum Scenario

SIMULATION OF 2,4-D TRANSPORT IN GROUNDWATER

	Distance from Source (ft)										
TYPE OF MODEL	0	20	40	60	80	100	120	140	160	180	200
No Degradation	5.75E-03	6.90E-04	3.60E-04	2.27E-04	1.51E-04	1.00E-04	6.33E-05	3.82E-05	2.18E-05	1.17E-05	5.83E-06
1st Order Decay	5.75E-03	6.39E-04	3.01E-04	1.74E-04	1.07E-04	6.67E-05	3.99E-05	2.31E-05	1.27E-05	6.60E-06	3.21E-06
95% UCL on the 95%	6.58E-03										



D4.4 Conclusions

Table D7 summarizes the maximum distances that PCP, toluene, and 2,4-D are expected to travel in groundwater if directly discharged to groundwater prior to reaching either a zero concentration or the analytical laboratory MRL. These estimates are conservative in that they assume direct discharge into groundwater and do not account for dilution at the point stormwater enters groundwater or for attenuation in unsaturated soil (*e.g.*, vertical separation distance) prior to stormwater reaching groundwater. Because of the complexities in the hydrogeologic system and variability in stormwater concentrations, both "average" and "reasonable maximum" scenarios, as defined by DEQ and EPA guidance, are provided to assess the uncertainties in the fate and transport calculations (see Section 5 of the Framework report).

Key Points of Analysis:

- PCP is the only pollutant detected where its annual geometric mean concentration above the MADL. For the reasonable maximum scenario, where the 95%UCL on the 95% percentile is conservatively used as the stormwater input concentration into City-owned UICs, the estimated PCP concentration is predicted to be below the MADL within 1 foot of the UIC.
- 2,4-D and toluene are well below the MADL/screening level concentration at the point of stormwater discharge into City-owned UICs. The 95% UCL on the mean for 2,4-D, based on Year's 1-3 data, is 0.68 µg/L; this is 2 orders of magnitude below the MADL of 70 µg/L. The 95% UCL on the mean for toluene, based on Year's 1-3 data, is 2.05 µg/L; this is 3 orders of magnitude below the MADL of 1000 µg/L. No individual MADL exceedences have occurred for either toluene or 2,4-D.

Table D7: Estimated Pollutant Travel Distances in Groundwater

Scenario		PCP	Toluene	2,4-D
MADL (µg/L)		1	1,000	70
Average [a]	Est. Stormwater Input Conc. (µg/L)	0.6	2.05	0.68
	Travel Distance (feet)	1	<1	4
Reasonable Maximum [b]	Est. Stormwater Input Conc. (µg/L)	2.62	8.08	6.58
	Travel Distance (feet)	6	10	75
Concentration at Specified Travel Distance		**0** µg/L	**0.5** µg/L (MRL)	**0.1** µg/L (MRL)

NOTES:
PCP = pentachlorophenol
2,4-D = 2,4-dichlorophenoxyacetic acid
MRL = Method Reporting Limit specified in the SDMP (BES, 2006b)
[a] Stormwater input concentration based on 95th UCL on the mean (see Section 4.3 of the Framework report)
[b] Stormwater input concentration based on 95th UCL on the 95th percentile value (see Section 4.3 of the Framework report)

D5 Works Cited

BES (2006a). *Corrective Action Plan*. Prepared by: City of Portland Bureau of Environmental Services, July.

BES (2006b) *Stormwater Discharge Monitoring Plan*. Prepared by: City of Portland Bureau of Environmental Services, August.

BES (2007). *Stormwater Discharge Monitoring Annual Report: Year 2 – October 2006 to May 2007*. Prepared by: City of Portland Bureau of Environmental Services, July.

DEQ (2005). *Fact Sheet and Class V Underground Injection Control (UIC) Permit Evaluation, Permit Number 102830*. Prepared by: Oregon Department of Environmental Quality, June.

EPA (1996). BIOSCREEN Natural Attenuation Decision Support System: User's Manual Version 1.3. Office of Research and Development, Washington DC: 100 pp.

Fetter, C. W. (1994). *Applied Hydrogeology*. 3rd Ed. Prentice Hall: Upper Saddle River, New Jersey. 691 pp.

Freeze, A., and Cherry, J. A. (1979). *Groundwater.* Prentice Hall: Englewood Cliffs, N.J. 604pp.

Gelhar, L. W., Mantoglu, A., Welty, C. , and Rehfeldt, K. R. (1985). A Review of Field-Scale Physical Solute Transport Processes in Saturated and Unsaturated Porous Media. EPRI EA-4190, Project 2485-5, Final Report, Electric Power Research Institute.

Gelhar, L.W., Welty, C., and Rehfeldt, K.R. (1992). A critical review of data on field-scale dispersion in aquifers. *Water Resources Research.* 28: 1955-1974.

GSI (2008a). Evaluation of Vertical Separation Distance Groundwater Protectiveness Demonstration. Prepared for: City of Portland Bureau of Environmental Services, May 7.

GSI (2008b). Category 4 UIC Corrective Actions Groundwater Protectiveness Demonstration. Prepared for: City of Portland Bureau of Environmental Services, April 7.

USGS (1998). Use of a Ground-Water Flow Model with Particle Tracking to Evaluate Ground Water Vulnerability, Clark County, Washington. Water Supply Paper 2488. United States Government Printing Office. Washington.

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