Portland Harbor RI/FS

Upland Groundwater Data Review Report
River Mile 2 – 11
Lower Willamette River

June 2, 2003

DO NOT QUOTE OR CITE
This document is currently under review by US EPA and its federal, state and tribal partners, and is subject to change in whole or part

USEPA Docket No: CERCLA-10-2001-0240

Prepared For:

The Lower Willamette Group

Prepared By:

Groundwater Solutions, Inc.
3758 SE Milwaukie Avenue
Portland, OR 97202

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Background

This report summarizes information from a review of hydrogeologic and groundwater quality data from upland sites in the vicinity of the Portland Harbor Initial Study Area (ISA), conducted for the Portland Harbor Superfund Site remedial investigation/feasibility study (RI/FS). This work was conducted on behalf of the Lower Willamette Group (LWG).

The groundwater data review (Data Review) is the first RI/FS task for the evaluation of groundwater-related risks to receptors described in the draft RI/FS Programmatic Work Plan (Work Plan) that was submitted to EPA on March 31, 2003 (SEA, et al, 2003). This report provides the results for the first and second steps of the overall groundwater evaluation process, as described in Section 7.2.3 of the Work Plan including:

1. An intensive review of upland groundwater data available in Oregon Department of Environmental Quality (DEQ) files to (1) understand the physical groundwater system and (2) identify upland sites where groundwater containing chemicals of interest (COIs)[1] are known or suspected to discharge to the ISA, either through surface seeps or subsurface discharge to sediments, porewater or human use areas.

2. Identification of sites where data are unavailable or insufficient to determine the potential for COIs to reach the river through the process of the DEQ file review. The potential for groundwater impacts at locations where groundwater data were unavailable was assessed by reviewing historical land uses.

The report provides the following information in support of these two steps, including:

- The approaches used to develop the hydrogeological conceptual site model (CSM) and to assess the upland groundwater quality information using information compiled from DEQ files (Section 2);
- A description of the physical hydrogeologic setting, including a detailed hydrogeologic conceptual model and a discussion of identified preferential pathways for groundwater flow (Section 3);
- A summary of current knowledge of the location of COIs in groundwater adjacent to the ISA and the potential for groundwater containing COIs to discharge directly to sediments or via seeps to surface water within the ISA (Section 4);

[1] COIs for the purposes of the Work Plan (SEA, et al, 2003) and this document are chemicals that have been detected in upland groundwater recently and have not been screened relative to potential impacts to the ISA using risk-based criteria.

- Identification of areas where groundwater data are not available and the results of a review of historical land use information for these properties (Section 4);
- Conclusions and how the conclusions will be used to further evaluate potential groundwater-related risks to receptors (Section 5);
- A summary of historical and current land uses, possible migration pathways of COIs to the ISA, the hydrogeologic setting and the regulatory status for each ECSI site between RM 2 and 11 (Appendix A). Appendix A also includes a summary of recent site-specific groundwater COI concentrations nearest the river, as well as the groundwater monitoring locations, groundwater elevation contours and COI concentration maps, where available;
- A technical memorandum that summarizes historical and current land uses for parcels of land adjacent to the river that are not listed in the ECSI database (Appendix B); and
- The seep reconnaissance survey memorandum (GSI, 2003) submitted to EPA in February 2003 (Appendix C).

The third step of the evaluation of potential groundwater-related risks to receptors will be to identify specific locations for further evaluation of potential risk to ecological and human receptors from COIs in groundwater. For ecological receptors, available groundwater COI concentrations near the river will be screened against conservative risk-based criteria to identify sites where evaluation of ecological risk from the discharge of COIs in groundwater to sediments or porewater is needed. The risk to human health from the discharge of COIs in groundwater to the ISA will be evaluated by identifying locations where the COIs in upland groundwater could reach shoreline seep locations within beaches identified as potential human use areas and comparing available groundwater COI concentrations near the river with conservative risk-based screening values for dermal contact with water. The general approach for identifying locations for further evaluation of risk to receptors in the ISA from COIs in groundwater discharging as seeps or to sediments or porewater is described in Section 7.2.3 of the Work Plan. The results of the process, and recommendations for sampling and analysis to assess the impacts of groundwater on risk will be provided in subsequent deliverables, as described in Section 5.0.

The information provided in this document, including tables, figures, and appendices, is a compilation of data from various investigations, sources, and sites readily available to date. However, many of the investigations are on-going or are in the initiation phase of investigation. As additional groundwater data or upland site information are gathered, and the understanding of groundwater conditions at various sites evolves, users of this document should ensure that the most up-to-date site-specific information is obtained to augment the information in this document.

1.2 Purpose and Objectives

The overall objective of the RI/FS, with respect to groundwater, is to identify areas of the ISA where the discharge of groundwater containing COIs results in unacceptable risks to receptors under the following scenarios:

- Benthic organisms in direct contact with sediments containing COIs from groundwater discharges that sorb to sediments;
- Benthic organisms in direct contact with porewater containing COIs from groundwater discharges that do not sorb to sediments;
- Humans in direct contact with COIs in groundwater discharging at the surface from seeps in identified human use areas.

The overall objective of the Data Review was to synthesize and evaluate available regional and local groundwater data at upland sites adjacent to the ISA to assess the potential effects of the groundwater COIs on risk to ecological and human receptors in the ISA. DEQ files were reviewed for the portion of the Portland Harbor located between river miles (RM) 2 to 11 (Figure 1-1).

The specific objectives of the Data Review were to:

- Develop a general understanding of the relationship between upland groundwater and the Willamette River and the influence of the hydrogeological physical system on exposure pathways in the ISA through development of a detailed hydrogeologic CSM.
- Identify locations where groundwater COIs are known or reasonably expected to enter the river.
- Identify areas where groundwater COIs are or may be present, but existing data are insufficient to assess whether the COIs are reaching the river.
- Identify areas where groundwater COIs appear not to be discharging to the ISA.
- Identify where groundwater seeps are located in potential human use areas.
- Identify the location of potential natural or man-made preferential pathways of groundwater flow to the river.

The purpose, objectives and uses of the Data Review are consistent with EPA's strategy for groundwater/surface water interaction studies (EPA 2000). The Data Review will take the part of the initial thorough assessment of site conditions based on existing data, which will be followed by a tiered approach to more focused data collection activities, if necessary.

Consistent with the data quality objectives for groundwater as presented in the Work Plan, the uses of this evaluation include:

1. **Evaluate whether COIs in groundwater discharging as surface seeps or to sediments or porewater poses risk to humans or to ecological receptors**: The Data Review identifies upland locations where COIs in groundwater are confirmed to or have a reasonable potential to reach the ISA. As stated earlier, groundwater data collected from these locations will be screened against conservative risk-based criteria to identify where further evaluation of surface seeps, sediments, porewater within the groundwater/surface water transition zone (Transition Zone)[2] may be needed to assess the risks from COIs in groundwater discharging within the ISA. If potential unacceptable risks to ecological or human receptors from groundwater COIs are identified during the screening process, the LWG intends to further assess ecological and human health risks within the ISA at these locations through an ecological risk assessment (ERA) and human health risk assessment (HHRA), as described in the Work Plan. Data for shoreline seeps in human use areas will be evaluated to assess human health risks from dermal contact.

2. **Identify locations where further assessment of upland groundwater quality may be necessary:** Locations where available data may not be adequate to assess the presence of COIs in groundwater or the likelihood for groundwater COIs to reach the ISA with reasonable certainty will be identified and referred to the DEQ for further characterization of groundwater as part of the upland site program.

3. **Evaluation of remedial alternatives**: The feasibility study will utilize information from the Data Review and any future data for use in the identification of sediment management areas (SMAs), to evaluate recontamination potential, and for assessment of the effectiveness of remedial alternatives, such as capping.

This report is not intended to evaluate the extent to which any property in the vicinity of the ISA is or is not a facility from which a release of a hazardous substance via any transport mechanisms to the ISA may have occurred. Rather, the report simply compiles current groundwater data as a starting point for the risk-based evaluation of groundwater discharges to the ISA at potential points of exposure for humans and for ecological receptors. As described in the Work Plan, hazardous substances have been released to the ISA from a variety of sources and through a variety of media. Groundwater is only one transport mechanism for hazardous substances, and based upon the small groundwater flux to the ISA relative to total river flow (predicted to be 0.1 to 2 percent maximum [see Section 3.3]), it likely is not the most significant transport mechanism overall. Additional sources of hazardous substance releases to

[2] The Transition Zone is defined for the purposes of the RI/FS as the interval where both groundwater and surface water comprise some percentage of the water occupying pore space in the sediments.

the ISA, including possible historic groundwater sources that may no longer be evident in recent groundwater data will be evaluated throughout the RI/FS.

1.3 Scope

The work elements completed for the Data Review included the following:

- Review of published and readily available unpublished geologic and hydrogeologic information regarding the lower Willamette River (LWR), with particular emphasis on the area around and including the ISA.
- Review of potential preferential groundwater flow pathways.
- A survey of groundwater seeps between RM 2.5 and 10.5. The results of the seep survey are summarized in a draft technical memorandum submitted to EPA (GSI, 2003). The memorandum is also included as Appendix C of this report.
- Development of a hydrogeological conceptual model for the ISA.
- Review of available data for all COIs analyzed in groundwater from DEQ files for sites between RM 2 to 11, including sites bordering the river and sites with documented groundwater plumes in certain areas up to approximately one-half mile inland from the river. The properties encompassed by the Data Review are shown in Figure 1-1. This evaluation did not include a rigorous review of soil COI data.
- Review of limited historical land use information for properties where groundwater data are not available and are not in the DEQ files.

Based upon this review, three categories of sites have been developed:

1. Sites with a reasonable likelihood to discharge groundwater containing COIs to the ISA. Concentrations of COIs at these sites will be screened against conservative risk-based numbers that will be one part of the process undertaken to determine whether further evaluation of risk to human and/or ecological receptors from groundwater discharge at this location is necessary. A screening procedure is currently being developed by the LWG.
2. Sites at which insufficient data exists to evaluate the potential for risk to receptors from groundwater discharge. These sites will be referred to DEQ for consideration of further upland evaluation.
3. Sites at which groundwater data suggests that no groundwater COIs can reach the river. It is anticipated that no further evaluation of risks to receptors will be performed by the LWG relative to these locations.

2.0 Approach and Methodology

2.1 General Approach

The approach to this study was to utilize existing information including local and regional geologic and hydrogeologic studies, and groundwater COI data collected as part of upland site investigations under DEQ oversight, to identify the locations where groundwater containing COIs is known or reasonably likely to discharge to the river, and to understand the mechanism for groundwater flow and discharge. The integrated physical hydrogeologic system and COI distribution data were used to identify locations where additional data are needed to assess risks to receptors in the ISA. The presence and distribution of COIs in groundwater was assessed through review of the most current groundwater quality data available in DEQ files from past or ongoing site investigations. Many of the upland groundwater plumes present near the ISA originated prior to the advent of modern hazardous materials handling practices, regulations and technologies during the last 25 years. The COIs detected recently in groundwater are typically a reflection of the historical presence of COIs, with the effects of transport, transformation and attenuation processes superimposed.

The approach to understanding groundwater flow and discharge to the ISA was to develop a hydrogeologic conceptual model for the ISA that incorporates the current understanding of the relationship between the river and the upland hydrogeologic units on an ISA-wide scale, as well as on a local scale. The steps and methods used for synthesizing the information regarding the physical groundwater system and the presence and distribution of COIs in groundwater are summarized in the following sections.

2.2 Hydrogeologic Conceptual Model Development

The approach to formulating a hydrogeologic conceptual model for the ISA was to develop a general understanding of the ISA-wide hydrogeologic setting. This was conducted by interpreting available data in a regional context, followed by an evaluation of facility-specific data to describe the spatial variability along the ISA and to provide the basis for development of a more detailed understanding of the relationship between groundwater and the river where groundwater COIs are present and to understand the influence of the hydrogeological physical system on exposure pathways in the ISA. It is beyond the scope of the Data Review or the RI/FS to describe in detail a conceptual hydrogeologic model for each facility. Development of facility-specific conceptual hydrogeologic models is a task that falls under the jurisdiction of DEQ under the upland source control program. However, Appendix A of this report provides a brief compilation of available site-specific information including current and historic land use, local hydrogeology, a list of chemicals detected in groundwater, potential groundwater to surface water pathways, and regulatory status. In addition, the site summaries include the most recent facility plans showing groundwater monitoring wells and explorations, maps with concentrations of COIs in groundwater near the river, and cross sections where readily available. At some facilities, available subsurface geologic information may not be adequate to understand the subsurface conditions, and/or groundwater COI concentration maps or gradient maps were not available; facility maps and tables summarizing COIs in groundwater were provided for these facilities. At locations where COIs in groundwater near the river exceed forthcoming screening levels, the LWG anticipates that a more detailed review of site-specific groundwater conditions may be necessary prior to field data collection.

The characterization of the physical hydrogeologic system involved understanding the following attributes:

- Spatial relationship between hydrogeologic units and the river.
- The hydraulic properties of hydrogeologic units.
- Spatial and temporal groundwater gradient and river stage data.
- The location and variability of groundwater discharge.
- Preferential pathway mechanisms and occurrences.

The process used to understand these attributes and develop the hydrogeologic conceptual model included the following steps:

1. Develop an understanding of the general relationships between various geologic units and the river by constructing geologic cross sections showing the geometry of large-scale geologic features, as well as the relationship of geologic units to the river on a local level. The regional sections were developed using published geologic maps and papers, as well as geologic logs of borings obtained from existing geotechnical and environmental investigation reports, and the Oregon Water Resources Department (OWRD) GRID database. In most cases, site-specific cross sections were derived from existing site characterization reports. In locations where this information has not yet been developed in the DEQ upland cleanup program, the cross sections were developed by using existing boring logs.
2. Identify hydrogeologic units on an ISA-wide and local level by reviewing site-specific and regional geologic and hydrogeologic data to understand the relationship between potential groundwater flow pathways and the river. Larger scale studies encompassing the ISA include published research by the US Geological Survey (USGS) and the Oregon Department of Geology and Mineral Industries (DOGAMI). More localized information was obtained from site investigations at specific properties in the study area, including logs for wells located in the study area obtained from OWRD and published and unpublished geotechnical studies, as well as interviews with local experts.

3. Review groundwater and surface water level data to understand spatial and temporal variations in groundwater flow in relation to the river.

4. Identify and describe hydrogeologic units and groundwater flow systems based on steps 2 and 3.

5. Compile groundwater flow system hydraulic parameters (e.g., hydraulic conductivity and storativity) for hydrogeologic units along the ISA.

6. Assess the relative contribution of groundwater flux to the overall flow in the river within the ISA based on review of USGS river flow data and USGS basin modeling estimates (Morgan and McFarland, 1996).

7. Identify the presence or potential for natural and anthropogenic (e.g., utilities) preferential groundwater flow pathways to the river by reviewing facility-specific evaluations of groundwater flow pathways, maps of outfall locations, and utility maps. It should be noted that available utility maps only provide a picture of City-owned utilities and generally do not depict facility-specific storm drains and other utilities. Information regarding facility-specific natural and anthropogenic flow paths is generally more comprehensive at facilities that are in the advanced stages of the site characterization and remediation process.

2.3 Groundwater Quality Assessment Approach

The objective of the review of groundwater COI data was to understand the nature and location of potential discharge of groundwater containing COIs to the ISA. The Data Review did not include the compilation of a database of all upland groundwater COI data. Rather, the Data Review primarily focused on review of recent groundwater data collected near the river. The review did not include a detailed evaluation of soil COI data. However, qualitative references to COIs in soil is provided where relevant to past releases that may have affected groundwater or with regard to source controls that have been implemented.

For the purposes of the Data Review, all properties bordering the river and properties on the DEQ Environmental Cleanup Site Inventory (ECSI) list in areas up to approximately one-half mile inland from the river between RM 2 and 11 were evaluated for potential discharge of groundwater COIs to the ISA, as shown on Figure 2-1. The properties evaluated for the Data Review can be grouped with regard to the availability of data as follows:

- Properties on the ECSI List: These properties include (1) those with groundwater data, and (2) those without groundwater data, but with information available for review regarding potential releases of contaminants. Both categories of properties with information are included on the ECSI list. The locations of properties listed on the ECSI database are shown in Figure 2-1.

- Properties not on the ECSI List: Groundwater data or other information indicating the potential for a contaminant release are not available for these properties. The locations of properties not listed on the ECSI database are shown in Figure 2-1. An assessment of historical land use information for these properties is presented in Appendix B.

The process for assessing the potential for groundwater COIs to discharge to the ISA at sites with and without available groundwater or other contaminant release information is described in the following section.

2.3.1 Properties on ECSI List

Data from work conducted at individual facilities in the vicinity of the ISA currently listed in the ECSI database were used to evaluate the potential for groundwater containing COIs to discharge to the ISA. DEQ implemented a comprehensive site screening process in 1999 that utilized environmental database lists to identify and assess properties that could have released hazardous substances to the ISA. The properties identified during the screening process were included on the ECSI list. This list was used as the initial basis for focusing the data review. The steps of the Data Review process used to evaluate the sites in the DEQ files are listed below:

- Obtained the list of properties and areas on the ECSI list.
- Met with each DEQ site manager to focus the literature review for each facility and to solicit the opinion of the manager regarding the distribution of groundwater COIs, the presence of nonaqueous phase liquid (NAPL), and the potential for COIs to reach the ISA.
- Reviewed the most currently available information describing groundwater contaminant sources, the nature and extent of groundwater COIs, groundwater flow, preferential pathways and implementation of groundwater source control measures. The review concentrated on the most recent groundwater data in the DEQ files.
- Compiled a list of all COIs detected in groundwater during monitoring events completed within the past year, or from a prior year, if recent data were not available.
- Determined whether NAPL has been confirmed to be present.
- Compiled the concentration of each COI detected in groundwater at monitoring points nearest the river, and estimated the distance from the Ordinary High Water level of the river for each of these monitoring points.
- Listed any groundwater source control measures that have been implemented for each facility.
- Listed the status of each facility with regard to the upland program RI/FS process as a general indication of how complete characterization of the site is.
- Listed potential preferential groundwater pathways to the river.

The results from review of information from properties on the ECSI list are presented in Section 4 of this report, and more detailed summary information for each property is provided in Appendix A.

2.3.2 Properties not on ECSI List

Properties lacking available environmental information were evaluated for groundwater contamination potential by reviewing select historical land use records. Historical aerial photographs, City Directories and Sanborn maps, as available, were used to identify the properties with evidence of past practices that could potentially impact groundwater. The review did not evaluate the potential for the property to be a facility from which a release of hazardous substances to the ISA may have occurred through any transport mechanism other than groundwater. The results of the historical land use review for properties where environmental information is not currently available are described in Section 4. A review summary for each individual property is provided in Appendix B.

2.4 Facility Groups

Based on the groundwater quality data compiled from the DEQ files for the upland sites, properties in the vicinity of the ISA were categorized with regard to their potential for groundwater containing COIs at those sites to discharge to the ISA. This was made based on the distribution of groundwater COIs in areas upland from the ISA and the physical hydrogeologic setting. Categorization of the properties in this document does not reflect an evaluation of risks to human receptors through exposure to seeps in human use areas or ecological receptors through exposure to sediment, porewater, or shoreline seeps in the ISA from COI concentrations detected within groundwater adjacent to the river. The process and results that will complete the evaluation of the potential for groundwater contaminants to affect risk in the ISA utilizing the information in this report, as outlined in Section 7.2.3 of the Work Plan, will be provided in subsequent deliverables (see Section 5.0). The site categories include:

- Sites with COIs in groundwater that are known or reasonably likely to discharge to the Transition Zone, shoreline seeps and/or surface water based on information in DEQ files (without regard to whether those COIs pose risk in the ISA).
- Sites with insufficient data to determine whether COIs in groundwater may discharge to the Transition Zone, shoreline seeps and/or surface water
- Sites with groundwater data suggesting that groundwater COIs are not discharging to the ISA.

The results of the evaluation of potential groundwater effects on the ISA are summarized in Section 4.

3.0 Hydrogeologic Conceptual Model

This section describes a conceptual hydrogeologic model of the ISA and includes a summary of the geologic setting, hydrogeologic units, groundwater flow, and factors influencing groundwater discharge to the river. The detailed hydrogeology of the upland areas on both sides of the river varies by location. This section attempts to describe in detail the similarities, as well as the spatial variability of the hydrogeology along the river. Additional available background and groundwater information for each facility or property adjacent to the river between RM 2 and 11 is provided in Appendix A.

3.1 Geologic Setting

The lower Willamette River in the ISA occupies a channel flanked by low-lying areas between approximately elevation 10 and 40 feet mean sea level (MSL) that define the historical floodplain of the river (Figure 3-1). The low-lying area on the west side of the river is bordered by the Portland Hills, a linear topographic feature that rises to over 1,000 feet above mean sea level (MSL). Upstream of approximately RM 4, a broad terrace separating the floodplains of the Columbia and Willamette rivers borders the east side of the ISA. The surface of the terrace rises to elevation 250 feet MSL. The terrace represents older flood deposits and alluvial sediments that the Willamette River has incised to form the current floodplain and channel. The topography adjacent to the river in the ISA generally consists of a steep embankment rising to an elevation of 25 to 40 feet MSL. A beach or shelf is often present at the base of the embankment, although at some locations this feature is exposed only during the lowest river stage levels. The embankments are commonly armored with riprap or a variety of retaining structures. A detailed discussion of the physical setting of ISA is presented in the Work Plan.

The lower Willamette River is located along the southwestern edge of a large geologic structure known as the Portland Basin. The Portland Basin is a bowl-like structure bounded by folded and faulted uplands. These northwest-trending structural zones are interpreted as dextral wrench faults that delineate the Portland, pull-apart basin (Beeson et al. 1985; Yelen and Patton 1991). The northwest-trending Portland Hills, also known as Tualatin Mountains, form the southwest margin of the basin and consist of an asymmetric anticline faulted along its northeastern limb by the northwest-trending Portland Hills fault.

The Portland Basin has been filled with up to 1,400 feet of alluvial and fluviolacustrine flood deposits between the middle Miocene (approximately 12 million years [my] ago) and the present. These sediments overlie older (Eocene and Miocene) rocks including the Columbia River Basalt Group (CRBG), Waverly Heights basalt and older marine sediments. The older rocks are exposed where uplifting has occurred on the margins of the basin, including adjacent to the lower Willamette River. The geologic evolution and general relationships between geologic units found in the area of the ISA are illustrated in Figure 3-2 and briefly described from youngest to oldest below (Beeson et al. 1991 and Swanson et al. 1993). Cross sections illustrating the relationships between the regional subsurface geology and the river are shown in Figures 3-3 through 3-11. The locations of the sections are shown on Figure 3-1.

Recent Fill: Fill blankets much of the lowland area next to the river and is predominantly hydraulically dredged river sediment, including fine sand and silty sand. Hydraulic dredge fill was used to fill portions of the flood plain, such as Doane Lake, Guilds Lake, Kittridge Lake and Mocks Bottom, and a number of sloughs and low-lying areas. Rocks, gravel, sand, and silt also were used to fill low-lying upland and bank areas. Dredge fill was used to connect Swan Island to the east shore of the Willamette River and to elevate or extend the bank along significant lengths of both sides of the riverfront by filling behind artificial silt and clay and natural flood levees as well as concrete retaining structures. The thickness of the fill unit typically ranges from 0 to 25 feet, but approaches 40 feet in portions of the historic Doane Lake area (Figures 3-7 and 3-10). The permeability of this unit, where it is composed of clean dredge fill sand, or certain areas of debris such as in the Guilds Lake area, is higher than the natural fine-grained alluvium. The presence of silt fill or a silty matrix in the sand fill generally reduces the permeability of the unit significantly.

Pleistocene and Recent Alluvium (Undifferentiated Silt and Sand Facies): This unit includes fine-grained facies of the Pleistocene Flood Deposits, as well as recent alluvium deposited by the present Willamette River. This unit generally consists of silt, clay, silty sand, and fine to medium sand that borders and underlies the present floodplain of the river and likely represents alluvial sediments (Beeson et al. 1991). This undifferentiated unit represents an alluvial depositional environment that is transitional between the Pleistocene catastrophic floods and the present-day Willamette River, with channel sand layers and lenses interbedded with overbank and backwater silt and clay deposits. The lower portions of this unit and where it forms the large bluffs bordering the east side of the river likely consist of the lower energy facies of the Pleistocene flood deposits (Figure 3-10), whereas, the upper portions near the river are likely more recent alluvium. The sands of this unit may be indistinguishable from overlying dredge fill in some places (Landau 2002b). The thickness of this unit ranges from 20 to over 100 feet. The permeability of the clay, silt, and silty sand of this unit is generally relatively low. This unit forms part of the Unconsolidated Sedimentary Aquifer regional hydrogeologic unit proposed by Swanson et al. (1993).

Coarse-Grained Pleistocene Flood Deposits (Gravel Facies): This unit includes fluvial deposits from the Pleistocene glacial floods. The deposits fill deep channels that were incised into the Troutdale Formation and CRBG during the floods. The unit consists of uncemented sand, gravel, and cobbles with boulders in places with generally high permeabilities. This unit is generally between 10 and 200 feet thick in the vicinity of the ISA and underlies fine-grained flood deposits and recent alluvium under much of the ISA. The Willamette River incised the flood deposits during the rise in sea levels from the end of the Pleistocene to the present to form the current floodplain channel of the river. This unit is generally well below the river, except in the vicinity of the railroad bridge where the unit is present near the bottom of the river (Figure 3-10).

Troutdale Formation

Upper Troutdale Formation: The upper Troutdale Formation in the vicinity of the LWR includes cemented and uncemented alluvial sand, gravel, and cobbles deposited by the ancestral Willamette and Columbia rivers. The Troutdale Formation comprises the Troutdale Gravel Aquifer hydrogeologic unit and generally has high permeabilities except where highly cemented. This unit is present in some places on the west side of the ISA to thicknesses of 100 feet, and is present along the entire length of the east side of the ISA at thicknesses of up to 200 feet (Swanson et al. 1993).

Sandy River Mudstone/Lower Troutdale Formation: The Sandy River Mudstone (SRM) is a fine-grained equivalent (over-bank facies) of the lower Troutdale Formation (channel facies) that overlies the CRBG in the center of the basin and at the margins of the basin away from the axis of the Columbia River. The SRM is present in places under the LWR (Swanson et al. 1993) and borders the Portland Hills, but is not considered a significant hydrogeologic unit within the ISA. The SRM consists mostly of silt and clay with lenses of sand and gravel. The SRM tends toward fine-grained (low permeability) lithologies at the basin margins (Swanson et al. 1993).

Columbia River Basalt Group: The CRBG consists of a thick sequence of Miocene basalt flows dating from between 17 my and 6 my ago, but the CRBG flows that underlie much of the Portland Basin entered the area between 16.5 my and 12 my ago. Basalt flows of the CRBG were folded and faulted during the uplift of the Tualatin Mountains, concurrent with eruption and emplacement of younger flows present in the Portland Basin (Beeson et al. 1991). The CRBG is present at the surface or at relatively shallow depths along the west side of the ISA and may be in direct contact with the river in places. The top of the unit drops off below ground surface (bgs) over a relatively short distance and is 400 or more feet bgs on the east side of the ISA. The thickness of the CRBG in the vicinity of the ISA is estimated to be approximately 600 feet (Beeson et al. 1991). Permeabilities in the CRBG interflow zones are relatively high while the basalt flow interiors generally have low permeabilities.

3.2 Hydrogeologic Units

This section describes how the geologic units described above have been grouped into hydrogeologic units for the purposes of developing an overall conceptual groundwater model for the ISA. The hydrogeologic units have been defined by grouping geologic units on the basis of generally similar hydrogeologic characteristics. Important hydrogeologic characteristics include the position of the groundwater surface relative to each hydrogeologic unit, the physical relationship between each hydrogeologic unit and the river, and physical characteristics of each hydrogeologic unit, such as hydraulic conductivity, heterogeneity, and anisotropy. The primary hydrogeologic units in the ISA include from uppermost to lowermost:

- Fill and fine-grained (silt and sand) Pleistocene flood and Recent alluvial facies.
- The coarse-grained (gravel) facies of the flood deposits and potentially the upper Troutdale Formation, where present.
- The lower Troutdale/Sandy River Mudstone.
- The CRBG.

Hydraulic parameter estimates for different soil types comprising these units are summarized in Section 3.2.1. Each unit is described in detail in Section 3.2.2. Detailed cross sections at a series of locations on both sides of the river are provided on figures 3-13 through 3-27 to illustrate the range of representative hydrogeologic settings adjacent to the river. The locations of these detailed sections are shown in red on Figure 3-1.

3.2.1 Unit Descriptions

Fill and Fine-grained Pleistocene and Recent Alluvial Facies (FGF): The FGF hydrogeologic unit blankets much of the lowland area next to the river and is the primary unit of importance in defining the interactions between upland groundwater and the river because of the following characteristics of the unit:

- The unit forms the boundaries of most of the river channel within the ISA, as well as the surrounding upland areas, and therefore groundwater interactions with the river occur mainly within this unit.
- Most groundwater chemical plumes present in the upland areas occur within strata of this unit.

The overall thickness of this unit ranges up to 150 feet; the thickness of the unit more typically ranges between 30 and 100 feet except near the river east of the Doane Lake remnants, where the unit directly overlies the CRGB. At this location the FGF is less than 10 feet thick adjacent to and below the river channel (Figure 3-24). The unit also is relatively thin in the vicinity of RM 9 (Figure 3-27).

The distribution of lithologies and thus groundwater flow characteristics of the FGF vary both vertically and horizontally by location along the ISA. However, some generalizations can be made. The shallow portions of the FGF (depths of 0 to 40 feet) typically are comprised of fill that volumetrically consists mostly of fine to medium silty sand and sand dredged material. Pockets of gravel, silt, clay and concrete and wood debris also comprise the fill at a number of locations. As discussed in Section 3.1, the dredge fill was placed behind low-permeability, natural flood and artificial clay levees at certain locations, such as the Willbridge terminal area (Figure 3-25).

The lower portion of the fill commonly is saturated where the fill unit is sufficiently thick and/or overlies a relatively fine-grained material.

Sequences of heterogeneous alluvial sediments underlie the fill and typically consist of silt and clay overbank or slack water deposits interbedded with layers and lenses of fine to medium channel sand. Silt and clay-predominant soil comprises the alluvium underlying the sandy dredge fill along much of the ISA, as shown in Figures 3-15 and 3-25. Exceptions to this generalization include the west side of the river near RM 8 (Figure 3-26), the east side of the river between RM 3 and 4 (Figures 3-13 and 3-14), and the vicinity of the McCormick & Baxter Superfund Site (Figure 3-17) where sand-predominant soil underlies dredged sand fill. In one area, in the vicinity of the ARCO Terminal near RM 5, a gravel paleochannel is present in the FGF beneath the fill (Figure 3-20).

Observations during the seep reconnaissance survey (GSI, 2003) indicate that silt and clay deposits are present on the surface of the riverbank and underlie beaches and retaining structures along much of the ISA, including locations where alluvial sand layers are present in the subsurface adjacent to the riverbank as shown in Figure 3-24. The presence, thickness and nature of the fine-grained overbank silt and clay observed adjacent to facilities during the seep reconnaissance survey are not observed in upland explorations at many of these facilities, and thus are not shown on the detailed cross sections. The presence of these materials next to the river suggests that these fine-grained sediments are recent overbank facies sediments.

The groundwater surface in the FGF is generally present in the lower portion of the thicker sequences of fill or in upper portions of the alluvial sediments. Consequently, the majority of contaminant releases that effect upland groundwater tend to be only present at relatively shallow depths within the FGF, with the exception of where dense non-aqueous phase liquid (DNAPL) has been released, such as at the McCormick & Baxter, Rhone Poulenc/Aventis Crop Science and Atofina sites. In particular, petroleum releases and most dissolved plume constituents are likely present within the upper portion of the FGF except where vertical preferential pathways and vertical gradients favor downward migration below the water table.

The predominance of lower permeability lithologies within the FGF unit suggest that fluxes to the river from shallow groundwater flow systems in the upland areas are small, except where the more permeable sand materials are present adjacent to the river. Fluxes to the river in areas where permeable sand layers are located adjacent to the river may be significantly reduced by deposition of a fine-grained sediment layer in shallow or quiescent areas, as noted on some beaches during the seep survey. Comparison of hydraulic conductivity values listed in Section 3.2.1 for different lithologies within the FGF unit illustrates the importance of the sand lenses and layers in understanding groundwater flow to the river at any particular location where present within this unit. Groundwater fluxes from the uplands to the river within the FGF are expected to be greater below low river stage levels in those areas where more permeable sand zones are present.

Coarse-grained Flood Deposits and upper Troutdale Formation (CGF): The CGF unit combines the unconsolidated coarse-facies flood deposits, including sands, gravels and cobbles, with the underlying uncemented and cemented gravels and cobbles of the upper Troutdale Formation. The Pleistocene flood gravels comprising the upper portion of the CGF typically occupy scour channel surfaces on older units (e.g., the CRBG). Fill and fine-grained alluvial sediments mostly blanket the CGF.

The CGF unit is present under much of the ISA at thicknesses typically in the range of 100 feet, but with maximum thicknesses exceeding 200 feet. However, the unit is discontinuous in places along the west side of the river (Figures 3-6 through 3-8 and 3-10). The top of the CGF unit is present at elevations of 50 feet to over -100 feet mean sea level (MSL). The unit is present at relatively shallow depths south of RM 4 (Figures 3-5, 3-8 and 3-9), and may be in contact with river sediments (Figure 3-10 on the west side of the river in the vicinity of the railroad bridge. The hydraulic conductivity of the CGF unit measured in the vicinity of the historic Doane Lake area ranges from 3 feet per day to greater than 40 feet per day (AMEC 2001). Consequently, this unit likely exerts a significant influence on deeper groundwater flow to the river at these locations and other similar settings along the ISA.

Because of the depth of this unit relative to location of the shallow groundwater surface in the FGF, the likelihood of being impacted by contaminant releases is relatively low, except where a DNAPL release of significant volume occurs.

Lower Troutdale Formation/Sandy River Mudstone (SRM): This hydrogeologic unit is present in some places under the west side of the ISA and is present under the entire length of the east side of the ISA. The unit, where explored in the vicinity of the ISA, is predominantly silt and clay, and thus the permeability of the unit is low. Where present, the unit overlies the CRBG below depths of –100 to –150 feet MSL. The unit tends to pinch out on the west side and towards the southern end of the ISA, where the CRBG is present at shallower depths (Figures 3-6, 3-7 and 3-8). The unit typically is separated from the river by at least 100 to 200 feet of alluvium and the upper Troutdale Formation, as shown in Figures 3-9 and 3-10. Based on the hydrogeologic characteristics of this unit and the depth relative to the river, it is not considered to contribute significantly to surface water/groundwater interactions within the ISA and may not discharge to the river at all.

***Columbia River Basalt Group (CRBG)*:** Groundwater flow in the CRBG is focused along the higher permeability interflow zones and in some areas of fracture-enhanced permeability (e.g., fault zones). Hydraulic conductivities measured in individual basalt interflow zones in the vicinity of the ISA range from 1.5 to 10.9 feet per day (AMEC 2001). Hydraulic conductivities measured in CRBG basalt flow interiors at Hanford, Washington range from 1×10^{-4} to 1×10^{-7} feet per day (Strait and Mercer 1986), illustrating that the basalt interflow zones (flow top and bottom collectively) are the primary groundwater flow mechanisms in the CRBG, and that vertical flow between interflow zones is low except at locations where discontinuities or significant fracturing of the flow interiors occurs.

The top of the CRBG unit is irregular on the west side of the ISA from scouring of channels during flood events and the ancestral Willamette River. The top of the unit on the west side of the ISA is between elevation 0 MSL and – 50 feet MSL north of RM 9, except for an ancestral channel in the vicinity of the historic Doane Lake area that was scoured to below elevation –150 feet MSL (Figure 3-7). The CRBG is present at relatively shallow depths (less than 50 feet bgs) along portions of the west side of the ISA and may be in direct contact with the river or separated from the river by a thin sequence of sediments at several locations on the west side of the river between RM 7 and RM 9 (Figures 3-24 and 3-27).

The top of the CRBG slopes down to an elevation of –250 feet msl or more across the river on the east side of the ISA (Figure 3-10). The relief of the unit across the ISA appears to be due to structural downwarping towards the center of the basin, and may be accentuated by faulting postulated along both sides of the ISA (Beeson et al., 1991; Beeson 2003 and Wong, 2001). The overall significance of the CRBG with regard to groundwater/surface water interactions within the ISA is not known; however, for the purpose of this evaluation groundwater interactions between the CRBG and the river appear to be most relevant on the west side of the river downstream of about RM 9 because of the direct contact of the CRBG with portions of the river in this area. Because of the presence of saturated sediments overlying the CRBG along the entire ISA, consideration of groundwater transport of contaminants downward to and horizontally within the CRBG is limited to only those westside locations where several releases of chemicals that are denser than water have occurred and/or where the CRBG are present at shallow depths and preferential pathways and gradients favor downward transport of COIs.

3.2.2 Summary of Hydraulic Properties

Hydraulic property estimates of various lithologies included in the hydrogeologic units described in Section 3.2.1 have been obtained from a number of facilities adjacent to the ISA by single well "slug" tests, constant discharge aquifer tests and other analytical and empirical methods. Hydraulic properties for the SRM unit in the vicinity of the ISA are not available. In addition, the SRM unit is not relevant to groundwater COI transport to the river in this area. Thus, hydraulic properties for the SRM are not provided. The ranges of parameters for different lithologies shown in Table 3-1 illustrate the heterogeneous nature of the FGF, CGF and CRBG.

Storage coefficient values measured in the shallow units (shallow FGF and CGF) are between 0.02 and 0.13, which are within the expected range for an unconfined system (Landau, 2001b). Storage coefficients measured from aquifer tests in the deeper FGF and CGF range from 0.0006 to 0.03 (AMEC, 2001), which are indicative of confined to semi-confined conditions. Storage coefficients of 0.003 to 0.00001 have been estimated for the CRBG by Squier (2002); these values also are representative of a confined aquifer. These values are within the range of typical storage coefficients for a confined basalt aquifer.

3.3 Groundwater Flow System

This section provides a discussion of groundwater occurrence and flow characteristics, including recharge, hydraulic gradients, hydraulic properties and discharge to the river in the vicinity of the ISA. The focus of this section is the FGF, CGF and CRBG hydrogeologic units since they comprise the primary units that could be impacted by groundwater COIs.

Up to three separate general groundwater flow systems that discharge to the Willamette River are recognized along the ISA for the purposes of this groundwater evaluation: a shallow (shallow FGF), an intermediate (deep FGF) and deep (CGF and CRBG) system. A deeper, regional flow system also is present, which includes the CRBG where present at depth below the river (on the east side of the river) and the lower SRM/Troutdale Formation. This deeper, regional flow system is not considered to be important in understanding the critical interactions directly between upland groundwater and the river that are relevant to this groundwater evaluation.

At a local level, these divisions between flow systems are likely indistinct in places along the ISA. Many investigations have focused on the FGF, and in places the CRBG, and have identified further flow system refinements or divisions based on the local hydrogeology. However, the general flow systems described above appear to apply for the majority of the ISA and provide a basis for evaluating variations from the general conceptual model.

Two flow systems within the FGF are described in this report based on descriptions from various facilities near the ISA where hydrogeologic conditions in the deeper portions of the FGF have been characterized. Flow systems in the FGF can be differentiated on the basis of lithology, hydraulic head differences and response to temporal fluctuations of river stage. Additional flow systems may be interpreted at some locations within the FGF, particularly where significant thicknesses of the unit are present and/or where reduced hydraulic connection is provided by separation by lower permeability materials. It is important to note that the shallow system is the most completely characterized in the ISA because the majority of groundwater contaminant releases have only affected the shallow system. Impacts have been mostly limited to the shallow system primarily since a majority of the releases have consisted of petroleum-related compounds that are less dense than water and tend to reside at the water table surface.

The three flow systems defined in this report, the shallow, intermediate and deep systems, discharge to the Willamette River in the vicinity of the ISA. The USGS used a calibrated numerical groundwater model of the Portland Basin to calculate groundwater fluxes to major surface water bodies in the basin (Morgan and McFarland, 1996). The range of head dependent fluxes modeled for the LWR was 7 to 85 cubic feet per second (cfs), which is between 0.2 and 2 percent of lowest recorded flow (4,200 cfs) in the lower Willamette River and is 0.1 to 1 percent of typical annual low flows (7,000 to 8,000 cfs).

3.3.1 Shallow System

The upper, unconfined or shallow system consists mostly of fill, where present, and silt and sand alluvial deposits of the shallow FGF, as defined earlier. This unconfined flow system is referred to as the Upper Zone, Surficial Zone or Shallow Zone at different facilities along the ISA. The shallow system occurs within the lower portion of fill and/or upper portion of the underlying alluvial sediments. At locations where sufficient thicknesses of fill are present and underlying alluvial sediments tend to be of lower permeability, the shallow system may occur mostly in the fill. Figure 3-22 illustrates an example of this situation. At other locations, the lithologic boundary between fill and the underlying alluvium may be indistinct or the groundwater surface is below the fill/alluvium contact (Figure 3-13).

Recharge
The shallow system is recharged by direct precipitation and infiltration, infiltration from the hills on the west side of the ISA, and exchange with several surface water bodies along the ISA (e.g., Doane Lake remnants). The amount of recharge to the shallow system received from direct precipitation is controlled by the amount of precipitation, the permeability of surface materials and the percentage of impervious surface area. Thus, the amount of recharge from precipitation is highly dependent on the type and density of land development. Recharge to the shallow system (excluding groundwater inflow from the adjacent hills) in most of the highly industrialized areas along the ISA is estimated by Snyder (1996) to range from 0 to 9 inches per year. Some areas adjacent to the ISA with less impervious surfaces, such as along the base of the Portland Hills, have estimated recharge rates of up to 24 inches per year.

Groundwater Levels
Groundwater elevations in the shallow system at a majority of the facilities within the lowland areas next to the river vary relative to the distance from the river, ground surface elevation, season, and to a lesser extent, lithology. The depth to the groundwater surface in the upland areas above the riverbank typically varies between 10 and 25 feet bgs. The elevation of the groundwater surface commonly varies from 20 and 30 feet MSL in the areas up to approximately 2,000 feet from river, to between 8 and 14 feet MSL above the embankment adjacent to the river. Shallow groundwater elevations approach river stage elevations below embankments next to the river and at locations where permeable aquifer materials are in direct connection with the river, such as areas of fill behind seawalls adjacent to berths. Shallow system groundwater levels typically vary seasonally from 3 to 8 feet with high groundwater conditions generally occurring in January and February, and low water occurring at the end of the dry season in October or November. Figure 3-28 shows an example of Shallow Zone groundwater elevations on the east side of the river in the vicinity of RM 4 in August 2002, during the period of low seasonal river stage. Figure 3-29

shows Shallow Zone groundwater elevations and gradients on the west side of the river around RM 7 during the spring 2002.

Investigations by Landau (2001b) indicate that the influence of high river stages on shallow system groundwater levels tends to be localized near the riverbank as peak river stage elevations are rarely greater than shallow system levels very far inland. Figures 3-30 and 3-31 show hydrographs of shallow system wells relative to river stage (Landau, 2001b). Figure 3-30 shows the groundwater levels relative to short-term river stage changes, including semi-diurnal fluctuations and an overall stage increase. This figure illustrates that tidal fluctuations have little or no effect on shallow system water levels. Furthermore, the overall rise in the river stage has only minor effect on shallow system groundwater levels and the effects are generally limited to areas more proximal to the river, as shown by well LW-4s.

Figure 3-31 shows seasonal water level trends in the shallow system relative to the river stage. The hydrograph shows that peak groundwater levels in the shallow system generally occur in the winter months, prior to average seasonal peak river stage elevations, which is consistent with the model that precipitation and infiltration of runoff are the primary mechanisms of recharge to the shallow system.

Groundwater Gradients

The overall direction of groundwater flow in the shallow system in the vicinity of the ISA is toward the Willamette River during all but the highest river stages. Typical horizontal groundwater gradients in the shallow system range between 0.005 and 0.05 with locally steeper gradients adjacent to the river. The highest gradients near the river are anticipated to occur during extended dry periods after recharge events in the winter and in the early summer when river stage elevations have dropped, but shallow groundwater elevations still reflect the effect of wet season recharge. A number of natural and anthropogenic features locally affect the gradient in the Shallow Zone including:

- Active recovery wells or cutoff trenches, which depress water levels and increase gradients.
- The presence of low permeability units that may restrict flow, such as the subsurface silt ridge feature in the vicinity of the Willbridge area on the west side of the river at approximately RM 7.8 (Figure 3-25).
- Buried utility corridors that are sufficiently deep to intersect the shallow groundwater surface.
- The presence of shallow surface water recharge and discharge features, such as Saltzman Creek in the Willbridge area (Figure 3-1) and the Doane Lake remnants on the west side of the river.
- Retaining structures adjacent to the river; these features may act to restrict groundwater discharge to the river, or to promote surface water/groundwater exchange behind them. In the first instance, a

retaining structure such as a concrete seawall may act as a barrier to groundwater flow and reduce shallow groundwater discharge thus increasing groundwater levels behind it. In the second instance where a riprap embankment or seawall with coarse-grained backfill and drains connecting it to the river is present, the interactions between shallow groundwater and surface water will primarily occur within or behind the retaining structure. The effect of the retaining structures on groundwater/surface water exchange depends on the relative permeability of fill behind them, and the presence and type of drainage pathways through them.

Groundwater level data in the upland areas indicate that there consistently is a downward gradient toward deeper units from the shallow system except at locations adjacent to the river where the intermediate system discharges to the river. Further discussion of the vertical gradients between the Shallow and Intermediate systems is provided in a following section.

Groundwater Discharge

Discharge from the shallow water-table (unconfined) groundwater system will tend to be focused at or below the river/shore interface. Low river stages expose seeps along the bank where the shallow groundwater surface intersects the ground surface (Appendix C).

The rate of discharge from the shallow system depends on the gradient between the river and shallow system. Groundwater levels in the shallow system adjacent to the river are affected by seasonal river stage changes. Full gradient reversals between the river and the shallow groundwater system are rare and likely localized near the bank because of the relatively high groundwater levels in the upland areas and resultant steep hydraulic gradients along the riverbank. However, very high river stages tend to reduce the shallow groundwater gradient locally.

Groundwater fluxes to the river from the shallow system are anticipated to be greatest in the early summer when groundwater levels are still relatively high and river stage levels have declined after the spring runoff cycle. Higher fluxes also will occur after extended dry periods during winter months when river stage levels have dropped, but groundwater levels remain high. However, the contribution of the shallow system to the overall groundwater flux, and thus the flow of the river is anticipated to be small.

The rate of discharge in any particular area also depends on the relative permeability of materials along the groundwater flow path and in the groundwater/surface water transition zone. Preferential pathways, including coarse backfill (e.g., around utilities), historic stream channels, or sand/gravel layers, focus groundwater flow, particularly where they occur in predominantly fine-grained sediment sequences in the shallow groundwater system. The highest rates of discharge to the river generally occur where these preferential pathways intersect the riverbank. For example, an alluvial gravel channel is present behind the seawall at the ARCO terminal at approximately RM 5 on the west side of the river (Figure 3-20). This feature, as well as a sea wall at the facility, exerts a strong influence on shallow system groundwater flow near the river. The channel intercepts and redirects shallow groundwater flow and both NAPL and dissolved petroleum constituents present at the site, while the seawall may act to reduce groundwater flow to the river in the shallow system.

Review of near shore sediment grain-size analysis and observations during the seep reconnaissance survey during seasonal low stage levels indicate that the much of the river shore and near shore areas consist of silt or clay, even in areas where soil borings indicate the presence of more permeable materials in the subsurface near the river. The presence of fine-grained sediments in the zone of shallow system groundwater discharge to the river will reduce seepage rates from the shallow system, suggesting that the relative contribution to the total groundwater flux to the ISA from the shallow system is low. This is consistent with observations of seeps during the seep reconnaissance survey (GSI, 2003).

Visible occurrences of groundwater discharge from the shallow system were inventoried for the seep reconnaissance survey conducted in October 2002 and were summarized in a technical memorandum submitted to EPA in February 2003 (GSI, 2003). The seep locations inventoried during the seep reconnaissance survey are shown on Figure 3-32. The seep reconnaissance survey identified several manifestations of shallow system groundwater discharge to the ISA including:

- **Seepage Lines at the Base of Embankments:** This type of seep occurs where the groundwater surface intersects the ground surface at a break in slope between the beach and embankment and is most commonly observed at low seasonal and/or river stage levels when this interface is not submerged.
- **Seepage at the Foot of Beaches:** Seepage to surface water from shallow groundwater typically is focused at or near the water’s edge (EPA, 2000). Because of river stage fluctuations, the discharge may occur across a zone between the daily low and high water level. Other factors affecting the occurrence of this type of seep include the distribution of lithologies (preferential flow pathways), and groundwater levels.
- **Seepage around Utilities:** This type of seep typically occurs where utility backfill around a pipe leading to the river is present below the seasonal shallow system groundwater surface and is of higher permeability than the surrounding soils. It also may occur if a pipe leading to the river is below the seasonal groundwater surface and is leaky and acts as a drain to the shallow groundwater surface.
- **Potential Seasonal Seeps:** Evidence of past seepage in the form of ferric oxide (a precipitate of naturally-occurring iron in groundwater) staining was observed at a number of locations along the ISA. The locations with staining were all dry and above the seasonal low river stage at the time of

the survey. These locations are interpreted to be seasonal seeps that occur during the period of high seasonal shallow system groundwater levels and most likely are influenced by one or more of the factors affecting the seep occurrences discussed above.

COI Occurrence

LNAPL spills are present only within the shallow flow system. Dissolved chemicals associated with upland releases are also predominantly present in the shallow flow system. Migration of dissolved plumes are affected by groundwater flow processes, such as advection, dispersion, and attenuation and may also be affected by vertical hydraulic gradients, which may cause vertical migration of the dissolved constituents and preferential pathways. The shallow system also appears to influence the effect of DNAPL releases by retaining a portion of the released volume through spreading and retention in or along less permeable sediment horizons. These stratigraphic controls can limit the depth of downward migration of DNAPL. The distribution of COIs in shallow system groundwater is discussed in detail in Section 4.

3.3.2 Intermediate System

A deeper semi-confined to confined groundwater flow regime is recognized at locations where site investigations have explored deeper into the FGF. This system is termed the intermediate system for the purposes of this report. The intermediate system approximately corresponds to the Alluvial, Intermediate or Deep systems described in the FGF by various investigators at specific facilities. The intermediate system is differentiated from the shallow system based on differing hydraulic heads and a substantially different hydraulic response to changes in river stage. Different lithologies or separation by lower permeability strata may define the flow systems; however, in some cases, the transition between systems may be gradational, such as in locations where lithologies hosting the respective flow systems are not hydraulically well separated.

Recharge

Recharge to the intermediate system adjacent to the ISA is derived from vertical flow from the overlying shallow system, as well as groundwater inflow from the adjacent highlands: the Portland Hills on the west side of the river (Geraghty Miller, 1991 and AMEC, 2001) and the terraces of the North Portland area on the east side of the river (Landau, 2001b). The Intermediate Flow system also receives recharge from the Willamette River near the river during periods of high river stage.

Groundwater Levels

The elevation of the piezometric surface in the intermediate system adjacent to the west side of the river range from between 25 and 30 feet MSL, inland near the base of the Portland Hills, to between 5 and 10 feet MSL near the river. Groundwater elevations on the east side of the river next to the ISA range between 12 and 5 feet MSL (Landau, 2001b). Examples of groundwater piezometric surface maps for the intermediate system adjacent to the river are provided in Figures 3-33 through 3-35.

Figure 3-33 shows an example of Intermediate Zone groundwater elevations on the west side of the river in the vicinity of RM 4 in August 2002, during the period of low seasonal river stage. Comparison of figures 3-28 and 3-33 illustrates the relative differences in hydraulic head between the Shallow and Intermediate systems and the predominantly downward vertical gradient that exists between the two systems.

Groundwater elevations in the intermediate system vary 3 to 7 feet seasonally. High groundwater levels generally occur in the spring and low levels occur in the late summer or fall. High groundwater levels in the system typically coincide with high river stage levels. The timing of groundwater level extremes within the intermediate system is consistent with recharge to the system by vertical flow from the shallow system, as well as inflow laterally from adjacent areas and the river.

Groundwater elevations in the intermediate system are strongly influenced by both seasonal and semi-diurnal (tidal) river stage changes, as well as recharge from the shallow system. The degree and timing of river stage influences are determined by the magnitude and duration of the river stage change, the lithology of the hydrogeologic unit and thus hydraulic connection to the river, and the distance from the river. Figure 3-36 shows a hydrograph of river stage changes relative to intermediate system groundwater levels in wells located on the east side of the river. This hydrograph illustrates several effects that river stage has on the intermediate system including:

- Groundwater levels in the system are strongly affected by tidal fluctuations, as well as overall rises in river stage. Exponent (1999) reported that tidal fluctuations affect water levels in an intermediate system well over 300 feet from the river.
- A rise in the river stage of approximately 2 feet reverses the gradient between the intermediate system and the river. Although the overall direction of groundwater flow in the intermediate system has been shown to be towards the river, seasonal stage changes can result in flow from the river into the intermediate system. This flow reversal is likely more accentuated on the east side of the river where groundwater levels in the flow system are generally lower and gradients are less steep than on the west side of the river.

Groundwater Gradients

Horizontal hydraulic gradients within the intermediate system tend to be flatter near the river than the shallow system, and thus high river stages and tidal changes exert a greater influence on fluxes from the intermediate system to the river by further flattening or reversing the gradient. However, the overall direction of groundwater flow in the intermediate system is toward the river. Calculated intermediate system gradients range from 0.0006 to 0.004.

Overall, inland groundwater level elevations on the west side of the river are greater than on the east side of the river with maximum groundwater levels in sites near the west side of the river exceeding 37 feet MSL (Figure 3-35). Groundwater elevations in the intermediate system on the east side of the river in the vicinity of the ISA rarely exceed 20 feet MSL. As a result, horizontal gradients appear greater on the west side than the east side of the river. The intermediate system on the west side of the river receives groundwater flow from units recharged at relatively high elevations in the Portland Hills. Low groundwater levels and the relatively flat gradient on the east side is consistent with regional groundwater studies that indicate the presence of thick, highly permeable Pleistocene flood deposits underlying the intermediate system in this area. In addition, the east side is influenced by both the Columbia and Willamette rivers, which, also contributes to the very flat gradients (Swanson et al. 1993).

Vertical gradients measured between the Shallow and Intermediate systems typically indicate a downward component of flow between the two systems, except at locations proximal to the river. Measured downward vertical gradients range from less than 0.05 to 0.6 with the vertical gradients generally decreasing with proximity to the river. Exponent (1999) measured an upward vertical gradient of -0.04 in a well pair near the river; the upward gradient near the river is consistent with discharge of the intermediate system to the river.

A number of natural and anthropogenic features locally affect the gradient in the Intermediate Zone including:

- Active recovery wells, which depress water levels and increase gradients; an example of the influence of a recovery well on groundwater levels in the intermediate system is apparent on the southern portion of the facility shown in Figure 3-33.
- The presence of low permeability units that may restrict flow.
- Higher permeability zones that may act as preferential groundwater flow pathways.

Groundwater Discharge

Groundwater in the deeper portions of the intermediate system in the FGF on the east side of the river flows and discharges to the Willamette River. Discharges from the intermediate system occur well below the river surface and thus direct observation of the mechanisms of discharge from the system was not possible during the seep reconnaissance survey.

Permeability contrasts of several orders of magnitude can be expected in the FGF where alluvial processes create lenses and channels of sand within or surrounding finer-grained materials. The result of these permeability contrasts is that groundwater discharge will tend to be heavily influenced by the location and geometry of higher permeability layers (e.g., sands) in relation to the river.

The overall flow direction in the intermediate system is toward the river. However, river stages strongly influence groundwater levels and flow in the intermediate system. River stage changes are observed to have the following effects on intermediate system groundwater levels and flow:

- High seasonal river stages may cause groundwater gradients near the river to temporarily reverse;
- High seasonal river stages appear to have a stronger effect on groundwater levels at a greater distance from the river on the east side of the river;
- The effects of river stage on groundwater levels and flow in the intermediate system are most pronounced on the east side of the river at locations where the system is well-connected to the river, because intermediate system groundwater gradients tend to be lower than those on the west side;
- Semi-diurnal tidal fluctuations also may result in very short-term decreases in gradients, or even in very localized flow reversals, particularly when groundwater levels are at seasonal lows. The effects of tidal fluctuations on groundwater discharge from the intermediate system is more pronounced during lower river stage and groundwater levels

The frequency and potential effects of both short-term and seasonal river stage changes on the intermediate system suggests that the depth and degree of mixing within the groundwater/surface water transition zone will be greater at locations where the intermediate system discharges to the river than where the shallow system discharges to the river.

COI Occurrence
The intermediate system is particularly relevant for groundwater transport of chemicals to the river where DNAPL is present or where chemical densities, preferential pathways or downward gradients could potentially allow dissolved chemical constituents to migrate downward from the shallow system. The intermediate system provides the most likely mechanism for groundwater discharge into subsurface sediments of the Willamette River. However, only a few groundwater chemical plumes have been identified in the upland areas of the ISA within the intermediate flow system, as discussed in Section 4, since most releases to groundwater are less dense than water (e.g., LNAPL).

3.3.3 Deep System

A deep confined flow system (deep system) occurs within the CGF and shallow basalt interflow zones of the CRBG in areas on the west side of the river. The deep system is likely present within the CGF on the east side of the river, where the CGF is present; however, in the vicinity of the Gunderson Facility at RM 9 on the west side, groundwater monitoring results suggest that the CGF is part of a shallower flow system because of the relatively shallow depth of the unit and lack of confining unit in this area.

Although significant thicknesses of CGF and CRBG have been encountered in deep geotechnical exploratory borings and water supply wells in the vicinity of the ISA, few contaminant investigations have characterized the CGF or the CRBG because the contaminant plumes at a majority of the facilities in the vicinity of the ISA are not present in these units. Where explored, CRBG investigations are generally limited to the upper portion of the basalt unit. The locations where groundwater flow in the CGF and CRBG has been well characterized include the west side of the river at? the railroad bridge and at the Gunderson Facility, where units comprising this system are relatively shallow. Some explorations also have been completed in the CGF on the east side of the river, in the vicinity of McCormick and Baxter. The CGF consists of discontinuous erosional remnants on top of the basalt in the vicinity of the historic Doane Lake area and at the Gunderson facility. The CGF is more continuous where encountered in deep geotechnical explorations south of RM 9.

Recharge

The CRBG and CGF on the west side of the river are recharged through direct precipitation in the Portland Hills, as well as upward vertical groundwater flow from deeper basalt interflows that are part of the CRBG. The CGF also receives direct recharge from precipitation where it occurs near the surface in North Portland. The portions of the deep system adjacent to the ISA is recharged by leakage from the overlying flow systems where vertical gradients indicate downward flow, as well as lateral groundwater inflows from recharge areas for the CRBG and CGF units.

Groundwater Levels

Groundwater levels in the deep system, where explored on the west side of the river, are not substantially different from intermediate system levels, generally ranging between 8 and 32 feet MSL in the fall and 12 to 38 feet MSL in the early spring in the vicinity of Doane Lake (AMEC, 2001). Groundwater levels in the shallow CRBG and CGF range between 5 and 8 feet MSL in the vicinity of RM 9. Deeper basalt groundwater levels range between 8 and 10 feet MSL in this area (Squier, 2002).

The CRBG ceases to play a role in the deep system on the east side of the river. The flow system becomes strongly affected by the Columbia River on the east side of the ISA with increasing distance from the Willamette River. The CGF is generally highly transmissive; however, gradients may be relatively flat. Seasonal gradient reversals are known to occur near the Willamette River during periods of high river stages. Where near the Willamette River, the connection and thus response to river stage changes is expected to be great, as is seen in the vicinity of the Doane Lake remnants (AMEC, 2001).

Groundwater Gradients

Groundwater gradients measured in the deep system on the west side of the ISA range between 0.007 and 0.01. Hydraulic head differences, and resulting vertical gradients between the uppermost flow at the top of the CRBG and overlying FGF and CGF are spatially variable and are often indistinct indicating that these units are hydraulically well connected. However, a strong upward gradient exists between a deeper basalt flow and the shallow basalt and overlying CGF next to the river at the Gunderson

Facility, which is consistent with groundwater discharge from the CRBG to the river (Squier, 2002)

Discharge
Groundwater in the deep system discharges to the Willamette River (or to the overlying units and then to the river) in the vicinity of the ISA. Discharge to the river from the system generally occurs in deeper portions of the river with discharges focused at the locations where the gravels and/or basalt interflow zones are near or intersect the river sediments. Upward gradients and groundwater elevations in this system that approach the river stage elevation in the vicinity of the river are consistent with groundwater discharge from the deep system to the river. Discharge of the deep system through the river sediments to surface water is controlled by: (1) the permeability contrast between the sediments and underlying aquifer, and (2) the difference between the hydraulic head in groundwater at the aquifer/sediment interface and the river stage, which determines hydraulic gradient. It is likely that groundwater in the deep CRBG is part of a deeper, regional flow system and does not discharge to the Willamette River because of the depth and hydraulic separation from the river.

COI Occurrence
Similar to the intermediate system, the deep system is particularly relevant for groundwater transport of chemicals to the river where DNAPL is present or where chemical densities, preferential pathways or downward gradients could potentially allow dissolved chemical constituents to penetrate into the deeper units. However, only three groundwater plumes adjacent to the river are known to be present in the deep system.

3.4 Assessment of Potential Preferential Flow Pathways

Groundwater preferential pathway information was compiled as part of the review of data from upland sites. Preferential pathways can focus groundwater flow and enhance groundwater transport relative to the surrounding soil, particularly where they occur within the fine-grained sediments of the shallow system. Discharge to the river will occur where these pathways intersect the riverbank.

There are four requisite attributes for a feature to be a preferential pathway for groundwater transport of contaminants to the river:

- The hydraulic conductivity of the feature must be greater than the material bordering it;
- The feature must saturated at least in part; that is, the groundwater surface must intersect the materials with higher hydraulic conductivities than the surrounding materials; and
- The feature must intersect a plume of groundwater contaminants.
- The feature must trend toward and intersect the river.

Preferential flow pathways include natural and man-made features. Natural preferential flow paths consist of linear or tabular deposits that have a higher hydraulic conductivity than surrounding soils, such as a sand or gravel-filled paleochannel. Man-made features that act as preferential flow pathways include granular backfill surrounding utilities, as well as natural depressions or drainages that have been filled with coarse-grained materials, such as historic channels or sloughs. Man-made preferential pathways are most relevant to transport in the shallow system because the maximum depth of most utilities is less than 20 to 30 feet below ground surface. Transport of groundwater contaminants in the shallow system along utility backfill has been documented at several sites in the ISA. Observations during the seep reconnaissance survey in October 2003 also indicated that a number of private outfalls appear to intersect the groundwater surface and drain shallow groundwater at some sites.

The evaluation of preferential pathways conducted for this study included:

1. Review of maps of private and public utility outfalls;
2. Review of cross sections and boring logs from groundwater investigations of upland facilities; and
3. Review of site-specific preferential pathway analyses conducted as part of groundwater investigations of upland facilities.

It is important to note that information regarding utilities at private facilities, including the depth of the utility, type of backfill and alignment of the utility, is not readily available to the public in a complete and reliable form, except for sites where an analysis of preferential pathways has been conducted. Maps of municipal utilities are available, but also are not necessarily complete and thus are not included in this report. Figure 3-38 shows the distribution of permitted public and private outfalls adjacent to the ISA.

An initial evaluation identified potential preferential groundwater pathways at 20 facilities. At the sites with identified preferential pathways, sewer/utility lines and historic stream channels were the most common types of pathways. Table 3-2 summarizes facilities in the vicinity of the ISA where preferential pathways are suspected or have been identified. Additional facilities in the ISA may also have natural or man-made potential groundwater preferential flow pathways. A rigorous evaluation of pathways at these sites is beyond the scope of this document. Evaluation of the potential for preferential pathways to effect migration of a groundwater plume is most effectively accomplished on a site-by-site basis as part of the upland groundwater investigation at a given facility where preferential groundwater flow associated with a plume is suspected based on stratigraphic or utility data.

3.5 Groundwater/Surface Water Transition Zone

The groundwater/surface water transition zone (Transition Zone) is the interval where both groundwater and surface water comprise some percentage of the water occupying pore space in the sediments. The physical and biochemical properties of the porewater within the Transition Zone reflect the effects of mixing between groundwater and surface water that occurs within the sediments. The Transition Zone is significant to the RI/FS because it is the location where important chemical and biological transformation processes occur that affect the properties of chemicals that may be present in porewater, and it encompasses the sediment bioactive zone where benthic infauna ecological receptors reside.

The zone of mixing between groundwater and surface water that defines the size of the Transition Zone exhibits temporal and spatial variability due to changes in gradients between the surface water and the groundwater systems. The extent of mixing is anticipated to be relatively small in shallow river sediments that are in contact with the shallow system. In these areas, groundwater heads are relatively high within the shallow groundwater flow system adjacent to the river in comparison to river stage. High river stages will change the relative hydraulic gradient and thus reduce the discharge rate from the shallow system through the sediments to the river, but will not likely result in a significant overall increase in the extent of mixing of surface water with shallow system groundwater. Therefore, groundwater is expected to comprise a greater percentage of the porewater in the shallower water bioactive zone where ecological receptors may be present than at locations where the deeper flow systems discharge to the river.

Much flatter gradients and lower hydraulic heads present in the Intermediate and deeper systems result in greater extent of mixing in the Transition Zone than in the shallow system due to river stage fluctuations. Mixing of groundwater from the Intermediate and deep systems with river water results in an increase in the overall percentage of surface water comprising the porewater within the bioactive zone during periods of high river stages.

The depth and rate of mixing within the Transition Zone may be greatest in the deeper sections of the river where the Intermediate and Deep flow systems discharge. Tidal fluctuations, under conditions where the gradient between groundwater and surface water normally is small, become more significant and result in frequent but short-term changes in hydraulic gradients, which promote mixing of surface water and groundwater within the Transition Zone. In this case, the percentage of surface water comprising porewater within the bioactive zone may be greater than the upper flow systems in general.

Seepage faces exposed along the riverbank during seasonal or semi-diurnal low river levels, such as those identified during the seep reconnaissance survey, may not have a Transition Zone as defined by a mixture of groundwater and surface water present in pore spaces. Seeps that are exposed seasonally consist of groundwater transitioning to surface water through physiochemical processes related to mixing directly with the atmosphere, rather than mixing with river water within the sediment matrix. This process primarily occurs at the seepage face. In contrast, groundwater seeps temporally discharging below the river level transitions to surface water through the Transition Zone in much the same way as described above for the shallow system during the time they are submerged. Seeps exposed and submerged several times a day through tidal fluctuations likely include a short-lived zone of surface water/groundwater mixing that forms during submergence of the seep (as described in the discussion of the shallow system above), and dissipates towards the end of the low river level as discharging groundwater becomes exposed and flushes the surface water/groundwater mixture from the porespaces.

Groundwater contaminant behavior in the Transition Zone is highly dependent on the characteristics of the contaminants being introduced to the sediment, as well as the nature of the sediment and surface water. The Transition Zone is a highly dynamic area where significant chemical transformation of groundwater occurs over a relatively short distance as waters of differing chemistries mix. As a result, significant chemical transformation of contaminants commonly occurs within this zone.

Groundwater contaminants with low water solubility and high soil adsorption coefficients will preferentially sorb to sediment particles, and only a small fraction will partition to porewater. Metals and hydrophobic organic contaminants typically have low mobility and high sediment sorption characteristics. For these chemicals, the concentration in porewater primarily is controlled by the rate at which the chemical desorbs or dissociates from the solid phases and becomes available in porewater to benthic infauna. Toxicity and risk of such chemicals can be effectively assessed through chemical analysis or toxicity testing of whole sediment samples.

Conversely, groundwater contaminants with high water solubility and low soil adsorption coefficients may not sorb to sediment, but may affect porewater concentrations as COIs in groundwater moves through the Transition Zone. Other factors such as organic carbon content of the sediment, volatilization and degradation of the groundwater contaminant(s), and co-solvency mechanisms, will also affect the fate and transport of groundwater contaminants through the Transition Zone. The concentration of such chemicals in porewater is more likely to be affected by the rate at which they are being introduced to sediments by contaminated groundwater flow (i.e., advective transport).

4.0 Groundwater Quality

This section summarizes the results from a review of groundwater quality data from upland facilities located in the vicinity of the ISA. Components of the review include: 1) a summary of the availability of groundwater quality data, 2) a summary of the COIs detected in groundwater samples collected near the river, 3) a grouping of the sites into categories related to the potential for COIs in groundwater to discharge to the ISA, 4) a summary of the site status with regard to upland site investigation and/or source control activities, and 5) identification of areas where additional data are needed.

Data tables are provided in this report to summarize the groundwater quality review information. Table 4-1 provides information about sources of groundwater COIs, preferential pathways, COIs detected in groundwater, and site status information. Table 4-2 identifies the potential for groundwater COIs at each facility to discharge to the ISA and identifies gaps in groundwater data that need to be filled to assess impact of groundwater COIs on risk in the river. Appendix A provides a summary of recent available analytical data for groundwater samples collected from groundwater monitoring points near the river for each property.

4.1 Data Availability

Approximately 86 properties have been identified on the DEQ ECSI database between RM 2 and 11. Of these properties, at least 68 have groundwater quality data. Fifty of the properties listed on the ECSI database adjoin the river; at least 44 of these have groundwater quality data. The distribution of properties with available groundwater data in the vicinity of the ISA is shown in Figure 2-1.

4.2 Chemicals of Interest

For the purposes of the Data Review, COIs include all chemicals detected in upland groundwater based on review of recent data. The classes of COIs detected at each site with available groundwater quality data are included in Table 4-1. Of the 68 sites with available groundwater quality data, 2 sites did not have COIs detected in groundwater. Constituents related to petroleum releases were the most common chemicals detected in groundwater. The classes of chemicals and number of sites with detections of each chemical class in groundwater are as follows:

Detected Chemicals (COIs)	# of Sites
Metals	27
Volatile Organic Compounds (VOCs)	26
Semi Volatile Organic Compounds (SVOCs)	17
Polychlorinated biphenyls (PCBs)	3
Pesticides	2
Dioxins/Furans	1
Phenolic Compounds	1
Butyltins	1

It is important to note that although metals were detected in groundwater at many sites, metals occur naturally in groundwater and no comparison was made with naturally occurring background levels. Thus, the detection of metals does not necessarily imply that a release from an anthropogenic source of metals has occurred at a site. The process of assessing the effect of groundwater on risks in the ISA will include a comparison of metals concentrations detected in upland groundwater to background concentrations of naturally occurring metals.

Several sites have monitored for Light and/or Dense Non-Aqueous Phase Liquids (LNAPL and DNAPL, respectively) during the completion of investigative borings and/or during groundwater monitoring. Available DEQ files indicate LNAPL in groundwater historically has been observed at 8 sites and DNAPL in groundwater has been confirmed in wells at 3 sites. Several other sites are suspected to have DNAPL present, based on anomalously high concentrations of dissolved constituents. Recent observations of LNAPL in groundwater discharging to the river have been reported at the ARCO and Terminal 4 – Slip 3 sites. DNAPL in groundwater has been observed to discharge into the river from the McCormick & Baxter site. Table 4-1 includes a summary of the sites with NAPL observed in groundwater.

4.3 Historical Land Use Review – Sites Not on ECSI List

Other properties along the ISA that are not included in the DEQ ECSI database and therefore, no groundwater data were available, were evaluated for potential for groundwater impacts using historical land use information, as described in Section 2.3.3. Seventeen parcels comprising 38 addresses not listed on the ECSI database were reviewed to identify areas of potential environmental concern (SEA, 2003). Table 4-3 lists the sites evaluated for the historical land use review. The results of the historical land use review for these properties are provided in Appendix B. The locations of the properties reviewed are shown on Figure 2-1. Additional detail regarding the location of these properties is provided in Appendix B.

4.4 Site Groups

The Data Review included placing the sites into groups with regards to potential for discharge of groundwater COIs to the ISA, as discussed in Section 2.4. Table 4-2 presents a summary of how each site is categorized. Many of the sites do not have sufficient data collected to determine the extent of groundwater COIs in relation to the river. A summary of the number of sites in each group is as follows:

Group A Sites

This group of sites includes locations where COIs in groundwater have been confirmed to discharge to the ISA historically or at present based on observations documented in DEQ files, as well as locations where data indicate the existing plume can reasonably be expected to reach the ISA, but discharge of COIs to the ISA has not been documented. This group of sites is not based on whether those groundwater COIs discharging to the river pose risk in the ISA; rather it is to identify the sites where any detectable concentration of COIs in groundwater are reasonably likely to discharge to the ISA. Basic factors used in grouping of these sites include:

1. A record in DEQ files that a sheen has been observed or other visual indication that COIs present in groundwater are discharging to the ISA;
2. The presence of relatively high concentrations of COIs in groundwater or NAPL at the site in groundwater or NAPL at the site;
3. Data indicating the presence of detectable concentrations of COIs in groundwater samples collected at or below the shoreline, or a lack of data indicating that COIs do not reach the ISA where the above two factors exist;
4. A plausible groundwater pathway to the river.

Nineteen Group A sites have been identified. This grouping does not imply that these sites are equivalent in their potential to discharge COIs in groundwater to the ISA.

Group B Sites
This group of sites includes those with insufficient data to determine whether COIs in groundwater may discharge to the ISA. These sites include: (1) sites with COIs in groundwater where existing data are insufficient to conclude whether the plume discharges to the ISA (33 facilities), (2) non-ECSI properties identified in Section 4.3 at which historical and current land-uses do not preclude hazardous materials releases that could impact groundwater near the ISA (17 groups of parcels or 38 separate addresses), and (3) ECSI sites that lack groundwater data (14 sites). The factors that formed the basis for determining which sites were placed in this group include:

1. The downgradient extent of COIs in groundwater has not been defined.
2. The lateral or vertical extent of a plume of groundwater COIs has not been delineated.
3. Potential source areas have not been adequately investigated to determine the presence or extent of COIs in groundwater.
4. The groundwater flow direction for the COI-impacted groundwater system is not defined at those sites where the plume has not been adequately characterized.

Eighty-five Group B sites have been identified. These eighty-five sites are comprised of the following:

1. Thirty-three facilities with evidence of COIs in groundwater where existing data are insufficient to assess the extent of the plume relative to the ISA;

2. Fourteen ESCI sites where no groundwater data has yet been obtained; and
3. Thirty-eight non-ECSI properties at which historical and current land-uses do not preclude the release of hazardous substances that may have impacted groundwater near the ISA (17 groups of parcels or 38 separate addresses).

Group C Sites
These sites include those with groundwater data demonstrating that groundwater COIs are not present, or that groundwater COIs are not likely to reach the river. The conclusion that groundwater COIs are not likely to reach the river at sites with COIs in groundwater is based on the following factors:

1. The extent of the existing plume is well-characterized
2. The existing plume is located at a significant distance from the river or at a distance where COIs are not expected to reach the river.
3. Source area concentrations are not significantly elevated.
4. Fate and transport properties of the COIs do not support migration of COIs to the river.
5. The amount of time since the period of release indicates that the plume has reached an equilibrium state.
6. Regulatory status; the site has received a no further action (NFA) determination or determination that the site does not affect the river from DEQ or EPA.

Nine sites with groundwater data demonstrating that groundwater COIs are not present, or that groundwater COIs are not likely to reach the river have been identified. Of these, there are seven facilities with COIs present in groundwater that are not likely to discharge to the ISA and two facilities with groundwater data where groundwater COIs are not detected.

Figures 4-1a through 4-1c show a generalized breakdown of data availability for each site evaluated in the Data Review. The figures identify sites with available groundwater data, distinguishing between sites where groundwater COIs are known or are considered to have a reasonable possibility to discharge to the river and all other sites in the vicinity of the ISA where groundwater COIs have been detected. The figures also show the locations of sites listed on the ECSI database that do not have available groundwater data and sites that are not listed on the ECSI database.

4.5 Site Status

The status of each site listed on the ECSI database along the ISA was assessed with regard to upland site investigation and/or source control activities. Most of the sites are managed by the DEQ under the Voluntary Cleanup Section. The EPA is providing regulatory oversight on 5 of the sites. Source controls have been implemented at 50 sites with soil removal as the primary source control measure. Table 4-1 identifies the regulatory status of each site, including the applicable regulatory program, groundwater investigation status, and source controls.

5.0 Conclusions and Groundwater Process Implementation

This section summarizes the conclusions of the Data Review with regard to the objectives described in Section 1.0, and describes how the conclusions will be used to implement the process to assess groundwater-related risks to receptors.

5.1 Conclusions

5.1.1 Hydrogeologic System

Groundwater in the uplands adjacent to the LWR flows through a dynamic and heterogeneous hydrogeologic system before ultimately discharging to the river. The contribution of groundwater flux to the overall flow of the river within the Lower Willamette River is relatively small: between 0.2 and 2 percent of lowest recorded flow (4,200 cfs) at the Morrison Bridge Gage and is 0.1 to 1 percent of typical annual low flows (7,000 to 8,000 cfs). However, spatial and temporal variability in groundwater flow characteristics and influences of river stage fluctuations strongly influence discharge to the river.

Three generalized flow systems relevant to transport of contaminants in groundwater toward the river have been distinguished: shallow, intermediate and deep systems. The first two of these flow systems are the most relevant to assessing risks from potential transport of COIs in groundwater to the river, primarily because the vast majority of groundwater COIs are present in the shallow and intermediate systems. In addition, these systems discharge to shallower portions of ISA where ecological habitat and potential human use areas exist. Based on these characteristics, assessment of groundwater-related effects on the river should focus on the shallower areas at the sides of the river, where groundwater in the shallow and intermediate systems discharges.

Shallow System

The shallow system is hydrogeologically the most completely characterized of the three flow systems. The system is unconfined and resides in fill and shallow heterogeneous alluvial sequences of silt, clay and sand. The shallow system is distinguished by the following characteristics:

- Most plumes of COIs in groundwater reside in the shallow system since all releases affecting groundwater affect the shallow system first. Also, a majority of releases in upland areas adjacent to the ISA consist wholly or in part of petroleum hydrocarbons, which are less dense than water and thus are found at the water table surface.
- The shallow system is least affected by river stage fluctuations because of high groundwater levels relative to the river stage and steep hydraulic gradients adjacent to the river.
- Shallow system groundwater levels respond more to seasonal precipitation patterns.

- The shallow system discharges near river edge and in surface seeps above the river level. Discharge from seeps is most prevalent during low river stage periods when the shallow system discharge areas are exposed.
- The vertical gradient between the shallow and intermediate systems is typically downward.
- Fine-grained soils (silt and clay) are prevalent along the riverbank throughout much of the shallow system along the ISA. Thus, the presence of preferential groundwater flow pathways is an important factor to consider for understanding transport of COIs in groundwater toward to the river from upland source areas.
- The presence of preferential groundwater flow pathways is an important factor to consider for understanding transport of COIs in groundwater toward to the river from upland source areas.
- The Transition Zone in which ecological receptors may be exposed to groundwater –related COIs is anticipated to be relatively thin in the shallow system.
- Discharge of COIs in shallow system groundwater at surface seep locations is the only potential exposure point for humans to contact groundwater-related COIs in the ISA.

Intermediate System

The intermediate system is generally very distinct from the shallow system where it has been characterized. This system also is mostly hosted in heterogeneous alluvial sand, silt and clay. The intermediate system is important for assessment of potential risks to receptors from transport of groundwater COIs in the system at locations where DNAPL may have been released, or potentially where significant vertical gradients may have transported dissolved COIs from the shallow system. Distinguishing characteristics of this system include:

- The intermediate system is generally confined to semi-confined.
- In general, groundwater in the intermediate system flows toward and discharges to the river.
- Discharge from the intermediate system occurs below the river surface and generally below approximately elevation –5 MSL or deeper.
- At many locations, the intermediate system occurs within higher permeability materials such as sand, and thus is in good hydraulic connection with the river.
- Groundwater levels and flow in the system are significantly affected by river stage fluctuations including both seasonal and semi-diurnal tidal changes. Increases in river stages may temporarily reverse the gradient in the system, particularly near the river.

- Intermediate system groundwater levels are more similar to river stage and groundwater gradients in the intermediate system are generally less steep than the shallow system.
- Seasonal groundwater level trends in the intermediate system mirror seasonal river stage trends.
- The Transition Zone where the intermediate system discharges to the river and where ecological receptors may be exposed to groundwater containing COIs likely is thicker than the shallow system due to overall lower hydraulic head in the intermediate system and greater impact of river fluctuations, including gradient reversals.
- The intermediate system contains few plumes of groundwater COIs relative to the shallow system
- There are no potential exposure point for humans to contact groundwater-related COIs in the ISA from groundwater discharging from the intermediate system.

Deep System

The deep system is confined and occurs in the CRBG and CGF hydrogeologic units. This system is only characterized at a few locations in the vicinity of the railroad bridge on both sides of the river due to the presence of very few COI plumes within the deep system. The deep system is distinguished by the following characteristics:

- The deep system is generally confined.
- Groundwater in the deep system generally flows toward and discharges to the river.
- At many locations, the deep system occurs within higher permeability materials such as sand, and thus is in good hydraulic connection with the river.
- Like the intermediate system, the deep system is highly responsive to river stage changes.
- Groundwater levels and flow in the system are significantly affected by river stage fluctuations including both seasonal and semi-diurnal tidal changes. Increases in river stages may temporarily reverse the gradient in the system, particularly near the river.
- Discharge from the deep system occurs deep within the river or does not occur and is part of a regional aquifer underlying the river.
- The permeability of many of the units hosting the deep system is relatively high.
- Very few COI plumes are documented in the deep system. Those that are consist of chlorinated solvents and chlorinated pesticides.

- The Transition Zone where the deep system discharges to the river likely is thicker than the shallow system due to overall lower hydraulic head in the deep system and greater impact of river fluctuations, including gradient reversals.
- Most groundwater discharge from the deep system occurs in the deep channel areas of the ISA, where little ecological habitat is present
- There are no potential exposure point for humans to contact groundwater-related COIs in the ISA from groundwater discharging from the deep system.

5.1.2 COIs in Groundwater

As described in Section 4.3, upland properties adjacent to the ISA have been placed in three different groups based on the potential for groundwater COIs to reach the river.

- ***Group A Sites***: Sites with COIs in groundwater that are known or to or are considered reasonably likely to discharge to the ISA based on information in DEQ files. There are 19 sites in this group, as listed in Table 5-1.

- ***Group B Sites***: Sites with insufficient data to determine whether COIs in groundwater may discharge to the ISA. This group includes: (1) sites with COIs in groundwater where existing data are insufficient to conclude whether the plume discharges to the ISA (33 facilities), (2) non-ECSI properties identified in Section 4.3 at which historical and current land-uses do not preclude hazardous materials releases that could impact groundwater near the ISA (17 groups of parcels or 38 separate addresses), and (3) ECSI sites that lack groundwater data (14 sites). The sites in this group are listed in Table 5-2.

- ***Group C Sites***: Sites with groundwater data suggesting that groundwater COIs are not present, or that groundwater COIs are not likely to reach the river. There are 9 sites in this grouping, as listed in Table 5-3.

The seep reconnaissance survey (GSI, 2003) identified shoreline seep locations in or near the vicinity of human use areas in the vicinity of the ISA. Sites in Groups A and B were further assessed to identify locations where COIs in groundwater may be present in seeps within human use areas. The locations where groundwater seeps are present within human use areas were identified during the seep reconnaissance survey (GSI, 2003). The results of the seep reconnaissance survey were integrated with the results of the groundwater data review. Figures 4-1a through 4-1c show locations of shallow system seeps, human use beaches and sites with COIs in groundwater. Four sites are identified in Table 5-4 as having COIs in groundwater adjacent to or upgradient of the seeps at human use beaches. COIs in groundwater at three of the four sites are Group A sites. That is, groundwater COIs as these sites are confirmed to or have a reasonable potential to reach the river, and thus potentially the seep. These three Group A sites will be assessed further to evaluate potential risks to human receptors in the ISA from dermal contact with groundwater.

One of the sites near seeps at human use beaches is categorized as a Group B site: a site having insufficient information to determine the extent of COIs in groundwater relative to the river. This site will be referred to DEQ to collect additional data to assess whether or not groundwater COIs could affect the seeps at the identified human use beach.

5.2 Groundwater Risk Process Implementation

The following section outlines the next set of steps that will be taken in the process to assess groundwater-related contributions to risk in the ISA outlined in the Work Plan. This section also includes a schedule for deliverables that will document the details and results of each step.

5.2.1 Evaluation of Groundwater COIs Relative to the ISA

Sites included in this Data Review will be further evaluated as follows:

1. Group A sites where COIs in groundwater have either been confirmed to, or have a reasonable potential to discharge to the river will be further evaluated for potential contributions to ecological and human health risks in the ISA from groundwater COIs through the processes outlined in Section 7.2.3 of the Work Plan.
2. Group B sites where the potential for groundwater COIs to reach the ISA cannot be determined based on available data will be referred to DEQ for determination if further groundwater characterization is necessary to determine whether COIs in groundwater potentially are reaching the river.
3. Group C sites where site-specific groundwater data indicates with a high degree of certainty that COIs in groundwater are not present or are not likely to reach the river will not be further evaluated by the LWG in the RI/FS.

5.2.2 Process and Schedule

A list and schedule for groundwater assessment deliverables that will document the details and results of the groundwater assessment approach, as well as future field data collection activities related to groundwater are listed below:

Groundwater Risk Evaluation Framework Technical Memo
This deliverable will summarize the details of how upland groundwater data will be evaluated to identify locations for additional assessment of groundwater-related risks to benthic ecological receptors and to human receptors, and will provide the data that

will be used for the evaluation. This deliverable is scheduled for submittal in July 2003.

Groundwater Ecological Risk Screening Technical Memo
This memorandum will summarize the results of the evaluation of upland groundwater COIs for the potential to contribute to risks to benthic ecological receptors. The memorandum will identify locations where additional evaluation of risk to ecological receptors from groundwater should be evaluated during Round 2B field data collection activities. This deliverable is scheduled for submittal 45 days after EPA's approval of the groundwater risk evaluation framework.

Groundwater Human Health Risk Screening Technical Memo
This deliverable will summarize the evaluation of groundwater data upgradient of seep locations within human use areas in the ISA to identify any seep locations that need additional assessment of potential human health exposures to groundwater COIs. The memorandum will identify any locations where further assessment of potential human health risks from groundwater discharge at seeps should be conducted during Round 2B field data collection activities. This deliverable is scheduled for submittal 45 days after EPA's approval of the groundwater risk evaluation framework.

Groundwater Ecological Transition Zone FSP (if needed)
A field sampling plan (FSP) will be prepared for collection of groundwater-related data for ecological risk assessment purposes in the Transition Zone of the ISA during Round 2B, if a need for such data is identified through the ecological risk assessment groundwater screening process. The FSP will describe the types and uses of the data, as well as the locations, rationale and methods that will be used to obtain the data. This deliverable, if necessary, is scheduled for submittal in December 2003.

Groundwater Seep FSP (if needed)
A field sampling plan (FSP) will be prepared for collection of water quality data from seeps for human health risk assessment purposes in the ISA during Round 2B, if a need for such data is identified through the human health risk assessment groundwater screening process. The FSP will describe the types and uses of the data, as well as the locations, rationale and methods that will be used to obtain the data. This deliverable, if necessary, is scheduled for submittal in December 2003.

REFERENCES

AMEC Earth & Environmental, Inc. 2001. Draft Groundwater Transport Evaluation Data Needs Report, RPAC, Portland Site, Portland, Oregon. AMEC Earth & Environmental, Inc., Portland, Oregon.

AMEC. 2001. Draft Groundwater Transport Evaluation Data Needs Report, RPAC – Portland Site, Portland, Oregon. Prepared for Aventis Crop Science. AMEC Earth & Environmental, Inc., Portland, Oregon.

AMEC. 2001. Final Groundwater Characterization Report, RPAC – Portland Site, Portland, Oregon. AMEC Earth & Environmental, Inc., Portland, Oregon.

AMEC Earth & Environmental, Inc. 2002. RP-07 Series Monitoring Well Installation Technical Memorandum, RPAC, Portland Site, Portland, Oregon. AMEC Earth & Environmental, Inc., Portland, Oregon.

Anchor Environmental & Hahn & Associates. 2000. Supplemental Preliminary Assessment Summary Report, Foss Maritime Company (Brix) Facility, 9030 NW St. Helens Road, Portland, Oregon. Anchor Environmental & Hahn & Associates.

Anchor Environmental & Hahn & Associates. 2001. Sampling Results Report in Support of the Preliminary Assessment of the Brix Maritime Company Facility. Anchor Environmental & Hahn & Associates.

Anchor Environmental, L. L. C. 2001. NW Natural "Gasco" Site, Draft Screening Level Nearshore Source Control Evaluation Results Report. Anchor Environmental, L. L. C.

Applied Geotechnology Inc. 1994. Volume I, Draft Remedial Investigation and Endangerment Assessment Report, Linnton Oil Fire Training Grounds, Portland, Oregon. Applied Geotechnology Inc.

Applied Geotechnology Inc. 1994. Volume II/Appendices, Draft Remedial Investigation and Endangerment Assessment Report, Linnton Oil Fire Training Grounds, Portland, Oregon. Applied Geotechnology Inc.

Applied Geotechnology Inc. 2000. Final Project Report Remedial Action, Linnton Oil Fire Training Grounds, Portland, Oregon. Applied Geotechnology, Inc.

ATOFINA Chemicals, Inc. 2001. Volume I, Quarterly Progress Report for April through June 2001, Acid Plant Area RI/FS, ATOFINA Portland Plant, Portland, Oregon. ATOFINA Chemicals, Inc.

ATOFINA Chemicals, Inc. 2001. Volume II, Quarterly Progress Report for April through June 2001, Acid Plant Area RI/FS, ATOFINA Portland Plant, Portland, Oregon. ATOFINA Chemicals, Inc.

ATOFINA. 2002. Phase II, Stage 2 Work Plan, Acid Plant Remedial Investigation, ATOFINA Portland Plant, Portland, Oregon. ATOFINA.

Beeson, M. H., K. R. Fecht, S. P. Reidel, and T. L. Tolan. 1985. Regional Correlations within the Frenchman Springs Member of the Columbia River Basalt Group; New Insights into the Middle Miocene Tectonics of Northwestern Oregon. *Oregon Geology* 47: 87-96.

Beeson, M. H., and T. L. Tolan. 1991. Geologic Map of the Portland Quadrangle, Multnomah and Washington Counties, Oregon and Clark County, Washington. Geological Map Series GMS-75. Oregon Department of Geology and Mineral Industries, Portland, Oregon.

Beeson, M. H. 2003. Personal Communication (internal review meeting on February 12, 2003 with Jason Melady, Groundwater Solutions, Inc.).

Bridgewater Group, Inc. 1998. Summary Report Focused Site Characterization for 10400 N. Burgard Way. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2000. Current Site Conditions Assessment, Burgard Industrial Park, 12005 North Burgard Road, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2000. DEQ Review Draft, Remedial Investigation/Feasibility Study Work Plan for the Portland Shipyard, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2000. Preliminary Assessment Kittridge Distribution Center, 4959 NW Front Avenue, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2000. Pre-RI Assessment Work Plan Burgard Industrial Park, 12005 North Burgard Road, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2000. Site History Review, Burgard Industrial Park, 12005 North Burgard Road, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2001. Draft Pre-RI Assessment Report Burgard Industrial Park, 12005 North Burgard Road, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2001. Phase I and II Preliminary Remedial Investigation Results Harborton Substation Facility. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2001. Preliminary Results – Remedial Investigation, Premier Edible Oils Site. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2001. Remedial Investigation Proposal, Burgard Industrial Park, 12005 North Burgard Road, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2002. Enhanced Best Management Practices, Storm Water Source Control Plan, Burgard Industrial Park, 12005 North Burgard Road, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2002. Phase I Remedial Investigation Data Report, Burgard Industrial Park, 12005 North Burgard Road, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2002. Preliminary Remedial Investigation (Pre-RI) Report for the Harborton Substation Facility. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2000. Preliminary Assessment Crawford Street Site, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2002. Black Sand Removal Action, Crawford Street Site, Portland, Oregon. Bridgewater Group, Inc.

Bridgewater Group, Inc. 2002. Preliminary Assessment Soil and Groundwater Sampling Report, Crawford Street Site, Portland, Oregon. Bridgewater Group, Inc.
Camp Dresser & McKee Inc. 2002. Semiannual Groundwater Sampling Report, October 2001 and April 2002, Linnton Oil Fire Training Grounds, Portland, Oregon. Camp Dresser & McKee, Inc.

Camp Dresser & McKee, Inc. 2001. Pre-RI Assessment Work Plan, Albina Yard, Union Pacific Railroad, Portland, Oregon. Camp Dresser & McKee, Inc.

Camp Dresser & McKee, Inc. 2002. Pre-RI Assessment Report Albina Yard, Union Pacific Railroad, Portland, Oregon. Camp Dresser & McKee, Inc.

CH2M HILL, Inc. 1996. Doane Avenue Storm Sewer Investigation Work Plan, Willbridge Facility, Riverfront Interim Action. CH2M HILL, Inc.

CH2M HILL, Inc. 1996. Willbridge Facilities Riverfront Interim Action Work Plan. CH2M HILL, Inc.

CH2M HILL, Inc. 2000. Agency Review Draft, Expanded Preliminary Assessment for the Linnton Site, Georgia-Pacific. CH2M HILL, Inc.

CH2M HILL, Inc. 2000. Agency Review Draft, Supplemental Preliminary Assessment Report for the Linnton Site, Georgia-Pacific West, Inc. CH2M HILL, Inc.

CH2M HILL, Inc. 2000. Preliminary Assessment for the Goldendale Alumina Unloading Facility. CH2M HILL, Inc.

CH2M HILL, Inc. 2000. Preliminary Evaluation of City Outfalls, Portland Harbor Study Area, Environmental Services, City of Portland, Notebook 1, Eastshore Stormwater and CSO Outfalls, Portland, Oregon. CH2M HILL, Inc., Portland, Oregon.

CH2M HILL, Inc. 2000. Preliminary Evaluation of City Outfalls, Portland Harbor Study, Environmental Services, City of Portland, Notebook 2, Westshore Stormwater and CSO Outfalls, Portland, Oregon. CH2M HILL, Inc., Portland, Oregon.

CH2M HILL, Inc. 2000. Preliminary Assessment for Northwest Pipe Company, Portland Facility, Portland, Oregon. CH2M HILL, Inc., Portland, Oregon.

CH2M HILL, Inc. 2001. Stormwater Pollution Control Plan for Compliance with: National Pollutant Discharge Elimination System, Oregon Department of Environmental Quality, General Permit No. 1200-Z. CH2M HILL, Inc.

CH2M HILL, Inc. 2002. Linnton Plywood Association Sampling and Analysis Plan, August 2002

CH2M HILL, Inc., 2002, Pre-Remedial Investigation Assessment Report, Linnton Plywood Association, Portland, Oregon. CH2M HILL, Inc., Portland, Oregon.

CH2M HILL, Inc. 2001. Preliminary Assessment and Dredging Sampling Results, Goldendale Alumina Unloading Facility. CH2M HILL, Inc.

Dames & Moore. 1987. Gould, Inc. Site, Portland, Oregon, Final Remedial Investigation Report. Dames & Moore, Portland, Oregon.

Dames & Moore. 1987. Hydrogeological Data Report Interim Evaluation NL/Gould RI/FS Portland, Oregon. Prepared for NL Industries, Inc. and Gould, Inc., Portland, Oregon. Dames & Moore, Portland, Oregon.

DEQ. 1999. Strategy Recommendation, Georgia Pacific – Linnton Fiber Terminal. Oregon Department of Environmental Quality, Portland, Oregon.

DEQ. 1999. Strategy Recommendation, ACF Industries. Oregon Department of Environmental Quality, Portland, Oregon.

DEQ. 1999. Strategy Recommendations, Harborton Substation Facility. Oregon Department of Environmental Quality, Portland, Oregon.

DEQ. 2002. Letter to Georgia Pacific Regarding Expanded Preliminary Assessment, Georgia Pacific – Linnton Fiber Terminal. Oregon Department of Environmental Quality, Portland, Oregon.

DEQ. 2002. Letter to Owens Corning Regarding DEQ Comments on Additional Sampling Results. Oregon Department of Environmental Quality, Portland, Oregon.

DEQ. 2002. Record of Decision Selected Remedial Action, Port of Portland Marine Terminal 1 South, Portland, Oregon, ECSI # 2642. Oregon Department of Environmental Quality, Portland, Oregon.

DEQ. 2002a. Project Status Report, ACF Industries. Oregon Department of Environmental Quality, Portland, Oregon.

DEQ. 2002b. Letter to ACF Industries Regarding DEQ Comments on the RI Report, ACF Industries. Oregon Department of Environmental Quality, Portland, Oregon.

Ecology and Environment, Inc. 1999. Phase 1 Soil Remedial Action Report, McCormick & Baxter Company Portland Plant, Portland Oregon. Ecology and Environment, Inc.

Ecology and Environment, Inc. 2001. Barrier Wall Geotechnical Sampling Report, McCormick and Baxter Creosoting Company, Portland, Oregon. Ecology and Environment, Inc.

Ecology and Environment, Inc. 2002. Remedial Actions Semiannual Report January 1 through June 30, 2002, McCormick and Baxter Creosoting Company Site, Portland, Oregon. Ecology and Environment, Inc.

Ecology and Environment, Inc. 2002. Scope of Work Surface Water Sampling Services, McCormick & Baxter Creosoting Company, Portland, Oregon. Ecology and Environment, Inc.

Ecology and Environment, Inc. 2002. Sediment Cap Basis of Design, McCormick and Baxter Creosoting Company Site, Portland, Oregon. Ecology and Environment, Inc.

Elf Atochem North America. 1999. Preliminary Assessment for Elf Atochem North America, 6400 NW Front Avenue, Portland, Oregon. Elf Atochem North America.

EMCON. 1989. Level II Environmental Site Assessment, St. Johns Riverfront Property, Portland, Oregon. EMCON.

EMCON. 1996. Supplemental Environmental Site Assessment, St. John Riverfront Property, Portland, Oregon. EMCON.

Environmental Resources Management. 2001. ATOFINA Chemicals, Inc., Interim Remedial Measures Implementation Report, ATOFINA Facility, Portland, Oregon. Environmental Resources Management.

Environmental Resources Management. 2002. Phase II Residual Dense Non-Aqueous Phase Liquid Investigation (Intermediate Zone Sampling), Acid Plant Area, Atofina Facility, Portland, Oregon. Environmental Resources Management.

EPA and DEQ. 1996. Record of Decision, McCormick and Baxter Creosoting Company, Portland Plant, Portland, Oregon. Environmental Protection Agency and Oregon Department of Environmental Quality, Portland, Oregon.

EPA. 2000B. Proceedings of the Ground-Water/Surface-Water Interactions Workshop, July 2000. EPA/542/R-00/007. U. S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

Evergreen Environmental Management, Inc. 2001. Preliminary Assessment for the Fred Devine Diving & Salvage, Inc. 6211 N. Ensign Street, Portland, Oregon. Evergreen Environmental Management, Inc.

Evergreen Environmental Management, Inc. 2002. Sub-Surface Soil & Catch Basin Debris Sampling, Fred Devine Diving & Salvage Facility, 6211 N. Ensign Street, Portland, Oregon. Evergreen Environmental Management, Inc.

Exponent. 1999. ELF Atochem Acid Plant Area Remedial Investigation, Interim Data Report. Exponent.

Exponent. 2001. Focused Preliminary Assessment Freightliner Truck Manufacturing Plant. Exponent.

Exponent. 2001. Pre-Remedial Investigation Field Activities Data Report, Oregon Steel Mills, Inc., Portland, Oregon Mill. Exponent.

Exponent. 2001. Pre-Remedial Investigation, Historical Investigation Report, Oregon Steel Mills, Inc., Portland Oregon Mill. Exponent.

Exponent. 2002. Phase I Remedial Investigation Work Plan, Oregon Steel Mills, Inc., Portland, Oregon ECSI Site 141. Exponent.

Exponent. 2002. Pre-Remedial Investigation, Assessment Report, Oregon Steel Mills, Inc., Portland, Oregon Mill. Exponent.

Exponent. 2002. Report of Geophysical Survey, Freightliner Truck Manufacturing Plant, Portland, Oregon. Exponent.

Exponent/Kleinfelder, Inc. 2002. Focused Feasibility Study: Exxon Mobil Portland Terminal. Exponent/Kleinfelder, Inc.

GeoEngineers, Inc. 1995. Report of Geoenvironmental Services Supplemental Site Characterization and Preliminary Remedial Options, Linnton, Oregon. GeoEngineers, Inc.

GeoEngineers, Inc. 2000. September 2000 Tank Farm Soil Sampling and Analysis, Olympic Pipe Line Company, Portland Delivery Facility, 9420 NW St. Helens Road, Portland, Oregon. GeoEngineers, Inc

GeoEngineers. 2000. Remedial Investigation, Former Pope & Talbot Wood Treatment Site, St. Helens, Oregon. Completed for Pope & Talbot, Inc. and the Port of St. Helens.

GeoEngineers, Inc. 2002. Preliminary Assessment Report, Shaver Transportation Site, 4900 NW Front Avenue, Portland, Oregon. GeoEngineers, Inc.

Geraghty & Miller. 1991. Hydrogeological Investigation of the Doane Lake Area, Portland, Oregon. Geraghty & Miller.

GSI. 2003. Technical Memorandum: Results of Seep Reconnaissance Survey, River Mile 22-10.5, Lower Willamette River. Groundwater Solutions, Inc., Portland, OR
.
Hahn and Associates, Inc. 2001. Data Package for Focused Remedial Investigation, Wacker Siltronic Corporation Property, 7200 NW Front Avenue, Portland, Oregon. Hahn and Associates, Inc.

Hahn and Associates. 2001. Terminal 1 South Remedial Investigation Report, Volume 1. Hahn and Associates, Inc.

Hahn and Associates. 2002. Groundwater Sampling Report, Port of Portland, Marine Terminal 1 South, 2100 NW Front Avenue, Portland, Oregon. Hahn and Associates, Inc.

Hahn and Associates. 2002. Progress Report for First and Second Quarter 2002 RI/FS Activities; NW Natural Gasco Facility, 7900 NW St. Helens Road, Portland, Oregon. Hahn and Associates, Inc.

Hahn and Associates. 1996. Data Package for Remedial Investigation/Feasibility Study for Northwest Natural Gas Company, GASCO Facility, 7900 NW St. Helens Road, Portland, Oregon. Hahn and Associates, Inc.

Hahn and Associates. 1998. Monitoring Well Abandonment and Installation Activities, Northwest Natural – GASCO Facility, 7900 NW St. Helens Road, Portland, Oregon. Hahn and Associates, Inc.

Hahn and Associates, Inc. 1998. Phase I Remedial Investigation Summary Report and Preliminary Analysis of Soil Data (As Appendix 1), Volume 1, Northwest Natural – Gasco Facility, 7900 NW St. Helens Road, Portland, Oregon. Hahn and Associates, Inc.

Hahn and Associates, Inc. 1998. Phase I Remedial Investigation Summary Report and Preliminary Analysis of Soil Data (As Appendix 1), Volume 2, Northwest Natural – Gasco Facility, 7900 NW St. Helens Road, Portland, Oregon, Hahn and Associates, Inc.

Hahn and Associates, Inc. 1999. Phase II Remedial Investigation Data Package and Progress Report for Fourth Quarter 1998 RI/FS Activities. Hahn and Associates, Inc.

Hahn and Associates, Inc. 2002. Report on Anode Groundbed Abandonment Activities, Northwest Natural – GASCO Facility, 7900 NW St. Helens Road, Portland, Oregon. Hahn and Associates, Inc.

Hahn and Associates, Inc. 2002. Work Plan (Addendum No. 1) for Groundwater Investigation, Brix Maritime Company Facility, 9030 NW St. Helens Road, Portland, Oregon. Hahn and Associates, Inc.

Hanson Engineers Inc. 1996, Environmental Site Assessment (Phase I), Premier Edible Oils refinery 10400 North Burgard Way, Portland, Oregon. Hanson Engineers Inc.

Hart Crowser. 1991. Corrective Action Plan Hill Investment Company Warehouse, 3322 NW 35th Avenue, Portland, Oregon. Hart Crowser.

Hart Crowser. 1997. Vapor Extraction Testing and Analysis, SFPP Portland Station, Portland, Oregon. Hart Crowser.

Hart Crowser. 1999. Remedial Investigation Report, Port of Portland Terminal 4, Slip 3 Upland, Portland, Oregon. Hart Crowser.

Hart Crowser. 1999. Sediment Characterization Study, Marine Terminal 4, Berth 416, Portland, Oregon, Volume 1. Hart Crowser.

Hart Crowser. 2000. Existing Data/Site History Report, Willamette Cove, Portland, Oregon. Hart Crowser.

Hart Crowser. 2000. Human Health and Ecological Baseline Risk Assessment, Terminal 4, Slip 3 Upland, Portland, Oregon. Hart Crowser.

Hart Crowser. 2000. Volume 1, Remedial Investigation Report, Terminal 4, Slip 3 Upland, Portland, Oregon. Hart Crowser.

Hart Crowser. 2001. Oregon Steel Mills North Fence Fuel Release Site, Portland, Oregon. Hart Crowser.

Hart Crowser. 2001. Phase I Progress Report, Remedial Investigation, Willamette Cove, Portland, Oregon. Hart Crowser.

Hart Crowser. 2002. Baseline Environmental Site Assessment, Phase I and II Investigation Report, Toyota Logistics Services, Inc. – Lower Parcel, Port of Portland – Terminal 4, Portland, Oregon. Hart Crowser.

Hart Crowser. 2002. Feasibility Study Report, Terminal 4, Slip 3 Upland, Portland, Oregon. Hart Crowser.

Hinkle, Steven R. 1997. Quality of Shallow Ground Water in Alluvial Aquifers of the Willamette Basin, Oregon, 1993-1995. United States Geological Survey Water-Resources Investigations Report 97-4082-B. Portland, Oregon.

In-Situ Oxidative Technologies. 2002. Laboratory Treatability Study Report, Time Oil – Northwest Terminal, Portland, Oregon. In-Situ Oxidative Technologies.

Integral Consulting, Inc. 2002. Submittal of Revised Focused Feasibility Study (FFS) and Response to Comments Former Exxon Mobile Portland Terminal, Portland, Oregon. Integral Consulting, Inc.

IT Corporation. 2001. Focused Remedial Investigation Interim Status Report, McCall Oil and Chemical Corporation, Portland, Oregon. IT Corporation.

Jacobs Engineering. 2000. Expanded Preliminary Assessment Data Report, Marine Finance Site, Portland, Oregon. Jacobs Engineering.

Jacobs Engineering. 2000. FINAL Expanded Preliminary Assessment Data Report, Union Pacific Railroad Albina Yard, Portland, Oregon. Jacobs Engineering.

Jacobs Engineering. 2000. FINAL Preliminary Assessment and Expanded Preliminary Assessment Work Plan, Union Pacific Railroad Albina Yard, Portland, Oregon. Jacobs Engineering.

Kennedy/Jenks. 2000. Expanded Preliminary Assessment, Linnton Site, Portland, Oregon. Kennedy/Jenks.

Kennedy/Jenks. 2001. Expanded Preliminary Assessment Sampling Results, Linnton Site, Portland, Oregon. Kennedy/Jenks.

Kennedy/Jenks. 2002. Additional Sampling Results Report, Linnton Site, Portland, Oregon. Kennedy/Jenks.

KHM Environment Management. 2002. 1st Quarter Progress Report, Kinder Morgan Linnton Terminal Remedial Investigation, DEQ File No. WPMVC WMCVC-NWR-00-17. KHM Environment Management.

KHM Environmental Management. 1999. Environmental Site Assessment, GATX Terminals Corporation, Linnton Terminal, 11400 Northwest St. Helens, Road, Portland, Oregon. KHM Environmental Management.

KHM Environmental Management. 1999. Phase I Environmental Assessment, GATX Terminals Corporation, Linnton Terminal 11400 NW Saint Helens Road, Portland, Oregon. KHM Environmental Management.

KHM Environmental Management. 2000. Draft Remedial Investigation Report, Willbridge Facility, Portland, Oregon. KHM Environmental Management.

KHM Environmental Management. 2002. Interim Remedial Action Measures Proposal, Kinder Morgan Linnton Terminal Remedial Investigation, DEQ File No. WPMVC WMVC-NWR-00-17, 11400 NW St. Helens Road, Portland, Oregon. KHM Environmental Management.

KHM Environmental Management. 2002. Remedial Investigation Work Plan, Kinder Morgan Liquid Terminals, LLC, Linnton Facility, 11400 NW St. Helens Road, Portland, Oregon. KHM Environmental Management.

KHM Environmental Management. 2002. Remedial Investigation, Volume I of II, Kinder Morgan Liquid Terminals, LLC, Linnton Facility, 11400 NW St. Helens Road, Portland, Oregon. KHM Environmental Management.

KHM Environmental Management. 2002. Remedial Investigation, Volume II of II, Kinder Morgan Liquid Terminals, LLC, Linnton Facility, 11400 NW St. Helens Road, Portland, Oregon. KHM Environmental Management.

KHM Environmental Management. 2002. Revised 60-inch Storm Sewer Interim Remedial Actions Report, Tosco Willbridge Terminal, Portland, Oregon. KHM Environmental Management.

KHM Environmental Management. 2002. Semi Annual Groundwater Monitoring Report (October 2001 through March 2002), Willbridge Bulk Fuel Facilities, Portland, Oregon. KHM Environmental Management.

KHM Environmental Management. 2003. Groundwater Assessment Report, Goldendale Alumina Unloading Facility. KHM Environmental Management.

KHM Environmental Management. 2003. Semi Annual Groundwater Monitoring Report (April 2002 through September 2002), Willbridge Bulk Fuel Facilities, Portland, Oregon. KHM Environmental Management.

Kinder Morgan. 2000. Groundwater Monitoring Report, Portland, Oregon. Kinder Morgan.

Kleinfelder. 1998. Addendum Number 1 Remedial Design/ Remedial Action Work Plan Mobil Oil Corporation Portland Terminal, Portland, Oregon. Kleinfelder.

Kleinfelder. 1998. Deeper Aquifer Characterization and Aquitard Geoprobe Survey Mobile Oil Corporation Portland Terminal #36-001, Portland, Oregon, Kleinfelder.

Kleinfelder. 2000. Exxon Mobil Corporation Remediation System Installation Report, Portland Bulk Terminal 36-001, 9420 NW St. Helens Road, Portland, Oregon. Kleinfelder.

Kleinfelder. 2002. Annual Remediation Status Report July 2000 through October 2001, Former Mobile Oil Portland Terminal 36-001, 9420 NW St. Helens Road, Portland, Oregon. Kleinfelder.

Landau Associates. 2001a. Groundwater Interim Action Completion Report, Time Oil Northwest Terminal, Portland, Oregon. Landau Associates, Inc., Lake Oswego, Oregon.

Landau Associates. 2001b. Report – Volume 1 of 2, Phase II Remedial Investigation Time Oil Northwest Terminal, Portland, Oregon. Landau Associates, Inc., Lake Oswego, Oregon.

Landau Associates. 2001c. Report – Volume 2 of 2, Phase II Remedial Investigation Time Oil Northwest Terminal, Portland, Oregon. Landau Associates, Inc., Lake Oswego, Oregon.

Landau Associates. 2001. Phase II Remedial Investigation, Time Oil Northwest Terminal, Portland, Oregon. Prepared for Time Oil Co. Landau Associates, Inc., Lake Oswego, Oregon.

Landau Associates. 2002. Fourth Quarter 2001 Groundwater Report, Time Oil Northwest Terminal, Portland, Oregon, April 8, 2002. Landau Associates, Inc., Lake Oswego, Oregon.

Landau Associates, 2002b, Phase I – Soil Stockpile Removal Action Plan, Time Oil Northwest Terminal, Portland, Oregon. Landau Associates, Inc., Lake Oswego, Oregon.

Landau Associates. 2002c. Removal Action Plan, Warehouse Demolition and Soil Excavation, Time Oil Northwest Terminal, Portland, Oregon. Landau Associates, Inc., Lake Oswego, Oregon.

Landau Associates. 2002d. Technical Memorandum re: Phase III Preliminary Evaluation, Time Oil Northwest Terminal, Portland, Oregon. Landau Associates, Inc., Lake Oswego, Oregon.

Landau Associates. 2003. Third Quarter 2002 Groundwater Monitoring and Groundwater Interim Action Status Report; Time Oil Northwest Terminal, Portland, Oregon. Landau Associates, Inc., Lake Oswego, Oregon.

Landslide Technology. 2000. Environmental Sampling Program, Portland Delivery Facility, Portland, Oregon. Landslide Technology.

Limno-Tech. 2002. Summary of the Remedial Investigation Activities from the Supplemental Remedial Investigation at Wacker Siltronic Corporation Property, 7200 NW Front Avenue, Portland, Oregon. Limno-Tech.

Maul Foster & Alongi. 1999. Baseline Sediment Assessment North Portland Yard Site (Former Riedel Property) Portland, Oregon. Maul Foster & Alongi.

Maul Foster & Alongi. 2001. Preliminary Assessment of Jefferson Smurfit Corporation (U.S.) Corrugated Container Facility, 9930 N. Burgard Way, Portland, Oregon. Maul Foster & Alongi.

Maul Foster & Alongi. 2002. Remedial Investigation for Soil, Triangle Park, LLC (North Portland Yard Site) 5828 North Van Houten Place Portland, Oregon, Volume 1. Maul Foster & Alongi.

Maul Foster Alongi. 2002. Preliminary Assessment of Front Avenue LP Site, 4950, 5034, & 5200 NW Front Avenue, Portland, Oregon. Maul Foster & Alongi.

Maul Foster Alongi. 2002. Workplan for Assessment of Geophysical Anomalies and Other Features of Interest, Truck Manufacturing Plant, Freightliner LLC. Maul Foster & Alongi.

Maul Foster Alongi. Relevant Historical Reports for 4950, 5034, & 5200 NW Front Avenue, Portland, Oregon. Maul Foster & Alongi.

Maul Foster and Alongi. 1998. Focused Environmental Site Assessment Terminal 1, Between Slip No. 2 and the Freemont Bridge, Northwest Portland, Oregon. Maul Foster & Alongi.

McKenna Environmental, LLC. 2001. Preliminary Site Assessment, Calbag Metals Co, 4927 NW Front Avenue, Portland, Oregon. McKenna Environmental LLC.

MFA. 2003. Technical Memorandum regarding Groundwater Quality, Truck Manufacturing Plan, Freightliner LLC. MFA.

Morgan, David S., and William D. McFarland, 1996. Simulation Analysis of the Ground-Water Flow System in the Portland Basin, Oregon and Washington. U.S. Geological Survey Water-Supply Paper 2470-B. Prepared in cooperation with Oregon Water Resources Department, City of Portland Bureau of Water Works and Intergovernmental Resource Center. Portland, Oregon.

Pacific Environmental Group. 1997. Interim Action Work Plan, Willbridge Terminal, Portland, Oregon. Pacific Environmental Group.

Pacific Environmental Group. 2000. Remedial Investigation Work Plan, Willbridge Facility, Portland, Oregon. Pacific Environmental Group.
Pacific Northern Environmental. 1995. Above Ground Petroleum Spill Response and Independent Cleanup Report, Olympic Pipeline, 9420 NW St. Helens Road, Portland, Oregon. Pacific Northern Environmental.

Parametrix. 2002. Draft Work Plan for Remedial Investigation. Parametrix, Inc.

Parametrix. 2002. Expanded Preliminary Assessment Mar Com Ship Repair Facility. Parametrix, Inc.

PBS Environmental. 2000. Phase One Environmental Site Assessment Update for Capital Consultants for Riverside Industrial Park, Portland, Oregon. PBS Environmental.

Port of Portland. 2000. Preliminary Assessment Appendix II, Port of Portland, Terminal 5, N. Lombard Street, Portland, Oregon. Port of Portland, Portland, Oregon.

Port of Portland. 2000. Preliminary Assessment Appendix, Port of Portland, Terminal 5, N. Lombard Street, Portland, Oregon. Port of Portland, Portland, Oregon.

Port of Portland. 2000. Preliminary Assessment, Port of Portland Terminal 2, 3556 NW Front Avenue, Portland, Oregon. Port of Portland, Portland, Oregon.

Port of Portland. 2000. Preliminary Assessment, Port of Portland, Terminal 1, 2200 NW Front Avenue, Portland, Oregon. Port of Portland, Portland, Oregon.

Port of Portland. 2000. Preliminary Assessment, Port of Portland, Terminal 5, N. Lombard Street, Portland, Oregon. Port of Portland, Portland, Oregon.

Port of Portland. 2000. Terminal 2 Preliminary Assessment Appendix II, Port of Portland, 3556 NW Front Avenue, Portland, Oregon.

Port of Portland. 2000. Terminal 4 – Auto Storage Facility, Preliminary Assessment, Port of Portland, Portland, Oregon.

Port of Portland. 2000. Terminal 4 – Auto Storage Facility, Preliminary Assessment Appendix II, Port of Portland, Portland, Oregon.

Port of Portland. 2000. Terminal 4 – Slip 1, Preliminary Assessment, Port of Portland, 11040 N. Lombard, Portland, Oregon.

Port of Portland. 2000. Terminal 4 – Slip 1 Appendix, Preliminary Assessment, Port of Portland, 11040 N. Lombard, Portland, Oregon.

PTI Environmental Services. 1992. McCormick & Baxter Creosoting Company, Remedial Investigation Report, Volume III of IV (Appendices E and F). PTI Environmental Services.

PTI Environmental Services. 1995. McCormick & Baxter Creosoting Company, Revised Feasibility Study. PTI Environmental Services.

PWB and CH2M HILL. 2001. Deep Aquifer Yield Groundwater Flow Model. Portland Bureau of Water Works, Portland, Oregon.

Roy F. Weston, Inc. 1994. Site Inspection Report Columbia American Plating, Portland, Oregon. Roy F. Weston, Inc.

S.S. Papadopulos & Associates. 1993. Site Assessment Rhone-Poulenc Ag Facility, Portland, Oregon. S. S. Papadopulos & Associates.

Science & Engineering Analysis Corporation. 1992. Preliminary Assessment; Trumbull Asphalt Plant, 3605 NW 35th Avenue; Portland, Oregon. Science & Engineering Analysis Corporation.

SEACOR. 1993. Environmental Site Assessment Report, Chevron Willbridge Asphalt Refinery, 5501 NW Front Avenue, Portland, Oregon. SEACOR.

SECOR. 2001. Beneficial Water Use Determination, ARCO 22T, 9930 NW St. Helens Road, Portland, Oregon, DEQ No. WMCVC-NWR-00-16. SECOR.

SECOR. 2001. Pre-Remedial Investigation Assessment Work Plan, Equilon Bulk Terminal, Portland, Oregon. SECOR.

SECOR. 2002. Final Remedial Investigation Report, Volumes I and II Atlantic Richfield Company BP Terminal 22T, Portland, Oregon. SECOR.

SECOR. 2002. Quarterly Groundwater Monitoring Report, First Quarter 2002, Shell Oil Products US Bulk Terminal and Product Pipeline, 3800 NW St. Helens Road, Portland, Oregon, 4350 NW Front Avenue, Portland, Oregon. SECOR.

Snyder, Daniel T., Morgan, D. S., and McGrath, T. 1994. Estimates of Recharge from Infiltration of Precipitation, On-Site Sewage-Disposal Systems, and Dry Wells in the Portland Basin, Oregon and Washington. U. S. Geological Survey Water Resources Investigations Report 92-4010. Portland, Oregon. 34 p.

Squier Associates. 1990. Environmental Site Assessment Conducted at Gunderson, Inc. 4350 NW Front Avenue, Portland, Oregon. Squier Associates.

Squier Associates. 1998. Geological Characterization, Gunderson, Inc., Portland, Oregon. Squier Associates.

Squier Associates. 1998. Identification of Chemicals of Concern, Migration Pathways and Preliminary Exposure Evaluation, Gunderson, Inc., Portland, Oregon. Squier Associates.

Squier Associates. 2001. Interim Remedial Measure, Historical 1, 1, 1-Trichloroethane Release, Portland, Oregon. Squier Associates.

Squier Associates. 2002. Expanded Preliminary Site Assessment, Gunderson Area 3, Former Schnitzer Steel Yard, Portland, Oregon. Squier Associates.

Squier Associates. 2002. Interim Remedial Measure, Aquifer Pump Test and Evaluation, Gunderson, Inc. Squier Associates.

Squier Associates. 2002. Preliminary Site Assessment Gunderson Area 2 Rail Car and Marine Barge Assembly Area, Portland, Oregon. Squier Associates.

Strait, S. R., and R. B. Mercer. 1986. Hydraulic Property Data from Selected Test Zones on the Hanford Site. Document No. BWI-DP-051. Prepared for the U. S. Department of Energy. Rockwell Hanford Operation, Richland, Washington.

Striplin Environmental Associates, Inc., Windward Environmental, LLC, Kennedy Jenks Consultants, Anchor Environmental, LLC and Groundwater Solutions, Inc., 2003. Portland Harbor RI/FS Programmatic Work Plan, Revised. Prepared on behalf of the Lower Willamette Group. Portland, Oregon.

Striplin Environmental Associates, Inc., 2003. Draft Land Use Screen, Non-ECSI Sites within Portland Harbor. Prepared on behalf of the Lower Willamette Group, Portland, Oregon.

Swanson, R. D., W. D. McFarland, J. B. Gonthier and, J. M. Wilkinson. 1993. A Description of Hydrogeologic Units in the Portland Basin, Oregon and Washington. Water-Resources Investigations Report 90-4196. U. S. Department of the Interior, U. S. Geological Survey, Portland, Oregon.

Sylvester, George H. 1996. Progress Report 50; Van Waters & Rogers Inc., 3950 NW Yeon Avenue, Portland, Oregon. George H. Sylvester, Van Waters & Rogers, Inc., Portland, Oregon.

The Earth Technology Corp. 1990. Report on an Environmental Site Assessment of Property Located at 4959 NW Front Avenue, Portland, Oregon. Prepared for Northwest Airgas, Inc. The Earth Technology Corporation.

The Earth Technology Corp. 1991. Summary Report for an Environmental Site Assessment and Remediation of Property Located at 4959 NW Front Avenue, Portland, Oregon. The Earth Technology Corporation.

The RETEC Group. 2002. Remedial Investigation Report ACF Industries Property 12160 NW St. Helens Road, Portland. The RETEC Group.

Trimble, D. E. 1963. Geology of Portland, Oregon and Adjacent Areas. A Study of Tertiary and Quaternary Deposits, Lateritic Weathering Profiles, and Quaternary History of Part of the Pacific Northwest. USGS Bulletin 1119. U. S. Department of the Interior, U. S. Geological Survey. U. S. Government Printing Office, Washington, D. C. 119 pp.

URS Corporation. 2000. Remedial Investigation Conceptual Work Plan, US Coast Guard, MSO/Group, Portland, Oregon. URS Corporation, Portland, Oregon.

URS Corporation. 2001. Final Remedial Investigation Report, US Coast Guard, MSO/Group, Portland, Oregon. URS Corporation, Portland, Oregon

URS. 2001. Northwest CSO Force Main River Crossing Study. Prepared by URS for the City of Portland Bureau of Environmental Services, Portland, Oregon. URS Corporation, Portland, Oregon.

URS. 2002. Draft Scoping Document for Source Control Measures, Atlantic Richfield Company BP Terminal 22, Portland, Oregon. URS Corporation, Portland, Oregon.

Windward Environmental/Kennedy Jenks/Striplin Environmental. 2002. Portland Harbor Superfund Site Preliminary Planning, Scoping, and Problem Formulation Document, DRAFT. Windward Environmental, Kennedy Jenks, Striplin Environmental.

Wohlers Environmental Services, Inc. 2000. Voluntary Preliminary Assessment for the Christensen Oil Company. Wohlers Environmental Services, Inc.

Wong, et al, 2001. The Portland Hills Fault: An Earthquake Generator or Just Another Old Fault? In: Oregon Geology, Volume 63, No. 2. Oregon Department of Geology and Mineral Industries, Portland, Oregon.

Woodward-Clyde. 1995. Quarterly Progress Report 1st Quarter 1995 Surface Water and Sediment, Rhone-Poulenc AG Company, St. Helens Road Facility, Portland, Oregon. Woodward-Clyde.

Yelen, T.S., and H. J. Patton. 1991. Seismotectonics of the Portland, Oregon Region. *Seism. Soc. Am. Bull.* 81:109-103.