Addendum to
FEASIBILITY STUDY

Land Application Treatment of Extracted Groundwater

LAKESIDE RECLAMATION LANDFILL

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## TABLE OF CONTENTS

### ABBREVIATIONS

Section 1.0 INTRODUCTION

1.1 Summary of Groundwater Quality
1.2 Feasibility Study Overview
1.3 Remedial Action Objectives

Section 2.0 SUMMARY OF RECOMMENDED ALTERNATIVE

2.1 Enhanced ET Landfill Cover
2.2 Groundwater Extraction
2.3 Treatment and Disposal of Extracted Groundwater

Section 3.0 SUMMARY OF LAND APPLICATION TREATMENT, SUCCESS CRITERIA, ADAPTIVE MANAGEMENT HYPOTHESIS, AND MANAGEMENT STRATEGIES

3.1 Summary of Land Application Treatment
3.2 Natrophilic Grasses
3.3 Success Criteria
3.4 Adaptive Management Process and Hypothesis
3.5 Management Strategies
3.6 Assumptions

Section 4.0 CONCEPTUAL MODEL OF LAND APPLICATION TREATMENT AT LAKESIDE

4.1 Estimating the Mass Loading of CPECs
4.2 Estimating Stand Transpiration and Potential Irrigation Rate
4.3 Estimating the Rate of Constituent Uptake
   4.3.1 Uptake of NaCl by Natrophilic grass species
   4.3.2 Uptake of Other Landfill-Related Constituents
4.4 Stand Productivity and Estimated Seasonal Uptake
4.5 Soil Properties in the Land Application Area

Section 5.0 LAND APPLICATION

5.1 Treatment of Recovered Groundwater
   5.1.1 Summary of Recovered Groundwater Treatment Approach
   5.1.2 Recovered Groundwater Pre-Treatment
   5.1.3 Treatment Wetlands
   5.1.4 Wetland Design Concepts and Operation
5.2 Water Conveyance and Storage
5.3 Land Application Area
5.4 Irrigation System
5.5 Preparation

Section 6.0 PERFORMANCE MONITORING AND DATA COLLECTION

6.1 Irrigation and Soil Moisture Control System
6.2 Concentrations of CPECs in Grass Cuttings
6.3 Stand Productivity and Uptake of CPECs
6.4 Suction Lysimeters
6.5 Soil Sampling
<table>
<thead>
<tr>
<th>Section</th>
<th>7.0</th>
<th>ADAPTIVE MANAGEMENT PROCESS .................................................................</th>
<th>7-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td>8.0</td>
<td>PILOT STUDY FOR ALTERNATIVE GROUNDWATER TREATMENT .....................................</td>
<td>8-1</td>
</tr>
<tr>
<td>8.1</td>
<td></td>
<td>Summary of Pilot Study ..................................................................................</td>
<td>8-1</td>
</tr>
<tr>
<td>8.2</td>
<td></td>
<td>Groundwater Extraction .................................................................................</td>
<td>8-2</td>
</tr>
<tr>
<td>8.3</td>
<td></td>
<td>Sampling .......................................................................................................</td>
<td>8-2</td>
</tr>
<tr>
<td>8.4</td>
<td></td>
<td>Aeration and Filtration ................................................................................</td>
<td>8-3</td>
</tr>
<tr>
<td>8.5</td>
<td></td>
<td>Treatment 1: Land Application to Natrophilic Grass ....................................</td>
<td>8-3</td>
</tr>
<tr>
<td>8.5.1</td>
<td></td>
<td>Preliminary Soils Characterization .............................................................</td>
<td>8-3</td>
</tr>
<tr>
<td>8.5.2</td>
<td></td>
<td>Estimated Transpiration Rates .....................................................................</td>
<td>8-4</td>
</tr>
<tr>
<td>8.5.3</td>
<td></td>
<td>Irrigation System ..........................................................................................</td>
<td>8-4</td>
</tr>
<tr>
<td>8.5.4</td>
<td></td>
<td>Performance Monitoring and Data Collection ...............................................</td>
<td>8-4</td>
</tr>
<tr>
<td>8.6</td>
<td></td>
<td>Treatments 2 and 5: Compost Filtration .....................................................</td>
<td>8-5</td>
</tr>
<tr>
<td>8.6.1</td>
<td></td>
<td>Treatment 2: Compost Filtration After Sand Filter .......................................</td>
<td>8-5</td>
</tr>
<tr>
<td>8.6.2</td>
<td></td>
<td>Treatment 5: Compost Filtration without Sand Filter ....................................</td>
<td>8-5</td>
</tr>
<tr>
<td>8.7</td>
<td></td>
<td>Treatments 3 and 4: Natrophilic Wetland ....................................................</td>
<td>8-6</td>
</tr>
<tr>
<td>8.7.1</td>
<td></td>
<td>Treatment 3: Wetland with Sand Filter .......................................................</td>
<td>8-7</td>
</tr>
<tr>
<td>8.7.2</td>
<td></td>
<td>Treatment 4 Wetland without Sand Filter ....................................................</td>
<td>8-7</td>
</tr>
<tr>
<td>8.8</td>
<td></td>
<td>Transpiration of Effluent Water ..................................................................</td>
<td>8-7</td>
</tr>
<tr>
<td>8.9</td>
<td></td>
<td>Selection of Alternative ...............................................................................</td>
<td>8-7</td>
</tr>
<tr>
<td>Section</td>
<td>9.0</td>
<td>REFERENCES .....................................................................................................</td>
<td>9-1</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS

TABLES ........................................................................................................FOLLOWING REPORT

Table 1-1  Remedial Action Concentration Limits
Table 1-2  Estimated Recovered Groundwater Concentrations, Concentration Benchmarks, and Up-Stream/Up-Gradient Concentrations
Table 2-1  Summary of Alternatives Screening
Table 4-1  Average Mineral Composition of Groundwater in Riverfront Wells
Table 4-2  Estimates of Potential Transpiration (ETo) for Grass Stand in Portland, OR
Table 4-3  Seasonal CPEC Mass Loading Compared to Estimated Stand Uptake
Table 8-1  Estimates of Potential Transpiration (ETo) for Test Plots
Table 8-2  Seasonal CPEC Mass Loading and Estimated Stand Uptake for Test Plots

FIGURES ........................................................................................................FOLLOWING REPORT

Figure 1-1  Site Location Map
Figure 1-2  Landfill Site Map
Figure 4-1  Effects of Increasing NaCl Concentration in the Growth Medium of Barley.
Figure 4-2  Yield of First Cutting of Bromegrass and N Concentration as Related to N applied From Ammonium Nitrate.
Figure 5-1  Conceptual Groundwater Extraction, Pre-Treatment, Conveyance, Storage, and Land Application
Figure 5-2  Land Application Area
Figure 8-1  Pilot-Scale Groundwater Treatment
Figure 8-2  Alternative Groundwater Treatment Pilot Test Locations
# LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Agreement</th>
<th>Voluntary Agreement for Remedial Investigation/Feasibility Study effective December 9, 2005</th>
</tr>
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<td>AWQC</td>
<td>ambient water-quality criteria</td>
</tr>
<tr>
<td>cm</td>
<td>centimeter</td>
</tr>
<tr>
<td>CPEC</td>
<td>contaminants of potential ecological concern</td>
</tr>
<tr>
<td>DEQ</td>
<td>Oregon Department of Environmental Quality</td>
</tr>
<tr>
<td>EPA</td>
<td>US Environmental Protection Agency</td>
</tr>
<tr>
<td>ET</td>
<td>evapotranspiration</td>
</tr>
<tr>
<td>ET cover</td>
<td>evapotranspiration cover</td>
</tr>
<tr>
<td>Fe</td>
<td>iron</td>
</tr>
<tr>
<td>Fe$^{3+}$</td>
<td>ferric (oxidized) iron</td>
</tr>
<tr>
<td>FS</td>
<td>feasibility study</td>
</tr>
<tr>
<td>gpm</td>
<td>gallons per minute</td>
</tr>
<tr>
<td>Grabhorn</td>
<td>Grabhorn, Incorporated</td>
</tr>
<tr>
<td>Ic</td>
<td>irrigation capacity</td>
</tr>
<tr>
<td>kPa</td>
<td>kiloPascals</td>
</tr>
<tr>
<td>lbs/ft$^3$</td>
<td>pounds per cubic foot</td>
</tr>
<tr>
<td>Lakeside</td>
<td>Lakeside Reclamation Landfill</td>
</tr>
<tr>
<td>mg/L</td>
<td>milligrams per liter</td>
</tr>
<tr>
<td>Mn</td>
<td>manganese</td>
</tr>
<tr>
<td>NEDC</td>
<td>Northwest Environmental Defense Center</td>
</tr>
<tr>
<td>NaCl</td>
<td>sodium chloride salt</td>
</tr>
<tr>
<td>POTW</td>
<td>publically owned treatment works</td>
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<tr>
<td>RAOs</td>
<td>Remedial Action Objectives</td>
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<tr>
<td>RDRA</td>
<td>remedial design/remedial action</td>
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<tr>
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<td>remedial action objectives</td>
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<td>remedial investigation</td>
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<tr>
<td>ROD</td>
<td>Record of Decision</td>
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<tr>
<td>$S_a$</td>
<td>plant-available water storage capacity</td>
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<td>Lakeside Reclamation Landfill</td>
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<tr>
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<td>soil water characteristic curves</td>
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<td>URS</td>
<td>URS Corporation</td>
</tr>
<tr>
<td>µ/L</td>
<td>micrograms per liter</td>
</tr>
<tr>
<td>$\theta_c$</td>
<td>volumetric water content at “field capacity”, 33 kPa soil moisture tension</td>
</tr>
<tr>
<td>$\theta_m$</td>
<td>volumetric water content at permanent wilting point, 1,500 kPa soil moisture tension</td>
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Summary

This addendum to the feasibility study provides additional details of treatment of extracted groundwater at the Lakeside Reclamation Landfill (Lakeside; the site) operated by Grabhorn, Incorporated (Grabhorn). The addendum describes details of land application treatment, as proposed in the FS, and describes a pilot test to assess groundwater treatment technologies and to assess whether land application treatment is necessary in addition to other groundwater treatment methods.

DEQ recently requested consideration of possible treatment of the extracted ground water and direct discharge without land application. The Grabhorn team is developed a plan for a pilot test to assess groundwater treatment options. The treatment could either precede land application, or it may be possible to directly discharge the treated groundwater to surface water without land application. The pilot test described in the addendum will provide data to assess the direct discharge option, in comparison to the land application approach assumed in the FS.

BACKGROUND

The Oregon Department of Environmental Quality (DEQ) required a remedial investigation (RI) and feasibility study (FS; collectively “RI/FS”) for Lakeside under the December 9, 2005 Voluntary Agreement (Agreement). Several reports document elements of the RI (URS Corporation [URS] and Parametrix, 2009b). Grabhorn’s July 2009 Draft RI report summarized the investigations. The RI and human health and ecological risk assessments identified chemicals of potential ecological concern in riverfront wells down gradient of the landfill. Constituents that have exceeded generic screening levels were identified as chemicals of potential ecological concern (CPECs). The site CPECs are metals, chloride, and ammonia.

RECOMMENDED REMEDY

The May 6, 2010 FS screened technologies and alternatives to enhance the final landfill cover and mitigate groundwater impacts. The screening of technologies and alternatives indicate that the following actions meet the criteria and are potentially cost effective:

- Enhancement of the evapotranspiration (ET) cover.
- Groundwater extraction barrier.
- Treatment and disposal of extracted groundwater.

These actions constitute the recommended alternative. Additional testing and analysis are ongoing to more fully develop the technical details and to design and implement the selected remedy. The remedial design/remedial action and adaptive management work plan (RDRA/AMP) will provide details of the remedy design for the alternative selected by the DEQ, as documented in the record of decision for the site.

The groundwater remedy will consist of pumping and treating impacted groundwater to prevent transport of landfill-related constituents to the Tualatin River. Groundwater will be pumped from an estimated 12 riverfront wells at an estimated combined rate of 15 gallons per minute (gpm).
Summary

from April through the end of September. Modeling indicates that seasonal groundwater pumping will provide adequate capture. The RDRA/AMP work plan will provide design details of the groundwater pumping system.

The treatment alternatives considered in the FS included chemical physical treatment, discharge to a publicly owned treatment works, and land application. Land application was recommended in the FS and selected by the DEQ as the most cost effective and implementable alternative. The RDRA/AMP will provide design details to implement the selected remedy.

SUMMARY OF GROUNDWATER TREATMENT

Land application is a treatment process whereby impacted water is applied to vegetated lands at loading rates that allow uptake or other attenuation of target constituents. The FS provided concepts of the land application treatment process at Lakeside. DEQ requested additional analysis and details of the land application treatment.

This addendum to the FS feasibility study provides additional discussion and details of the land application treatment and describes pre-treatment to remove constituents from groundwater. If additional treatment is necessary, treated groundwater would be applied to a stand of salt-tolerant natrophilic (“sodium-loving”) plants that can take up the target constituents.

Analysis of groundwater pumping volume and distribution and the likely constituent concentrations in groundwater indicates that an 8-acre stand of natrophilic grass will be sufficient to transpire all of the irrigation water plus rainfall during the land application season (April or May through the end of September).

Some pre-treated groundwater may also be used to irrigate the landfill cover to provide water to young trees to minimize drought stress in the summer. The extent of irrigation to the cover will depend on the constituent load in the pre-treated groundwater and the expected ability of the cover trees to take up the constituents that remain after pre-treatment.

Sodium and chloride are the constituents that require the greatest land application area to assure uptake and prevent degradation of soil quality. Chloride is a CPEC. Although sodium is not a CPEC, attenuation of sodium is necessary to prevent its accumulation in soil and the potential deterioration of soil quality. A salt-tolerant natrophilic grass species will be selected and planted to take up the sodium chloride. The grass will be managed as a forage crop, and one or more cuttings per season will be removed from the site. A native natrophilic grass species will be selected based on the results of pilot studies.

Based on studies in the literature for biomass production and the mineral content in grass shoots, sodium chloride salt (NaCl), and other minerals in groundwater, including barium, calcium, magnesium, nitrogen, potassium, silicon, and zinc will be removed by plant uptake. However, land application to an 8-acre parcel of grass would not provide adequate uptake of iron and
manganese at the expected mass loading. Therefore, a pre-treatment step would be required to remove iron and manganese.

Pre-treatment will consist of a cascade aerator to oxidize iron and manganese followed by filtration and sorption in an engineered emergent wetland or similar treatment system. Constructed wetlands are common and effective means to treat storm water, industrial wastewater, and landfill leachate. At Lakeside, a constructed wetland will remove a substantial percentage of the iron, manganese, and other landfill-related constituents from the groundwater.

Pilot testing described below may indicate that treatment including aeration and a constructed wetland, or other treatment methods, may provide adequate treatment so that land application is not necessary. In that case, treated groundwater would be discharge directly to surface water (e.g., the Tualatin River).

**PILOT TEST**

Pilot-scale studies will test five groundwater treatments. Groundwater for the pilot test will be pumped from the extraction well installed for the pumping test (EX1) and from up to two additional monitoring wells. Monitoring wells selected for the test will provide representative groundwater quality to assess removal efficiency in a full-scale system. The proposed scale of these pilot studies assures representative and quantitative results supportive of selection and full-scale implementation.

In all cases, the recovered groundwater will first be routed through a cascade aerator to oxidize ferrous iron. The oxidized water stream then will be split to Treatments 1 through 5 listed below.

One portion will be routed through a sand filter to remove particulates, specifically ferric iron and manganese. The filtered water then will be routed to the following:

- **Treatment 1**: Drip-irrigation system of four plots of natrophilic grass species (400 square feet total area);
- **Treatment 2**: Compost sorption cell (55 gal drum);
- **Treatment 3**: Treatment wetland using natrophilic plants (dimension; 6 feet x 30 feet).

The unfiltered portion of the water stream will be routed to the following:

- **Treatment 4**: Treatment wetland cell (6 feet x 30 feet) containing natrophilic plants; or
- **Treatment 5**: Compost sorption cell (55 gal drum).

In Treatment 1, two to four different candidate species of natrophilic grass (each in a 100 square foot plot) will be pilot tested for their ability to take up the minerals dissolved in the aerated/filtered groundwater. The plots are sized and the hydraulic loading rate designed to that all of the irrigation water will be transpired during the irrigation season. Irrigation water will be
stored during the non-growing season. Therefore, Treatment 1 is zero-discharge (there will be no effluent water).

In full scale application, treatment Treatments 2 through 5 would generate treated water that would be discharged directly to the river. Under these treatment approaches, the treated water must meet the remedial action concentration limits (RACLs) before discharge. The RDRA/AMP and DEQ’s Record of Decision (ROD) would specify the concentration limits. For the test, however, treated water will be routed to a spray-irrigation system consisting of an approximately 0.2-acre stand of perennial ryegrass (a natrophilic grass). The objective of the grass irrigation during the pilot test is to transpire the water stream generated from treatment systems, thereby allowing the pilot test to be conducted with zero-discharge.
1.0 INTRODUCTION

This report is an addendum to the feasibility study (FS) for mitigation alternatives at the Lakeside Reclamation Landfill (Lakeside; the site) operated by Grabhorn, Incorporated (Grabhorn). The landfill is adjacent to the Tualatin River in Beaverton, Oregon (Figure 1-1). Figure 1-2 is a map of the landfill.

The addendum describes additional details of treatment of extracted groundwater including several optional treatment/discharge configurations. The FS described land application for treatment of extracted groundwater. The FS considered, but rejected, on-site chemical/physical treatment as being overly complex and maintenance intensive. This addendum provides additional discussion of the land-application treatment at Lakeside and also discusses potential on-site treatment in a wetland or other treatment with direct discharge to the Tualatin River. These alternative treatments are referred to hereafter as the “direct discharge” alternatives. This addendum also describes pilot treatment tests to assess alternative treatment technologies.

1.1 Summary of Groundwater Quality

The revised Level II Ecological Risk Assessment ERA (URS and Parametrix 2009a) identified the following CPECs in groundwater on the basis of screening:

<table>
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<tr>
<th>Screening by Frequency, Background Levels, Toxicity:</th>
<th>Bioaccumulation Potential:</th>
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<tbody>
<tr>
<td>ammonia</td>
<td>barium</td>
</tr>
<tr>
<td>barium</td>
<td>beryllium</td>
</tr>
<tr>
<td>calcium</td>
<td>cobalt</td>
</tr>
<tr>
<td>chloride</td>
<td>copper</td>
</tr>
<tr>
<td>iron</td>
<td>nickel</td>
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<tr>
<td>magnesium</td>
<td>zinc</td>
</tr>
<tr>
<td>manganese</td>
<td></td>
</tr>
<tr>
<td>zinc</td>
<td></td>
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Table 1-1 lists remedial action concentration limits for CPECs1. As proposed by DEQ (DEQ 2008d), the hierarchy of RACLS is as follows:

1. Oregon Ambient Water Quality Criteria (AWQC) value. If none, then,
2. Federal AWQC. If none, then,

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1 As proposed in the FS. The DEQ has not yet issues its Staff Report and the CPECs listed in the FS and the proposed values may change. Certain constituents that do not have a SLVs and are not CPECs but are detected will be monitored and assessed using trend analyses.
3. DEQ screening level values (SLVs).
4. Background concentrations of naturally-occurring constituents present in groundwater.  

As presented in the Lakeside 2009 and 2010 Annual Environmental Monitoring Reports, a comparison of groundwater quality samples collected at the site during 2009 and 2010 to AWQCs (or SLV if AWQC is not available) identified eight CPECs (ammonia, barium, calcium, chloride, iron, magnesium, manganese, and zinc) that were detected at a concentration above an AWQC (or if not available, then its SLV). Table 1-2 identifies the average concentration in riverfront wells of the CPECs and several treatment-related constituents or parameters of interest. Up-gradient groundwater and up-stream river concentrations for these eight CPECs are also listed on Table 2-1.

Discussions of treatment in this document focus on sodium, chloride, iron, and manganese. These constituents are the limiting constituents in determining the land area needed for treatment and the need for pre-treatment. Chloride, iron, and manganese are CPECs. Sodium is not a CPEC, but sodium could accumulate in soil in the land application area and eventually affect the hydraulic properties and agricultural quality of the soil in the land application area.

1.2 Feasibility Study Overview

The purpose of the FS (URS and Parametrix, 2010) was to evaluate remedial action alternatives (RAOs) to address any environmental risk, as identified in a risk assessment. Oregon Rules (OAR 340-122-0085) and DEQ guidance (DEQ 1998a) specify the general FS elements and process. An FS is required if “remedial action might be necessary to protect public health, safety or welfare or the environment,” as determined by a risk assessment.

The results of the ecological risk assessment show that concentrations of ammonia-nitrogen and certain naturally occurring earth metals (e.g., calcium, iron, manganese) in groundwater exceed ecological screening level values for surface water. The site data, however, do not indicate current unacceptable risk to human health or impacts to the river caused by the landfill.

1.3 Remedial Action Objectives

The RAOs establish the conceptual goals of the remediation. The FS established RAOs for Lakeside.

RAO #1: Prevent Further Degradation of Groundwater Quality Beneath the Landfill
RAO #1 will be achieved by maintaining and enhancing the cover to assure it meets performance objectives.

2 Background concentrations will be determined by methods specified in the RDRA work plan and ROD.
RAO #2: Protect Beneficial Uses of the Tualatin River
RAO #2 will be achieved by preventing current or future transport of constituents in groundwater that might result in violations of applicable AWQC or other risk-based criteria in the river. The target concentration limits are referred to hereafter as remedial action concentration limits (RACLs).
2.0 SUMMARY OF RECOMMENDED ALTERNATIVE

The screening of technologies and alternatives in the FS indicated that the following actions will meet the RAOs and are potentially cost effective:

- Enhancement of the evapotranspiration (ET) cover.
- Groundwater extraction barrier.
- Treatment and disposal of extracted groundwater.

Table 2-1 summarizes the technologies screened in the FS. These retained technologies constitute the recommended alternative.

2.1 Enhanced ET Landfill Cover

Native conifers will be planted on the landfill cover to increase the density of the stand. New stands of conifers will be planted in areas of the landfill where there are currently no trees and in areas where the existing tree stand is sparse. Existing trees that are healthy (e.g., not damaged by voles) will be left in place, but conifers will be planted within existing stands of hardwoods with the objective of gradually phasing out the hardwoods. Site cover soil may be processed and/or amended to enhance and promote conifer growth and root-zone development results. Drainage controls such as grading and swales will be enhanced to optimize run-off, promote drainage, and minimize ponding. The existing cover has similar drainage controls.

2.2 Groundwater Extraction

Groundwater flows south beneath the landfill and flows toward the Tualatin River. Vertical extraction wells located along the northern bank of the Tualatin River will recover groundwater down gradient of the landfill.

Aquifer testing and groundwater flow modeling enhanced the conceptual hydrogeologic model presented in the FS and provided additional information for the groundwater extraction design that will appear in the RDRA work plan. Groundwater modeling indicates that pumping 12 extraction wells from April through September will hydraulically control the plume and prevent possible transport of landfill-related constituents to the river. The model indicated that the pumping rate necessary for groundwater capture will be approximately 1.25 gpm per recovery well, resulting in a total rate of groundwater recovery of approximately 15 gpm. Groundwater elevation monitoring that will be part of the RDRA/AMP will assess capture of groundwater beneath the landfill and to the west of the landfill boundary.

Due to higher river levels in the winter, the hydraulic gradient from beneath the landfill toward the river is nearly flat and occasionally the direction of groundwater flow is to the north (i.e., from the river toward the landfill). Accordingly, modeling indicates that it will be possible to discontinue the pumping of groundwater during winter months and still achieve plume containment when pumping resumes in the spring. Monitoring during implementation will verify the assumptions and results of the groundwater modeling.
2.3 Treatment and Disposal of Extracted Groundwater

The FS concluded that land application is the most cost effective and implementable alternative for treating the extracted groundwater. Most of the landfill-related constituents in the groundwater should be readily treated by land application.

The FS provided only a general description and evaluation of the land application treatment of extracted groundwater. The FS stated that the RDRA work plan will provide additional details of storage and land application of extracted groundwater.

The FS considered several methods to treat extracted groundwater:

- On-site chemical-physical treatment and discharge to Tualatin River
- Off-site treatment
- Land application

Chemical-physical treatment typically includes chemical addition, precipitation, flocculation, dewatering, and sludge management. Treated groundwater would be discharged to the river under requirements specified in the record of decision or land applied. Chemical-physical treatment processes are common for wastewater and industrial process. Treatment by chemical-physical processes alone would be energy intensive, subject to upsets, and not cost effective. Sludge management is often problematic.

Off-site treatment would involve piping or hauling the extracted groundwater to a collector sanitary sewer and treatment at a publically owned treatment works (POTW). In general, DEQ expresses a preference on for on-site treatment due to the potential for off-site impacts. In the case of Lakeside, impacts of off-site treatment and disposal could include construction of pipelines or off-site hauling. A permit and fee would be required to discharge to the POTW.

Treatment by land application (e. g., flood, spray, or drip irrigation to agricultural fields or forest land) is a common and potentially reliable method of wastewater treatment and disposal. Uptake of nutrients and other wastewater constituents by plants and a number of chemical/physical and biological degradation and attenuation processes in soil can be effective in treating a wide range of waters containing nutrients, metals, and biological oxygen demand. Land application to agricultural fields is effective if uptake by plants or the assimilation capacity of the soil is greater than the constituent loading rate. The FS recommended land application for treatment of extracted groundwater.

At DEQ’s request, this addendum to the FS provides additional discussion and analysis of the land application approach. The DEQ also recently requested additional review of alterantives that use on-site treatment (other than chemical-physical treatment) with direct discharge to the Tualatin River. This addendum describes such alternative treatment technologies that might allow direct discharge and describes a pilot test to assess candidate treatment methods.
SECTION TWO

Summary of Recommended Alternative

Previous communications with the DEQ focused on potential land application to agricultural lands north of the landfill. Although land application to existing lands (e.g., Christmas tree farm), may be effective, a refined analysis indicates that land application to planted stands of natrophilic grass will be a better alternative.

In response to DEQ’s request, Grabhorn has reviewed and assessed on-site treatment processes including aeration, compost filtration, and treatment wetland. This addendum includes discussion of those technologies and a pilot test performance of alternative technologies.
3.0 SUMMARY OF LAND APPLICATION TREATMENT, SUCCESS CRITERIA, ADAPTIVE MANAGEMENT HYPOTHESIS, AND MANAGEMENT STRATEGIES

3.1 Summary of Land Application Treatment

This section assumes that groundwater extracted from the riverfront wells will be treated by land application. Later section of the report consider other, or additional treatment methods. Following a pre-treatment step, CPECs will be removed by using the recovered groundwater to irrigate a crop with the capacity to take up the landfill-related constituents sustainably, without deleterious effect on the soil. The conceptual model (Section 4) assumes that pre-treated groundwater will be applied to a stand of natrophilic (i.e., sodium loving) grass that is managed as a forage crop (see Section 3.2). Pilot experiments, Phased implementation, and the adaptive management process (see Section 3.4) may indicate that a variety of grasses and other crops may be suitable.

As stated in DEQ’s 1992 guidance document for Land Application of Industrial Wastewaters (DEQ, 1992), land treatment systems can achieve a level of treatment equal to or greater than other treatment systems using less energy and at lower cost. The US Environmental Protection Agency (EPA) also describes treatment processes and provides design guidance for land application of domestic and industrial wastewaters (EPA 2006).

Land application treatment involves natural physical, chemical, and biological processes. Solid particles are physically filtered and chemical processes including ion-exchange, adsorption and desorption, solubility-precipitation, complex formation, and oxidation-reduction reactions transform or immobilize wastewater constituents. Biological processes include microbial transformations and plant uptake. In some cases, irrigation to agricultural lands can produce a harvestable, marketable crop (EPA 2006).

Land application of landfill leachate and other wastewaters has been demonstrated effective at a number of landfill sites in Oregon. For example, operators of the Riverbend Landfill in Yamhill County, Oregon irrigates stands of poplar trees with landfill leachate and rainwater. The DEQ considers the operation effective treatment for the recovered leachate and rain water.

At Lakeside, land application (irrigation) of extracted groundwater to adjoining lands, and limited application to the landfill cover itself, will be an effective means of treatment and disposal of the extracted groundwater. The earth metals and salts in the groundwater are both macro- and micro-nutrients to plants and are therefore amenable to treatment by land application. Testing proposed in the FS work plan addendum and in this document provides additional information.
3.2 Natrophilic Grasses

Sodium is present in groundwater at Lakeside, although not at concentrations that suggest it will cause environmental harm (i.e., it is not a CPEC). Nonetheless, long-term application of the extracted groundwater to a land application plot could result in accumulation of sodium that could eventually inhibit plant growth.

It would, therefore, be advantageous to select a grass species for land application treatment that will take up sodium and incorporate it into plant tissue. Natrophilic plants have the capacity to accumulate relatively large amounts of sodium (and chloride) in their leaf tissue but have comparatively low concentrations in their roots (Smith et al., 1978, 1980, 1983). Common natrophilic grasses include varieties of perennial ryegrass (Lolium perenne), orchard grass (Dactylis glomerata), barley (Hordeum vulgare), and oats (Avena sativa).

Growth of many natrophilic plants is enhanced by sodium chloride (NaCl) salinity and the levels of Cl\(^-\) and Na\(^+\) in the shoot increases with increasing external supply. Accordingly, use of a natrophilic species would have the added benefit of taking up chloride, which is a site CPEC. Natrophilic grasses are discussed further in Section 4.3.

3.3 Success Criteria

The treatment approach for the recovered groundwater at Lakeside will be irrigation of recovered groundwater to stands of natrophilic grasses planted on an area north of the landfill (i.e., not overlying primary fill areas) and or on adjoining agricultural lands to the north (see Figure 5-2).

The primary performance criteria for successful land application are as follows:

1) CPECs in the irrigation water must not leach below the root zone of the grass stand, potentially contaminating the groundwater, or accumulate in the soil, and

2) The irrigation must not be deleterious to the agricultural characteristics of the irrigated soils.

3) The irrigation method must not create an operational nuisance, such as propagating off-site odors, mists, etc.

To meet the first criterion, a water balance must be maintained. That is, the rate of stand evaporation and transpiration must equal the rate of irrigation plus precipitation. Estimates of the potential transpiration rates (ET\(_o\)) for candidate grass crops that the rate of water use by the grass stand will be sufficient to maintain a water balance. Moreover, the rate of sodium and chloride uptake by natrophilic grass species will be sufficient such that by the beginning of the rainy season in the Portland area, the sodium and chloride will have already been taken up by the grass and removed from the site in the cuttings (chloride would be the most likely CPEC to leach below the root zone if the water balance was not maintained). If land application is to areas with...
SECTION THREE

Summary of Land Application Treatment, Success Criteria, Adaptive Management Hypotheses, and Management Strategies

no underlying waste, and plant up-take is adequate, infiltration of clean water below the root zone (i.e., infiltrated precipitation) is not problematic. Monitoring during operation (e.g., with suction lysimeters in soil beneath the irrigation area) will demonstrate attenuation.

For the second performance criterion to be achieved, the agronomic characteristics of the irrigated soil must be maintained, with no deleterious accumulation of CEPCs in the root-zone soil of the grass stands. Accumulation of CPECs in the soil could create either adverse salt effects or specific ion effects (i.e., phytotoxicity). In this regard, sodium would be the most likely to adversely impacts the soil physical characteristics or cause phytotoxicity.

Mass balance estimates indicate that a natrophilic grass stand will take up the sodium and chloride. Many of the other CPECs are plant macro- or micro-nutrients and also will be taken up. However, certain minerals would not be taken up by the grass at sufficient rate to keep pace with the rate of mass loading. Specifically, the loading rates of iron (Fe) and manganese (Mn) might result in accumulation of these elements in soil. Therefore, part of a land-application treatment strategy will be to pre-treat the irrigation water to remove iron and manganese by aeration to produce ferric iron ($Fe^{3+}$) and amorphous manganese carbonate (rhodocrosite) followed by routing the resulting water through the constructed treatment wetland.

This section of the FS addendum provides details of an assumed land application treatment regimen. The pilot test described in Section 8 may demonstrate that treatment including aeration, a constructed wetland, compost filtration, or some combination may provide adequate treatment so that land application is not necessary. In that case, treated groundwater would be discharged directly to surface water (e.g., the Tualatin River).

3.4 Adaptive Management Process and Hypothesis

The remedial design/remedial action (RDRA) work plan for Lakeside will follow an adaptive management process. URS is preparing a combined RDRA work plan and adaptive management plan (“RDRA/AMP”) in collaboration with the Northwest Environmental Defense Center (NEDC). Adaptive management is a structured, iterative approach to assessment and decision making for resource management. The term “adaptive management” indicates that management of an environmental system is not fixed from the conceptual outset of the project, but rather it is a process of learning by doing where management strategies are refined and modified based on system performance data acquired during implementation of the project. This FS addendum provides additional discussion of the adaptive management process.

Adaptive management of the Lakeside remedy will apply the following general process:

RAO $\rightarrow$ Chemical/Physical Mechanism(s) $\rightarrow$ Parameter(s) $\rightarrow$ Criteria $\rightarrow$ Monitoring $\rightarrow$ Comparison $\rightarrow$ Adaptive Management

For each element of the selected remedy, one or more hypotheses provides the bases for the process. For the land application system, the hypothesis is:
Extracted groundwater can be land applied to a suitably sized stand of natrophilic grass at hydraulic and constituent loading rates such that the selected crops can take up the constituents (i.e., in the applied groundwater without unacceptable accumulation of the constituents in the soil).

According to the hypothesis, land application at suitable hydraulic and constituent loading rates must not result in the following:

- Accumulation of landfill-related constituents to levels that exceed DEQ standard ecological risk screening values in soil.
- Conditions that are deleterious to growth of either the treatment crop or to future agricultural crops after treatment is complete.
- Soil moisture content greater than field capacity for prolonged periods, resulting in leaching of constituents and degradation of groundwater quality.
- Impacts to groundwater that exceed the RACLs or could be transported to the river at concentrations that would exceed the RACLs or background concentrations.
- Conditions that violate RAO #1 if irrigation occurs on the landfill.

### 3.5 Management Strategies

At Lakeside, “management strategies” are treatment approaches conducted under the adaptive management process to achieve the RAOs. The approach for the treatment of recovered groundwater will be to use the water to irrigate a stand of natrophilic grass established on the areas north of the landfill.

Components of the groundwater treatment approach include the following:

- Water pre-treatment for iron and manganese. Pre-treatment may also significantly attenuate other CPECs and reduce the overall constituent loading to the land application area.
- Water conveyance system.
- Temporary (i.e., non-irrigation season) water storage.
- Irrigation system for the grass stands.
- Crop management protocol for the grass stand involving one or more cuttings and harvests per season. Harvested grass will be removed from the site.
- Irrigation monitoring instrumentation and control protocols.
- Monitoring of soil, plant, and groundwater quality in the land application area.

Regarding mass loading, irrigation loading rates of CPECs to a selected salt-tolerant natrophilic grass will take up the sodium chloride and translocate the salt to the grass shoots (see discussion...
Summary of Land Application Treatment, Success Criteria, Adaptive Management Hypotheses, and Management Strategies

SECTION THREE

in Section 4.3.1). The grass will be managed as an animal feed crop, and grass cuttings (one or more per season) will be removed from the site. Based on assumptions from the literature for biomass production and mineral content in the shoots, and in light of ground water constituent concentrations and Lakeside’s intended application rate, sodium and chloride will not accumulate in the root-zone soil, but will be removed from the site in the grass cuttings. Further, most of the other CPECs (calcium, iron, magnesium, manganese, nitrogen potassium, and zinc) are plant nutrients that will be taken up and incorporated into the plant biomass.

Iron and manganese may not be taken up by the grass at sufficient rates to accommodate the mass loading. Therefore, part of the treatment strategy will be to pretreat groundwater to remove iron and manganese (Section 5.1.2). Pre-treatment to remove iron and manganese will also remove other metals with similar oxidation chemistry and pre-treatment is expected to considerably reduce the mass loading to the irrigation system. The pilot test (see Section 8.0) will verify this assumption. Pre-treatment of iron will also reduce potential for clogging of the spray irrigation system.

3.6 Assumptions

The following assumptions and observations apply to development of the land application system to a level applicable to the FS. The RDARA/AMP will provide additional details of the irrigation system design and it phased implementation.

- Groundwater will be pumped from 12 riverfront extraction wells at a combined rate of approximately 15 gpm. Pumping will occur from late April through September. Groundwater modeling indicates that seasonal pumping will provide adequate capture without having to pump during the winter when ET from land application would be low.

- The expected pumping volume is 3.2 million gallons during the 5-month irrigation season.

- The ratios of CPECs in recovered groundwater will be similar to those in riverfront monitoring wells, but the overall concentrations will be lower by approximately half due to the effects of dilution from the river hyporheic water (river water outside the river channel) and extraction of deeper, cleaner groundwater.

- The extracted groundwater is expected to have an electrical conductivity of 815 µS/cm, and contain sodium at 29 milligrams per liter (mg/L) and chloride at 106 mg/L. Such water used for irrigation will be considered “high salinity” (USDA Handbook 60 Evaluation).

- We estimate that the recovered groundwater can be used to irrigate an 8-acre stand of natrophilic grass established on the northern portion of the landfill without contaminating the groundwater beneath the grass stands, exceeding standards established in the ROD for soil, or damaging the agronomic characteristics of the soils.
SECTION THREE

- The use of natrophilic grasses able to take up and accumulate sodium chloride is an important aspect of the treatment approach because excess sodium has an adverse impact on agricultural soil and chloride is highly mobile.
4.0 CONCEPTUAL MODEL OF LAND APPLICATION TREATMENT AT LAKESIDE

Land application treatment at Lakeside will consist of irrigation of extracted groundwater to a suitable crop. The conceptual model assumes that pre-treated groundwater will be applied to a stand of natrophilic grass that is managed as a forage crop. A pilot study, Phased implementation, and the adaptive management process may indicate that a variety of grasses and other crops may also be suitable.

The grass species will be selected and the irrigation area sized to transpire the applied groundwater and to take up the associated earth metals and salts that are landfill-related constituents in groundwater. The following sections summarize the conceptual model of land application treatment at Lakeside.

4.1 Estimating the Mass Loading of CPECs

The mass of CPECs added to the grass stand per season is a function of the concentrations of the various CPECs in the irrigation water multiplied by the volume per season that the grass stand is irrigated (estimated at up to 3.2 million gallons during the 5-month irrigation season).

The long-term average CPEC concentration in extracted groundwater is uncertain. Routine groundwater monitoring indicates the concentrations of individual CPECs in the various riverside wells (see Table 4-1). Pumping from extraction wells, however, will likely dilute concentrations in riverfront wells with deeper, and relatively cleaner, groundwater and potentially with river water. Therefore, the recovered groundwater will be a mixture of water represented by the well concentrations and water with lower concentrations of CPECs. Not only is the mixing ratio unknown, but the ratio could change as the groundwater pumping proceeds. For purposes of the mass accounting calculations in this document, we assumed that the average concentrations in riverfront wells will be diluted 2-fold.

4.2 Estimating Stand Transpiration and Potential Irrigation Rate

By definition, the transpiration rate of the grass stand will equal ET₀ as described by Allen et al. (1998). The Penman-Monteith equation is used to calculate evapotranspiration (ET₀) for a standard reference crop (well-irrigated 0.4 foot high stand of grass). The meteorological data inputs required for the Penman-Monteith equation include radiation, temperature, humidity and wind speed. Average values for ET₀ in the Portland area are presented in Table 4-2.

The potential irrigation capacity (Iₑ) for the grass stands is calculated as follows:

\[ Iₑ = ET₀ - P \]

where \( P \) = infiltrating precipitation. The average monthly rates of infiltrating precipitation in the Portland area are listed in Table 4-2. The lowest \( Iₑ \) during the irrigation season is 1.9 inches for September. Thus, for the 8 acre stand of grass, the lowest \( Iₑ \) will be 412,700 gallons per month during September.
SECTION FOUR

Conceptual Model of Land Application Treatment at Lakeside

Groundwater will be pumped from the 12 riverfront wells at an approximate average continuous rate of 15 gpm from April or May through the end of September. Accordingly, the monthly rate of production of irrigation water will be 648,000 gallons per month. For a spray irrigation system, typical irrigation efficiency is 60% (i.e., water that actually infiltrates the soil—the reminder is evaporated in the open air after leaving the nozzle or off the surface of the vegetation). Therefore, the actual rate at which water will be delivered to the root zone of the grass stand will be 40% lower than that the amount extracted from the wells.

Based on monthly averages, 8 acres of grass will be sufficient to transpire all of the irrigation water plus precipitation. Depending on the daily distribution of infiltrating precipitation, it also would be possible to irrigate a grass stand with recovered groundwater during April and potentially at much higher rates during some months. For example, if the typical 2.3 inches of infiltrating precipitation occurs during the first week of April, the irrigation control system (see Section 6.1) would allow irrigation during the remaining weeks of April depending on the soil moisture readings.

4.3 Estimating the Rate of Constituent Uptake

Several of the CPECs that will be present in the recovered groundwater are plant nutrients. Nitrogen, calcium, and magnesium are macro-nutrients; chloride, iron, and zinc are micro-nutrients. Barium is not a significant plant nutrient. These nutrients (as well barium) are components of plant tissue. The mass of a given nutrient taken up by a grass stand during a specific time period is a function of the concentration of the nutrient in the plant tissue and the biomass accumulation (stand productivity) during the time period.

4.3.1 Uptake of NaCl by Natrophilic grass species

Plant species are characterized as natrophilic or natrophobic depending on their growth response to sodium. Natrophilic plants have the capacity to accumulate relatively large amounts of sodium in their leaf tissue but have comparatively low concentrations in their roots. In natrophobic plants, sodium preferentially accumulates in the roots and only small quantities of this element are present in the leaf tissue (Smith et al., 1978, 1980, 1983). These differences in plant physiology with respect to sodium are especially marked in grasses and are an important aspect of animal nutrition. For animals, sodium is a major essential element, and many natrophobic plant species do not provide adequate sodium from grazing animals.

Common natrophilic grasses include varieties of perennial ryegrass (Lolium perenne), orchard grass (Dactylis glomerata), barley (Hordeum vulgare), and oats (Avena sativa). Common natrophobic grasses include meadow grass (Poa trivialis), tall fescue (Festuca arundinacea), timothy (Phleum pratense), and brown top (Agrotis tenuis). Each of these grasses generally represents commercially desirable horse and cattle hay sources.
Growth of many natrophilic plants is enhanced by NaCl salinity and the levels of Cl⁻ and Na⁺ in the shoot increases with increasing external supply (Figure 4-1). In contrast to natrophiles, natrophobic species have a low salt tolerance and tend to act as salt “excluders”.

4.3.2 Uptake of Other Landfill-Related Constituents

Most of the CPECs (i.e., calcium, iron, magnesium, manganese, nitrogen, and zinc) are plant nutrients that will be taken up and incorporated into the plant biomass (see Table 4-3 and reference literature). The attenuation capacity of the crop for the constituent is calculated by the constituent concentration in the plant tissue multiplied by the stand productivity.

4.4 Stand Productivity and Estimated Seasonal Uptake

The mass of a given nutrient taken up by a grass stand during a specific time period is a function of the concentration of the nutrient in the plant tissue and the biomass accumulation (stand productivity) during the time period. The grass stand will be managed as a forage crop and grass cuttings (one or more cuttings per season) will be removed from the site. Given that the grass stand is provided with optimal mineral nutrients, three cuttings of a perennial ryegrass stand during the 5-month irrigation season in the Portland area may yield a total shoot biomass of 10,000 kg/acre (Figure 4-2).

A preliminary estimate for CPEC uptake by the grass stand was compared to the seasonal mass loading of CPECs via irrigation with recovered groundwater (Table 4-3). The estimates are based on the following assumptions:

- The irrigation rate = 15 gpm = 3.2 million gallons (12.2 million liters) per season for the 5 months irrigation season (May through the end of September).

- The concentrations of analytes in the recovered groundwater will be a 2-fold dilution of those in the river-front well water.

- Seasonal biomass production for the grass stand will be 10,000 kg/acre.

- Analyte concentrations in the shoots of the natrophilic grass plants (see Table 4-3 and noted references).

- Area of the grass stand will be up to 8 acres. Note that the pilot test described in Section 8 will provide additional information to assess the need for land application.

Based on the assumptions listed above, the grass stand’s seasonal uptake capacity for most of the CPECs will accommodate the estimated seasonal mass of CPECs that would be applied in the irrigation water (Table 4-3). However, iron and manganese not expected be taken up by the grass at sufficient rate to keep pace with the rate of mass loading. Therefore, part of the treatment strategy will include an irrigation water pretreatment step to remove iron, manganese (and other cationic constituents).
4.5 Soil Properties in the Land Application Area

Soil core samples were collected from 0 to 2 feet bgs in each of 13 study plots on the landfill on agricultural lands north of the landfill. Future studies will more thoroughly characterize the soils in the land application area.

Soil water characteristic curves. Soil water characteristic curves (SWCCs) were developed for the 13 soil samples. Data for SWCCs involved analyses of percent gravimetric soil moisture at 0, 10, 100 and 1000 kPa of suction. Estimates were made for $\theta_c$ (field capacity, 33 kiloPascals [kPa]), $\theta_m$ (wilting point, 1,500 kPa), and the average plant-available water storage capacity ($S_a$) for soils from the 13 sampling plots. The $S_a$ is the soil moisture held in cover soils that is available for plant uptake, where $S_a \sim (\theta_c - \theta_m)(L)$, and L is the depth of the soil profile under consideration.

Available water storage capacity, soil texture, bulk density. For the 13 study plots, the average $\theta_c$ was 38.8% by volume, and the average $\theta_m$ was 17.6% by volume. The average $S_a$ was 2.5 inches per foot. The soil texture was a silt loam at 9 of the 13 study plots; three of the plots were silty clay loam, and one plot was a loam. The average soil bulk density for the 13 samples was 113 pounds per cubic foot (lbs/ft$^3$) with a range of 100 to 123 lbs/ft$^3$.

Agronomic characteristics. The agronomic characteristics were determined for the same 13 core samples mentioned above, and the assumption is that the characteristics of the soil samples were representative of soils from the entire landfill area from which the sample was collected. The soil nutrient status was adequate for 5 of the landfill areas, magnesium amendment was required at 3 of the areas, zinc amendment was required for 3 of the areas, copper amendment for one, and both copper and zinc for one.
5.0 LAND APPLICATION

The FS recommended land application for groundwater treatment. This addendum demonstrates the viability of land application, particularly when natrophilic plants are the receiving crop. This addendum also provides additional evaluation of potential on-site treatment alternatives, including aeration, compost filtration, and wetland swales. Note that, while this FS assumes land application will be necessary to achieve the RACLs, if alternative treatment results in adequate water quality (i.e., the RACLs or other treatment standard achieved in the ROD), then land application may not be necessary and direct discharge to the river may be possible. Section 8 further discusses the potential direct discharge alternatives and describes a pilot test to assess treatment efficiency.

5.1 Treatment of Recovered Groundwater

5.1.1 Summary of Recovered Groundwater Treatment Approach

The groundwater treatment system will consist of extraction from 12 riverfront wells, pre-treatment by aeration and natural filtration, conveyance and storage, and land application or alternative treatment if indicated by the proposed pilot test (Section 8). Figure 5-1 shows the general layout of the treatment system.

The estimated extraction rates will be 15 gpm from May through the end of September and parts of April. Extracted groundwater will be spray irrigated to a stand of natrophilic grass located north of the landfill. Irrigation will occur such that a water balance is maintained and the rate of water entering the system via irrigation plus precipitation will be balanced with the rate of water exiting the system by evaporation and transpiration.

The project will treat groundwater to support the following management objectives of the land application system: 1) Remediate the extracted groundwater; 2) Protect the groundwater by preventing unacceptable leaching of CPECs beneath the root zone of the grass stand; and 3) Protect the agricultural characteristics of the soil in the application area. Irrigation will be controlled to meet the objectives and monitoring will assess whether the management objectives are met.

5.1.2 Recovered Groundwater Pre-Treatment

The recovered groundwater is expected to contain and average approximately 18 mg/L iron. This level of iron will exceed the calculated rate of iron uptake by the grass stand. Specifically, the estimated loading rate for iron is be 215 kg iron/season, while the expected iron uptake by the grass stand will be about 12 kg/season, indicating that land application alone would not provide adequate treatment. Moreover, the iron in the recovered groundwater will probably be primarily in the Fe^{2+} (reduced) oxidation state. During spay irrigation, the Fe^{2+} would oxidize to Fe^{3+}, which would precipitate and clog the irrigation system. The proposed pre-treatment process outlined below will remove iron from the recovered groundwater.
The recovered groundwater will be piped to a cascade aerator to oxidize Fe$^{+2}$ to Fe$^{+3}$. Effluent from the aerator containing suspended Fe$^{+3}$ would be filtered in an emergent wetland to remove the particles before being piped to the irrigation system. An emergent wetland containing cattails or similar vegetation will reduce the flow velocity of the water stream and allow the Fe$^{+3}$ particles to settle out and adsorb to the biomass. The wetland will be designed to provide a residence time of 10 to 20 minutes (per standard design guidance) to allow for particulate settling. The swale will contain a suitable soil matrix to establish wetland vegetation, and it will be lined to prevent potential leaching.

### 5.1.3 Treatment Wetlands

Wetlands are ecosystems in areas where water conditions are intermediate between uplands and deep-water aquatic systems (Kadlec and Wallace, 2009). Shallow water conditions in wetlands result in saturated soils and colonization by adapted plant communities. Wetlands, such as those natural systems to be adapted for treatment at Lakeside, have a natural ability to improve water quality.

The general class of wetland proposed in the pilot study is an emergent wetland where plants grow in the saturated soils but emerge through the free water surface. The proposed wetlands for treatment at Lakeside would be colonized by natrophilic wetland species, in which water flows over the soil surface from an inlet point to an outlet. Inflow water containing particulate and dissolved pollutants slows and spreads through a large area of shallow water and emergent vegetation. Particulates settle and are trapped in the sediment due to lowered flow velocities, and tend to enter the biogeochemical element cycles within the water column and surface soils of the wetlands. Metals, nitrogen and phosphorus are taken up by plants or sorbed by soils.

Many natrophilic plants are adapted to wetlands. Emergent wetlands are autotrophic systems with high carbon availability and short diffusional gradients, and the net effect is a general reduction of pollutant concentrations between inlet and outlet of the constructed wetlands. Pollutants assimilation is proportional to the surface area of the wetland.

The fundamental parameters of wetland performance are inlet (Ci) and outlet (Co) contaminant concentrations, volumetric flow rate (Q), wetland area (A) and water depth (h). Wetland water volume is defined as wetland area times depth times porosity, $\varepsilon$.

\[
V = Ah\varepsilon
\]

*Equation 1*

One measure of relative flow rate is the wetland detention time, $\tau$:

\[
\tau = \frac{Ah\varepsilon}{Q} = \frac{\varepsilon h}{q}
\]

*Equation 2*

where $q = Q/A$ is the hydraulic loading rate. The detention time is also equal to the free water depth, $sh$, divided by the flow rate per unit surface area, $q$. Water depth in surface flow wetlands range from 15 to 30 cm and should be adjusted to optimize plant growth.
An emergent wetland system will likely remove a substantial percentage of the iron and manganese in the groundwater. Other cationic CPECs and non-CPEC metals in the groundwater (e.g., sodium, and magnesium) will also be substantially reduced by the pretreatment by complexes that form with the iron floc and organic matter in the wetland. Although substantial removal is expected, the removal efficiencies cannot be easily predicted. A pilot test described in Section 8 will assess the removal efficiency of alternative on-site treatment.

5.1.4 Wetland Design Concepts and Operation

The conceptual wetland will be divided into two parallel cells. The first cell will receive the groundwater stream for a period and then be shut down and the stream routed to the second cell. The estimated dimensions of each of two swales are 60 feet by 15 feet, plus 4:1 side slopes. The net estimated width (per cell) will be approximately 24 feet wide. Final details of the design and proposed species will be developed in the RDRA work plan.

After a period of operation (estimated 2 years), the matrix will be removed from the first cell and disposed of, fresh matrix installed, and the swale cell re-established. After first swale is established, the second will is cleaned and re-established.

5.2 Water Conveyance and Storage

The extracted groundwater will be pumped to a transfer tank and then to a cascading aerator and then flow by gravity to the treatment wetland. If the irrigation system is not operating for short periods (e.g., during mowing and raking and rainy periods during April, May and June), the treated groundwater will be stored in the storage pond.

A lined pond will provide temporary storage of pre-treated water from the treatment wetland. A liner will prevent leakage from the pond. The estimated pond volume is between approximately 60,000 and 80,000 cubic feet, or approximately a one-month storage capacity of groundwater at an extraction rate of 15 gpm. The pond will be located approximately as shown in Figure 5-1. The predictably low CPEC concentrations in the recovered groundwater, and marginal habitat value of the pond, will make a cover on the pond unnecessary.

5.3 Land Application Area

Figure 5-2 shows the available and proposed land application area. The indicated area is approximately 8 acres. The area is north of the landfill and extends on to adjoining agricultural lands currently farmed for Christmas trees and hazelnuts.

The proposed irrigation area is north of the portion of the landfill that was recently graded and covered and includes the active soil stockpile area. Accordingly, significant earthwork is required to bring the area to a smooth final grade. Grabhorn stockpiles clean fill in the stockpile area and will move it to the cover and grade the cover when sufficient fill is available. Grabhorn estimates that sufficient cover soil can be identified and procured in summer 2012 to complete final grading of the land application area.
In the meantime, an approximately 2-acre area of the proposed land application area could be available to initiate treatment (Phase 1 application area; Figure 5-2). Existing trees would be removed and the area prepared for planting in summer 2011, pending final approval of the proposed remediation plan by the DEQ. The RDRA work plan will provide additional discussion and details of the phased implementation of irrigation.

Some pre-treated groundwater may also be irrigated to the landfill cover to provide water to young trees to minimize drought stress in the summer, as part of the landfill cover enhancement construction. We estimate that up to 20 percent of the water would be irrigated to the cover. The extent of irrigation to the cover will depend on the constituent load in the pre-treated groundwater and the expected ability of the cover trees to take up the constituents that remain after pretreatment. Irrigation of landfill cover vegetation will be a temporary component of the remedial action, and only if necessary and only for so long as required to support the rapid development of the new conifer plantings and establishment of an effective root zone.

5.4 Irrigation System

When completely developed and installed, the irrigation system will be divided into zones that will be activated one zone at a time during the irrigation season (May through September and dry periods in April). Cycles will be controlled by an automated irrigation timer.

The CPECs will be taken up by the plants soon after application to the soil. However, in the event of a cool, rainy period during the irrigation season, it might be possible for irrigation to exceed the ET potential of the crop. To minimize this potential, irrigation will be controlled by pairs of soil moisture sensors in each irrigation zone. The sensors will prevent an irrigation cycle from starting, and the zone will not be irrigated, if the soil moisture in the zone is greater than a certain set point (Section 6.1). During these periods, the effluent from the treatment wetland would be routed to temporary storage.

5.5 Preparation

Suitable preparation of the planting area will optimize performance of the land application treatment. The following preparation is recommended:

- Soils in the land application area will be sampled (0 to 2 foot cores samples) on a grid pattern, and soil properties (e.g., available water storage capacity, soil texture, agronomic properties) determined following the same protocols referred to in Section 4.5.

- Herbicide will be applied to the site to kill existing vegetation.

- The irrigation system (and irrigation control system) will be installed and tested (Sections 5.4 and 6.1).

- Based on the analytical data, soils will be amended to optimize grass establishment and growth.
- The land application area will be thoroughly tilled.
- Seed will be planted following standard agricultural procedures.
- Weeds will be controlled by the judicious use of herbicides.

The grass stand will be irrigated as described in Section 5.4. The various grass plots will be managed as forage crops (i.e., they will be cut and the shoots harvested). Cuttings will be removed from the site and subsamples of the cuttings analyzed for CPECs. The final use or disposition of the cuttings will be determined according to standards established in the RDRA/AMP and the ROD.
6.0 PERFORMANCE MONITORING AND DATA COLLECTION

The irrigated grass stand will be monitored to meet the following management objectives: 1) Potential leaching of the CPECs beneath the root zone of the grass will be minimized, thereby protecting the groundwater beneath the stand; 2) The agricultural potential of the soils in the irrigated areas will not be allowed to deteriorate by accumulation of CPECs. Soil concentrations of chemicals of concern will not exceed SLVs or other applicable standards established in the ROD.

Discussion is this section presumes that land application will be part of the remedy. If pilot testing indicates that direct discharge is feasible and is selected by the DEQ, then the monitoring program will be modified for the selected alternative.

6.1 Irrigation and Soil Moisture Control System

The grass stand will be irrigated at the rate of about 1.9 inches per month during the irrigation season (May through September), depending upon actual weather and operating conditions. Based on average weather conditions, the irrigation capacity (Ic) of the grass in September, the month with lowest ET0, is 1.9 inches. Therefore, the rate of water input to the grass stand (water actually infiltrating the planted soil; see discussion in Section 4.2) resulting from irrigation plus precipitation will not exceed ET0 (Table 4-2). The favorable water balance indicates that the potential leaching of CPECs beneath the root zone of the grass stand is unlikely. Depending on the daily distribution of infiltrating precipitation, it also would be possible to irrigate and the grass stand with recovered groundwater during April.

If there is a cool, rainy period during the irrigation season, and if irrigation were to continue, it would be possible for the soil moisture to exceed field capacity. If the percent volumetric soil moisture exceeded field capacity (θc), it would be possible for salts to leach beneath the root zone soil before they are taken up by the grass. Field capacity is tentatively assumed to be 38.8% (see Section 4.5). Future data for the irrigation area will refine this estimate.

Each of the irrigation zones will be controlled by a pair of electrical resistance-type soil moisture sensors. The sensors, installed at 1 and 1.5 feet bgs in each zone, will prevent an irrigation cycle from starting if the average soil moisture is above a certain set point. The sensors will be calibrated to prevent irrigation if the soil moisture is above 38.8%, or another suitable set point.

Water meters will be installed on the main irrigation supply line to track the irrigation volume. Samples of irrigation water will be collected quarterly to quantify the input mass of individual CPECs. Regional weather station data for ET0 and precipitation will be gathered monthly and compared to the long term data listed in Table 4-2. If the monthly values for the weather parameters deviate significantly from the design parameters (e.g., if the Ic value decreased significantly) changes to the irrigation protocol may be indicated.
6.2 Concentrations of CPECs in Grass Cuttings

The grass will be managed as a forage crop and grass cuttings (one or more cutting per season) will be removed from the site. Samples of shoot tissue will be taken for each grass cutting and analyzed for CPECs. Data will be compared to literature values for CPECs assumed in Table 4-3.

6.3 Stand Productivity and Uptake of CPECs

The fresh weight of the grass cuttings from each harvest will be estimated, and percent moisture determined. The mass of a given CPEC taken up during the season will equal the concentration of the CPEC in the plant tissue (mg CPEC/kg dry weight of plant tissue, analyses determined by an analytical lab) multiplied by the biomass accumulation (total dry weight of the cutting).

6.4 Suction Lysimeters

Suction lysimeters will be installed at 3 feet bgs in each of four quadrants of the grass stand area. Samples of soil water will be taken quarterly and analyzed for chloride (one of the most leachable of the CPECs). The performance objective will be to maintain minimal (RACLs or background) levels of chloride in the soil water at 3 feet bgs (see Section 7.0).

6.5 Soil Sampling

Soil samples (0 to 2 feet bgs) will be taken in each of four quadrants of the grass stand area. Soil samples will be analyzed for electrical conductivity, CPECs, and chloride. The performance objective will be to maintain minimal (background) levels of electrical conductivity and chloride (Section 7.0).

6.6 Groundwater Sampling

Three groundwater monitoring wells will be installed in the land application area. One well will be located in the center of the irrigation area and two wells will be located down-gradient on the edge of the fill. The wells will be screened in the water-bearing unit. The existing up gradient well will indicate background groundwater quality. Groundwater samples will be analyzed for CPECs to assess trends.
7.0 ADAPTIVE MANAGEMENT PROCESS

Adaptive management responses are adaptations in the implementation or operation of the treatment system to reflect operating conditions or treatment performance. The three primary performance criteria are 1) that a water balance is maintained and 2) salts do not accumulate in the soil to levels that would exceed SLVs or impair future plantings and crop or tree growth, and 3) no objectionable offsite odors, spray or other effects are created.

To minimize excess irrigation, the irrigation system will be de-activated if soil moisture exceeds certain pre-set values (i.e., if the soil moisture exceeds field capacity), to minimize the potential that the grass stand will be over-irrigated. Therefore, we will know that the soil moisture is in an acceptable range if the irrigation system is activated.

Other performance standards for water balance are as follows:

- The percent volumetric soil moisture will be measured by manual readings in the quadrants of the grass stand using access probes and a soil moisture sensor. These data will be related to the plant available water storage capacity ($S_a$) of the soil (Section 4.5).

- Groundwater quality will be monitored quarterly by a series of three monitoring wells (one well within and two down-gradient) near the grass stand. Background values will be established for the leachable CPECs (e.g., chloride). Average concentrations and standard deviations will be calculated based on the baseline values. Trends in CPEC concentrations (especially chloride concentration and EC) will be noted.
  - Success criterion: The chloride concentration stays within 3 standard deviations of the baseline mean concentration.
  - Trigger condition. If the chloride concentration deviates from the mean value by more than 3 standard deviations, irrigation will be stopped and the system re-evaluated.

- Suction lysimeters will be installed in the quadrants of the land application area at 3-feet bgs (below the root zone of the grass). Samples from the lysimeters will be soil water at that depth and will therefore be sensitive indicators of CPEC leaching below the root zone. Trends in chloride concentrations and EC in the soil water will be noted.
  - Success criterion: The chloride concentration stays within 3 standard deviations of the baseline mean concentration.
  - Trigger condition. If the chloride concentration deviates from the mean value by more than 3 standard deviations, irrigation will be stopped and the system re-evaluated.

Performance standards that relate to the CPEC mass balance involve the monitoring of root zone soils. Soil core samples will be taken from the quadrants of the grass stand on a quarterly basis. Baseline values will be obtained for both soil EC and chloride concentration in the samples, and trends in EC and chloride will be noted.

- Success criterion: The chloride concentration stays within 3 standard deviations of the baseline mean concentration.
- Trigger condition. If the chloride concentration deviates from the mean value by more than 3 standard deviations, irrigation will be stopped and the system re-evaluated.
8.0 PILOT STUDY FOR ALTERNATIVE GROUNDWATER TREATMENT

This section describes a pilot study for treatment technologies as alternatives or additions to land application to the natrophilic grass stands currently identified as the preferred alternative. The technologies selected for further evaluation include those that are potentially suitable for the site CPECs, are adaptable to the site conditions, and are relatively easy and cost-effective to implement and operate. The technologies to be tested in the pilot program include aeration, land application to natrophilic grass, compost filtration, and wetland treatment. A final remedy could include pretreatment followed by land application, or if treatment efficiency assures achievement of the RACLs without land application, the treated water could be directly discharged to the river after treatment. For direct discharge alternatives, the treatment criteria for the CPECs will be the RACLs to be established in the RDRA/AMP and ROD.

8.1 Summary of Pilot Study

The pilot study will simultaneously test five groundwater treatments (Figure 8-1). In all cases, the recovered groundwater will first be routed through an aeration step to oxidize ferrous iron and manganese.

The oxidized water stream then will be split to Treatments 1 through 5 listed below.

- One portion will be routed through a sand filter to remove particulates, specifically ferric iron. The filtered water will then be routed to the following:
  1) Drip-irrigation system of four plots of natrophilic grass species (400 square feet total area);
  2) Compost sorption cell (55 gal drum);
  3) Treatment wetland cell containing natrophilic plants (dimension; 6 feet x 30 feet).

- The unfiltered portion of the water stream will be routed to the following:
  4) Treatment wetland cell (6 feet x 30 feet) containing natrophilic plants; or
  5) Compost sorption cell (55 gal drum).

In Treatment 1, four different candidate natrophilic grass species (each in a 100 square foot plot) will be pilot tested for their ability to take up the minerals dissolved in the aerated/filtered groundwater, and all of the irrigation water will be transpired. Therefore, Treatment 1 is zero-discharge (there will be no effluent water).

In full scale application, Treatments 2 through 5 would generate effluent water that would be discharged directly to the river. For the test, however, treated water will be routed to a spray-irrigation system consisting of an approximately 0.2-acre stand of perennial ryegrass (a natrophilic grass). The objective of the grass irrigation during the pilot test is to transpire the water stream generated from treatment systems, thereby allowing these treatments to be tested with zero-discharge. However, based on the results of the water analytical data, it may be
feasible in a full-scale version of one of these treatments to discharge treated groundwater directly to the Tualatin River (direct discharge alternative) if treatment achieves RACLS.

The expected location of the pilot-scale studies is on a relatively level bench on the southern slope of the landfill above the river, although an alternative location south of the irrigation ponds is also being considered (Figure 8-2).

8.2 Groundwater Extraction

Groundwater for the test will be extracted from three riverfront wells: MW-9, MW-10 and Extraction Well EX1 (see the FS; URS and Parametrix 2010). These wells were selected due to their proximity to each other and to the test site and to generate a representative range of constituent concentrations in the extracted groundwater. The pumping rate from the three wells will vary during the expected 5-month irrigation season, with an estimated seasonal average of 0.42 gpm, which matches the calculated seasonal average evapotranspiration rate ($ET_o$) for the cumulative area of the grass stands proposed for the pilot test.

Groundwater modeling indicates that the mineral concentrations in the recovered groundwater will be diluted by approximately 2-fold, as compared to concentrations detected in nearby monitoring wells. The pilot test will provide data to verify that assumption. Assuming a 2-fold dilution, the recovered groundwater would have an electrical conductivity of 815µS/cm, and contain elevated concentrations of Na (29 mg/L), Cl (106 mg/L) and Fe (17.5 mg/L). Such water used for irrigation would be considered “high salinity” (USDA Handbook 60 Evaluation). Flow rates to each of the test elements will be regulated according to the seasonal extraction rate, the calculated $ET_o$, and the sampling results.

8.3 Sampling

Samples of soils and water will be collected on a determined schedule and analyzed for CPECs and field parameters (conductivity, dissolved oxygen, pH, turbidity, etc.). A sampling plan produced as part of the remedial action plan will develop the details. Samples of soils will be collected from each of the four candidate natrophilic grass plots and from the sediments of the two wetland cells.

Water samples will be collected at the following locations (see Figure 8-1):

- **a**, combined flow from the three wells (up-stream of aerator).
- **b**, effluent from sand filter
- **c**, effluent from compost sorption cell
- **d**, effluent from treatment wetland cell.
- **e**, effluent from compost filtration/sorption cell.
- **f**, effluent from filtration/treatment wetland cell.
8.4 Aeration and Filtration

We expect that iron in the recovered groundwater will be predominantly in the reduced ferrous form (Fe$^{2+}$). Initial aeration will oxidize the iron to Fe$^{3+}$, making it readily removable by filtration and sorption. There are several potential aeration methods. For the pilot tests, a simple cascade aerator (e.g., tricking water over rocks) will likely be a simple and effective method for the pilot study.

Approximately half of the aerated groundwater will be routed directly to Treatments 4 and 5 with the remainder routed through a sand filter before being routed to Treatments 1 to 3. The sand filter will be designed to remove suspended solids, including Fe$^{3+}$.

8.5 Treatment 1: Land Application to Natrophilic Grass

The pretreated groundwater (effluent from the sand filter) will be used to drip-irrigate each of four test plots containing four candidate natrophilic grass species (flow path 1; Figure 8-1). Drip irrigation is proposed for the pilot test—as opposed to spray irrigation for the full scale system—to more closely control the loading rates. Each of the four plots will be about 100 square feet. Suction lysimeters will be installed in each plot at a depth of 2.5 foot the below ground surface.

A water balance will be maintained for the pilot plots. Water input from irrigation and precipitation will be matched to the expected transpiration rate for the grass plots to minimize the leaching of dissolved minerals below the root zone of the plants. Water meters on the irrigation lines will record water added to the plots, and grass cuttings will be removed from the plots per season for analysis. The concentration of CPECs will be tested in the plant tissue and the mass of minerals taken up will be calculated. Soil samples will be taken at specified time intervals, and the mass of minerals accumulating in the soils will be calculated. The criteria for the successful application of Treatment 1 would be that there would be no leaching of irrigation water beneath the root-zone of the grass stands, and that there would be no significant accumulation of CPECs nor sodium or other potentially deleterious constituent in the root-zone soil.

8.5.1 Preliminary Soils Characterization

Soils within the test plots will be characterized as follows:

- Soil water characteristic curves (SWCCs) will be determined for the soil samples (data for percent gravimetric soil moisture at 0, 10, 100 and 1000 kPa of suction). These data will allow calculation of field moisture capacity, $\theta_c$.

- Available water storage capacity and soil texture will be analyzed, $(\theta_c - \theta_m)(L)$, where $\theta_m$ is the soil moisture at 1,500 kPa and $L$ is the thickness of the soil profile (2 feet).

- The agronomic characteristics will be determined and soils will be amended (fertilized) based on these analyses. Background values for each of the CPECs will be determined.
8.5.2 Estimated Transpiration Rates

By definition, the transpiration rate of the grass stand will equal ET₀. As described by Allen et al. (1998), the Penman-Monteith equation is used to calculate evapotranspiration (ET₀) for a standard reference crop (well-irrigated 0.4 foot high stand of grass). The meteorological data inputs required for the Penman-Monteith equation include radiation, temperature, humidity and wind speed. Average values for ET₀ in the Portland area are presented in Table 8-1. The potential irrigation capacity (I_c) for the tree stands is calculated as follows:

\[ I_c = ET_o - P \]

where P = infiltrating precipitation. The average monthly rates of infiltrating precipitation in the Portland area are listed in Table 8-1 (similar to Table 4-2 but transpiration is expressed in units liters per 100 square feet or irrigation area). To maintain a water balance, the rate of water input to the grass stand resulting from irrigation plus precipitation will be balanced against the predicted ET₀.

8.5.3 Irrigation System.

Four 100 square foot drip-irrigation zones will be set up, one for each natrophilic grass plot. Each zone will consist of a network of drip lines containing about 80 drip emitters. Water from the sand filter will be routed to a holding tank. When the system is activated, water will be pumped from the tank to an irrigation zone (plot) at a rate of about 0.5 gpm. Irrigation in each zone will be controlled by a pair of electrical resistance-type soil moisture sensors. The moisture sensors, installed at 1 and 1.5 feet below the ground surface in each zone, will prevent an irrigation cycle for starting if the average soil moisture is above a certain set point. The moisture sensors will be calibrated to prevent irrigation if the soil moisture is greater than θ_c. Water meters will be installed on the main irrigation supply line to track the volume of recovered groundwater that is applied to the grass stand.

8.5.4 Performance Monitoring and Data Collection

Following are examples of expected performance data and analysis:

- **Concentrations of CPECs in Grass Cuttings.** The grass would be managed as a forage crop and grass cuttings (one or more cuttings per season) would be removed from the plots. Samples of shoot tissue will be taken for each grass cutting and analyzed for CPECs. Data will be compared to literature values for CPECs assumed in Table 8-2.

- **Stand Productivity.** The fresh weight of the grass cuttings from each harvest will be estimated, and percent moisture determined. Given that the grass stand is provided with optimal mineral nutrients, three cuttings of a perennial ryegrass stand during the 5 month irrigation season in the Portland area may yield a total shoot biomass of 10,000 kg/acre, or 23 kg/100 square foot plot (Figure 4-2).
- **Rate of CPEC Uptake.** The mass of a given CPEC taken up during the season will equal the concentration of the CPEC in the plant tissue (mg CPEC/kg dry weight of plant tissue, analyses determined by an analytical lab) multiplied by the biomass accumulation (total dry weight of the cutting). The seasonal mass loading of CPECs is compared to the estimated stand uptake in Table 8-2. For all of the analytes except Fe and Mn, the seasonal uptake by the grass is nearly equal to the mass loading. However, the recovered groundwater would undergo pre-treatment for iron removal, and the excess manganese will precipitate in the root zone soil as amorphous manganese carbonate (rhodocrosite). Moreover, the rate of uptake of sodium and chloride is expected to increase if the concentration in the root-zone soil increases (Figure 4-1).

- **Suction Lysimeters.** Suction lysimeters will be installed at 2.5 feet below ground surface in each of the four grass plots. Samples of soil water will be taken on a regular basis and analyzed for the presence of Cl (one of the most leachable of the CPECs). The performance objective will be to maintain minimal (background) levels of chloride in the soil water at 2.5 feet bgs.
  - Success criterion: If the chloride concentration stays within 3 standard deviations of the baseline mean concentration.
  - Trigger condition. If the chloride concentration deviates from the mean value by more than 3 standard deviations, the rate of irrigation will be appropriately reduced.

- **Soil Sampling.** Soil samples (0 to 2 foot soil cores) will be taken in each of the four plots. Soil samples will be analyzed for electrical conductivity, CPECs, and sodium. The performance objective will be to maintain minimal (background) levels of electrical conductivity and CPECs.
  - Success criterion: If the CPEC and sodium concentration stays within 3 standard deviations of the baseline mean concentration (especially for calcium, magnesium, and zinc; see Table 8-2).
  - Trigger condition. If the CPEC and sodium concentration deviates from the mean value by more than 3 standard deviations, the rate of irrigation will be appropriately reduced.

### 8.6 Treatments 2 and 5: Compost Filtration

Extracted groundwater will be routed to 55 gallon drums packed with a mix of sand and compost from the Grabhorn composting operation. For Treatment 2, pretreated groundwater (effluent from the sand filter) will be routed to the “Compost Sorption Cell” (Figure 8-1). For Treatment 5, unfiltered water from the aerator will be routed to the “Compost Filtration/Sorption Cell”. Based on the discussion below, the design flow rate for the combined Treatments 2 and 5 is 0.1 gpm.

#### 8.6.1 Treatment 2: Compost Filtration After Sand Filter

The rationale for testing Treatment 2 is that compost predictably has a very high capacity to sorb inorganic compounds and it is readily available at the site. The aerated filtered water should pass readily through the compost/sand and sorption of CPECs may occur to sufficient extent that
direct discharge of the treated water to the river may be possible. The following parameters would be tested in the pilot study:

- **Hydraulic conductivity of the compost.** At what rate can water percolate through the 55 gal drum (2.9 foot high, 2 foot diameter) packed with compost? Given the cross sectional area of the drum and an approximately 1 inch hydrostatic head, what flow rate can be obtained? How does the flow rate change as a function of time? An estimate for flow rate based on preliminary assumptions was calculated using Darcy’s law:

\[ Q = K (d_w) \frac{A}{d_s} \]  

*Equation 4*

were, \( K = \) hydraulic conductivity, \( d_w = \) depth of water, \( A = \) area, \( d_s = \) depth of compost. Inserting assumed values into this equation: \( K = 3 \) feet/d; \( d_w = 2.9 \) feet; \( A = 3.14 \) square feet; \( d_s = 2.7 \) feet; \( Q = 0.05 \) gpm.

- **Sorptive capacity of the compost.** The effluent from the sand filter (input water) will contain a mixture of CPECs, and each CPEC will have a background concentration. The effluent from the Compost Sorption Cell (output water) will also contain a mixture of CPECs. For each specific CPEC, what is the concentration ratio in the output/input water? What is the percent removal for each CPEC? How does removal efficiency change after 3, 5, 10, and 20 pore volumes of water percolates through the cell?

### 8.6.2 Treatment 5: Compost Filtration without Sand Filter

Treatment 5 builds on that for Treatment 2 by testing three additional questions:

- How effective is the compost filtration/sorption cell compared to the sand filter for removal of suspended solids, including Fe\(^{+3}\)? Does Fe\(^{+3}\) break through?

- How does the hydraulic conductivity of the compost filtration/sorption cell compare to that of the compost sorption cell? Do suspended solids clog the pores and reduce the flow rate? How does the flow rate change as a function of time?

- What is the percent removal for each CPEC? How does removal efficiency change after 3, 5, 10, and 20 pore volumes of water percolates through the cell?

### 8.7 Treatments 3 and 4: Natrophilic Wetland

Extracted groundwater will be routed to treatment wetland cells containing natrophilic wetland plants. For Treatment 3, pretreated groundwater (effluent from the sand filter) will be routed to a wetland. For Treatment 4, unfiltered water from the aerator will be routed to a parallel cell. The wetland cells, 6 feet wide and 30 feet long (water 6 inches deep on average), will be exactly the same for both treatments. In order to allow sufficient time for NaCl uptake by the natrophilic wetland species, the detention time will be approximately 1 day, thus using (*Equation 1*:)

\[ \tau = \frac{A \epsilon}{Q} = \frac{(180 \text{ ft}^2)(0.5 \text{ ft})(0.3)}{(29 \text{ ft}^3/\text{d})} = 0.93 \text{d} \]
8.7.1 Treatment 3: Wetland with Sand Filter

The rationale for testing the Treatment 3 is that the natrophilic plants have a considerable capacity to remove NaCl, and the other CPECs may also be removed by the wetland system. The extent of CPEC removal (especially chloride) may be sufficient that direct discharge of the treated water to the river may be possible. The following parameters will be tested in the pilot study:

- Inflow vs. outflow concentrations of CPECs (including NaCl) will be compared, and percent removal for each CPEC will be calculated.
- The detention time will be varied, if necessary, by decreasing flow (Q) to increase the extent of NaCl removal.

8.7.2 Treatment 4 Wetland without Sand Filter

Treatment 4 builds on Treatment 3 by testing the effectiveness of the wetland system to remove suspended solids. How effective is the wetland, compared to the sand filter, for removal of suspended solids, including Fe^{+3}?

8.8 Transpiration of Effluent Water

Treatments 2 through 5 will generate effluent water. These water streams will be combined and routed to an irrigation system for a 0.2 acre grass stand containing a specific natrophile (e.g., perennial ryegrass). The objective of the grass irrigation is to transpire the combined water streams, thereby allowing these systems to be tested with zero-discharge. Treated water may also be irrigated to the cover. As indicated in Figure 8-1, the water streams from the various test systems will be routed to a holding tank. A pump system, operated on a sprinkler system timer, will pump the water to rain-bird-type sprinkler heads installed on the grass stand. Based on estimates presented in Table 8-1, the rate of water use by the 0.2-acre stand will be sufficient to use the water stream. The NaCl contained dissolved in the water predictably will be taken up into the shoots. The grass will be cut, and the cuttings removed from the site.

8.9 Selection of Alternative

The results of the pilot study will indicate the treatment efficiency of the treatment alternatives. We assume that the criteria for potential direct discharge alternatives would be the RACLs (Section 1.1). If the pilot test indicates that treatment can achieve the RACLs, then the most cost-effective and implementable of the direct discharge alternatives would be proposed. If treatment efficiency were inadequate or still uncertain, then a phase 1 implementation of land application to natrophilic grass would be proposed. Phase 1 would consist of preparation and land application to approximately 2 acres until the full 8-acre area could be prepared and planted (see figure 5-1). In either case, the RDRA work plan and the DEQ ROD would specify details of the selected remedy.
9.0 REFERENCES


Smith, G. S., K. R. Middleton, and A. S. Edmonds. 1978. A classification of pasture and fodder plants according to their ability to translocate sodium from their roots into aerial parts. N. Z. Journal of Experimental Agriculture. 6:183-188.


### Table 1-1
Remedial Action Concentration Limits  
Feasibility Study Addendum  
Lakeside Reclamation Landfill

<table>
<thead>
<tr>
<th>Chemicals of Potential Ecological Concern</th>
<th>Water Quality Criteria</th>
<th>Tualatin River Concentrations</th>
<th>Proposed Remedial Action Concentration Limit (mg/l)</th>
<th>rationale/basis of limit</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>DEQ Level II Screening Level Values - surface water fresh aquatic (mg/l)</td>
<td>Table 20 water quality criteria - fresh acute criteria (mg/l)</td>
<td>Table 20 water quality criteria - fresh chronic criteria (mg/l)</td>
<td>EPA national recommended fresh water quality criteria (1) (mg/l)</td>
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<tr>
<td>ammonia</td>
<td>0.017</td>
<td>pH &amp; temp dependent</td>
<td>0.159</td>
<td>0.176</td>
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<td>beryllium</td>
<td>0.004</td>
<td>nl</td>
<td>0.017</td>
<td>0.021</td>
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<td>calcium</td>
<td>116</td>
<td>nl</td>
<td>15.5</td>
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<td>chloride</td>
<td>nl</td>
<td>860</td>
<td>230</td>
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<td>0.018+</td>
<td>0.012+</td>
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</table>

Notes:
The DEQ has not issued its final staff report and the final RACLS and the concentration limits might change from those shown here.
Chemical of Potential Ecological Concern identified in Section 5.12 of the Screening-Level Human Health Risk Assessment & Level II Screening Ecological Risk Assessment revised July 30, 2009.
bolded value - indicates apparent water quality screening level based on DEQ's June 6, 2008 stated standards hierarchy application method.
nl - a value is not listed on Table 20 (or associated Tables 33A, 33B, or 33C) (OAR 340-041).
na - data not available.
+ - indicates criteria value is hardness dependent and determined using formulae at bottom of Table 20.
Dissolved species - detected concentrations of calcium, iron, magnesium, and manganese represent dissolved species.
Total species - detected concentrations of barium, beryllium, copper, and zinc are total species.
(1) EPA (2006) national recommended water quality criteria, freshwater, continuous chronic concentration (mg/l)
(2) Tualatin River site-specific concentration based on mean concentrations as presented in Table 3-10 in 9/15/09 draft RI Report.
(3) Tualatin River mean concentration reported at DEQ Elsner Road sample station 10458.

- : Exceeded in Tualatin River up-stream of landfill site.
- : Also exceeded in up-gradient well MW-UG1.
- : Typically exceeded at MW-3 or MW-4 where galvanized pipe may have been used in well construction.
<table>
<thead>
<tr>
<th>Analytes</th>
<th>Average concentration in riverfront wells (mg/l)</th>
<th>Estimated discharge water concentration (mg/l)</th>
<th>Recovered Groundwater (mg/l)</th>
<th>AWQC (mg/l)</th>
<th>DEQ Groundwater Quality Reference or Guidance Level (mg/l)</th>
<th>Average Up-Gradient Well Concentration (mg/l)</th>
<th>Average Up-Stream River Concentration (mg/l)</th>
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<td>Ammonia</td>
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<td>113.0</td>
<td>84.8</td>
<td>45</td>
<td>82</td>
<td>nl</td>
<td>7.2</td>
<td>4.18</td>
</tr>
<tr>
<td>Manganese</td>
<td>5.2</td>
<td>3.9</td>
<td>4.1</td>
<td>0.120</td>
<td>0.05</td>
<td>0.06</td>
<td>0.094</td>
</tr>
<tr>
<td>pH</td>
<td>6.6</td>
<td>6.6</td>
<td>nl</td>
<td>6.5 to 7.5</td>
<td>6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td>5.9</td>
<td>4.4</td>
<td>2.50</td>
<td>53</td>
<td>nl</td>
<td>1.90</td>
<td></td>
</tr>
<tr>
<td>Silica</td>
<td></td>
<td></td>
<td></td>
<td>31.5</td>
<td>nl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>71.8</td>
<td>53.9</td>
<td>28.5</td>
<td>680</td>
<td>nl</td>
<td>8.1</td>
<td></td>
</tr>
<tr>
<td>TOC</td>
<td>57.0</td>
<td>42.8</td>
<td>nl</td>
<td>nl</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td>134</td>
<td>101</td>
<td>nl</td>
<td>nl</td>
<td>1020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>1.2 (*)</td>
<td>0.9</td>
<td>0.5</td>
<td>0.120</td>
<td>5.0</td>
<td>0.028</td>
<td>0.0076</td>
</tr>
</tbody>
</table>

See table notes next page
Notes:
Analytes listed are parameters of interest associated with treatment of extracted groundwater. Non-italicized parameters are not identified CPECs.

Average concentration in riverfront wells: based on 2006 thru 2010 results from wells 3, 4, 8, 9, 10, & 11.
Estimated discharge water concentrations: assumes 25% dilution of average riverfront concentration.
AWQC are OAR 340-041 Table 20 values or if not available, DEQ's Ecological Risk Level II Screening Level Value.
Recovered groundwater assume 2-fold dilution of estimated discharge water concentration.
Average up-gradient well concentration: average concentrations detected in monitoring well MW-UG1.
Average up-stream river concentration: average concentrations detected at DEQ's Elsner Road sample station 10458 located at rivermile 25.1 upstream of Lakeside which is situated between rivermiles 21 and 22.

(1) Average nitrate concentration is ~3.0 mg/l.
(2) DEQ 2/1/11 Proposed arsenic concentration for human health fish consumption. Current value is 0.000175 mg/l.
* Average concentration in riverfront wells. Average zinc concentration is 0.0291 mg/l if samples from MW-3 and MW-4 are not included. Use of galvanized pipe in wells MW-3 and MW-4 considered to be source of elevated zinc detected in these two wells.

TDS, TSS, TOC, & pH concentrations provided for treatment related information.
nl - a value is not listed.
<table>
<thead>
<tr>
<th>Technology</th>
<th>Effectiveness (H, M, L) (1)</th>
<th>Implementability (easy to difficult)</th>
<th>Comments</th>
<th>Cost (M$)</th>
<th>Retained Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Landfill Cover</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing ET cover (no action alternative)</td>
<td>Low to Medium</td>
<td>Easy</td>
<td>Low to medium effectiveness due to incomplete implementation of the closure. Certain enhancements are necessary to improve performance.</td>
<td>$2.0 M</td>
<td>No</td>
</tr>
<tr>
<td>Enhanced ET landfill cover</td>
<td>High</td>
<td>Moderate</td>
<td>An enhanced ET cover is specified by the facility closure permit and the DEQ Cleanup Program. The enhanced ET cover will be effective and relatively easy and inexpensive to implement, as compared to an impermeable cap.</td>
<td>$2.3 M</td>
<td>Yes</td>
</tr>
<tr>
<td>Impermeable cover</td>
<td>High</td>
<td>Difficult</td>
<td>The very high cost of an impermeable cover are not warranted or required.</td>
<td>$8.0 M</td>
<td>No</td>
</tr>
<tr>
<td><strong>Mitigation Barrier</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative 1</td>
<td>Medium</td>
<td>Easy</td>
<td>There is no evidence that landfill-related constituents have impacted the river. Constituents are present in groundwater at concentrations greater than RACLs.</td>
<td>$01.2M</td>
<td>No</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>High</td>
<td>Moderate</td>
<td>Groundwater extraction is effective and reliable. Groundwater extraction wells are well understood and implementable.</td>
<td>$4.9 M (2)</td>
<td>Yes</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>High</td>
<td>Moderate to Difficult</td>
<td>Challenges and cost of horizontal drilling and deep trenching may make horizontal wells and trenches impractical and less cost effective than wells.</td>
<td>$5.2 M</td>
<td>No</td>
</tr>
<tr>
<td>Alternatives 4 &amp; 5</td>
<td>Low</td>
<td>Moderate</td>
<td>An impermeable barrier would cut off groundwater flow. Impacted groundwater would not be treated. Construction costs are high and groundwater extraction and treatment would still be required.</td>
<td>$3.2 M to $6.3 M</td>
<td>No</td>
</tr>
<tr>
<td>Alternative 6</td>
<td>Uncertain to High</td>
<td>Moderately Difficult</td>
<td>PRBs are a proven technology for in-situ groundwater treatment. Selection of treatment media would require bench and pilot testing. Deep construction would be moderately difficult and expensive. It may not be possible to construct a barrier deep enough to key into the Helvetia clay.</td>
<td>$23.0M</td>
<td>Yes</td>
</tr>
</tbody>
</table>
### Table 2-1
Summary of Alternatives Screening
Feasibility Study Addendum
Lakeside Reclamation Landfill

<table>
<thead>
<tr>
<th>Technology</th>
<th>Effectiveness (H, M, L) (1)</th>
<th>Implementability (easy to difficult)</th>
<th>Comments</th>
<th>Cost (M$)</th>
<th>Retained Yes/No</th>
</tr>
</thead>
</table>
| **Alternative 7**  
Phytoremediation by deep-rooted trees (3) | Uncertain pending additional analysis | Easy | A phytoremediation barrier could be an effective method to control ground-water and minimize potential transport of constituents. However, due to DEQ’s uncertainties about the treatment depth and space (concerns that have not been proven by analysis), DEQ concluded that a phyto-remediation barrier should not be carried through in the FS as a stand-alone technology. | $3.0 M | Yes |

**Treatment and Disposal of Extracted Groundwater**  
(applicable to groundwater pumping alternatives)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Effectiveness</th>
<th>Implementability</th>
<th>Comments</th>
<th>Cost (M$)</th>
<th>Retained Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>No treatment</td>
<td>Low</td>
<td>Easy</td>
<td>No treatment. Constituent concentration in groundwater are sufficiently high that treatment is necessary.</td>
<td>N/A (4)</td>
<td>No</td>
</tr>
<tr>
<td>On-site chemical-physical treatment, NPDES discharge</td>
<td>Medium to High</td>
<td>Difficult</td>
<td>The treatment processes are maintenance intensive, expensive and subject to upset.</td>
<td>N/A (4)</td>
<td>No</td>
</tr>
<tr>
<td>On-site aeration, filtration, and wetland treatment, direct discharge</td>
<td>High to uncertain</td>
<td>Easy</td>
<td>The treatment processes are reliable, sustainable and relatively easy to implement. Treatment efficiency for direct discharge is uncertain. A pilot test will assess treatment efficiency.</td>
<td>N/A (4,5)</td>
<td>Yes</td>
</tr>
<tr>
<td>Non-discharge land application (e.g., spray irrigation)</td>
<td>High to uncertain</td>
<td>Easy</td>
<td>Treatment effectiveness of most constituents is high. Pilot test needed to assess uptake by alternative natrophilic grass species. Implementation would be easy and relatively inexpensive.</td>
<td>N/A (4,6)</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Notes:**
- Recommended alternative. FS assumed that land application would be required. This addendum considers a direct discharge alternative.
- H, M, L = High Medium, and Low effectiveness.
- Cost updated from FS.
- Retained for possible future consideration as a polish technology or in combination with other treatment.
- Treatment and disposal costs are incorporated into applicable alternatives (Alternatives 2, 3, and 5).
- Added in the addendum to reflect additional analysis and the DEQ’s request.
- The FS described land application to conifers. This addendum describes land application to natrophilic grass.
### Table 4-1
Average Mineral Composition of Groundwater in Riverfront Wells
Feasibility Study Addendum
Lakeside Reclamation Landfill

<table>
<thead>
<tr>
<th>Monitoring wells</th>
<th>Analyte (mg/L)</th>
<th>TDS (mg/L)</th>
<th>EC (µS/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ba</td>
<td>Ca</td>
<td>Cl</td>
</tr>
<tr>
<td>River front</td>
<td>0.3</td>
<td>194</td>
<td>212</td>
</tr>
<tr>
<td>Up-gradient</td>
<td>0.1</td>
<td>17.8</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Notes:
Average values for the 8 riverfront wells (3, 4, 6 – 11) are compared to an up-gradient well (UG-1).

Analytes K, Si, Na and parameters TDS and EC are not CEPCs but used as indicator parameters for treatment analysis.

### Table 4-2
Estimates of Potential Transpiration (ETₒ) for Grass Stand in Portland, OR
Feasibility Study Addendum
Lakeside Reclamation Landfill

<table>
<thead>
<tr>
<th>Month</th>
<th>Pan Evap.</th>
<th>ETₒ</th>
<th>Infiltrated Precipitation (P)</th>
<th>Potential irrigation capacity (Iₑ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inches</td>
<td>inches</td>
<td>inches</td>
<td>inches</td>
</tr>
<tr>
<td>Jan</td>
<td>1.1</td>
<td>0.9</td>
<td>3.3</td>
<td>--</td>
</tr>
<tr>
<td>Feb</td>
<td>1.5</td>
<td>1.2</td>
<td>2.7</td>
<td>--</td>
</tr>
<tr>
<td>Mar</td>
<td>2.2</td>
<td>1.8</td>
<td>2.6</td>
<td>--</td>
</tr>
<tr>
<td>Apr</td>
<td>3.1</td>
<td>2.5</td>
<td>2.3</td>
<td>0.2</td>
</tr>
<tr>
<td>May</td>
<td>4.7</td>
<td>3.8</td>
<td>1.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Jun</td>
<td>5.8</td>
<td>4.6</td>
<td>1.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Jul</td>
<td>7.5</td>
<td>6.0</td>
<td>0.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Aug</td>
<td>6.1</td>
<td>4.9</td>
<td>0.7</td>
<td>4.2</td>
</tr>
<tr>
<td>Sep</td>
<td>3.9</td>
<td>3.1</td>
<td>1.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Oct</td>
<td>2.1</td>
<td>1.7</td>
<td>2.0</td>
<td>--</td>
</tr>
<tr>
<td>Nov</td>
<td>1.3</td>
<td>1.0</td>
<td>3.4</td>
<td>--</td>
</tr>
<tr>
<td>Dec</td>
<td>0.9</td>
<td>0.7</td>
<td>3.7</td>
<td>--</td>
</tr>
</tbody>
</table>

Notes:
Estimates for pan evaporation are for Portland, Oregon (NOAA Tech. Report, NWS 34). ETₒ is estimated from pan evaporation data (ETₒ = pan evap. X 0.8). Monthly infiltrating precipitation was estimated assuming 15% of total is intercepted and evaporates directly from leaves. Iₑ = ETₒ – P (Equation 1)

September: 15 gpm = 2 ft³/min = 86,600 ft³/month over 8 acres = 0.24 feet = 3.0 inches. Assume 60% irrigation efficiency and 20% irrigation to cover = : 1.4 inches irrigation + 1.2 inches precipitation = 2.6 inches water input vs. ETₒ = 3.1 inches.
### Table 4-3
Seasonal CPEC Mass Loading Compared to Estimated Stand Uptake
Feasibility Study Addendum
Lakeside Reclamation Landfill

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Recovered groundwater mg/L</th>
<th>Mineral loading rate kg/season</th>
<th>Mineral content of grass stand mg/kg DW</th>
<th>Reference</th>
<th>Mineral uptake by grass stand kg/acre/season</th>
<th>Stand area for complete mineral uptake acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ba</td>
<td>0.15</td>
<td>1.8</td>
<td>40</td>
<td>Markert, 1992</td>
<td>0.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Ca</td>
<td>97</td>
<td>1,180</td>
<td>13,000</td>
<td>Smith et al., 1983</td>
<td>130</td>
<td>9.1</td>
</tr>
<tr>
<td>Cl</td>
<td>106</td>
<td>1,290</td>
<td>20,000</td>
<td>Garthwaite et al., 2005</td>
<td>200</td>
<td>6.5</td>
</tr>
<tr>
<td>Fe</td>
<td>17.5</td>
<td>215</td>
<td>150</td>
<td>Markert, 1992</td>
<td>1.5</td>
<td>140</td>
</tr>
<tr>
<td>Mg</td>
<td>45</td>
<td>550</td>
<td>5,000</td>
<td>Smith et al., 1983</td>
<td>50</td>
<td>11</td>
</tr>
<tr>
<td>Mn</td>
<td>4.1</td>
<td>50</td>
<td>200</td>
<td>Smith et al., 1983</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>N</td>
<td>0.7</td>
<td>8.5</td>
<td>40,000</td>
<td>Smith et al., 1983</td>
<td>400</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>K</td>
<td>2.5</td>
<td>31</td>
<td>35,000</td>
<td>Smith et al., 1983</td>
<td>350</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Si</td>
<td>31.5</td>
<td>385</td>
<td>5,000</td>
<td>Marschner, 1995</td>
<td>50</td>
<td>8.0</td>
</tr>
<tr>
<td>Na</td>
<td>28.5</td>
<td>350</td>
<td>4,000</td>
<td>Smith et al., 1983</td>
<td>40</td>
<td>8.75</td>
</tr>
<tr>
<td>Zn</td>
<td>0.5</td>
<td>6.1</td>
<td>50</td>
<td>Smith et al., 1983</td>
<td>0.5</td>
<td>12.2</td>
</tr>
</tbody>
</table>

Notes:
Mineral content in recovered groundwater assumed to be 2-fold dilution typical concentrations in riverfront wells. Biomass production for grass stand assumed to be 10,000 kg/acre/season. It is assumed that: the recovered groundwater would undergo pre-treatment for iron removal. The excess manganese would precipitate in the root zone soil as amorphous manganese carbonate (rhodocrosite).

Ammonium nitrogen (NH₄), K, Si, and Na are not CPECs but analytes of interest to evaluate land application treatment effectiveness.
Table 8-1
Estimates of Potential Transpiration ($ET_o$) for Test Plots
Feasibility Study Addendum
Lakeside Reclamation Landfill

<table>
<thead>
<tr>
<th>Month</th>
<th>Pan Evap.</th>
<th>$ET_o$ (inches)</th>
<th>Infiltrated Precipitation (P)</th>
<th>Potential Irrigation Capacity ($I_c$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1.1</td>
<td>0.9</td>
<td>3.3</td>
<td>--</td>
</tr>
<tr>
<td>Feb</td>
<td>1.5</td>
<td>1.2</td>
<td>2.7</td>
<td>--</td>
</tr>
<tr>
<td>Mar</td>
<td>2.2</td>
<td>1.8</td>
<td>2.6</td>
<td>--</td>
</tr>
<tr>
<td>Apr</td>
<td>3.1</td>
<td>2.5</td>
<td>2.3</td>
<td>0.2</td>
</tr>
<tr>
<td>May</td>
<td>4.7</td>
<td>3.8</td>
<td>1.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Jun</td>
<td>5.8</td>
<td>4.6</td>
<td>1.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Jul</td>
<td>7.5</td>
<td>6.0</td>
<td>0.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Aug</td>
<td>6.1</td>
<td>4.9</td>
<td>0.7</td>
<td>4.2</td>
</tr>
<tr>
<td>Sep</td>
<td>3.9</td>
<td>3.1</td>
<td>1.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Oct</td>
<td>2.1</td>
<td>1.7</td>
<td>2.0</td>
<td>--</td>
</tr>
<tr>
<td>Nov</td>
<td>1.3</td>
<td>1.0</td>
<td>3.4</td>
<td>--</td>
</tr>
<tr>
<td>Dec</td>
<td>0.9</td>
<td>0.7</td>
<td>3.7</td>
<td>--</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>4,054</td>
</tr>
</tbody>
</table>

Notes:
Estimates for pan evaporation are for Portland, Oregon (NOAA Tech. Report, NWS 34).
$ET_o$ is estimated from pan evaporation data ($ET_o = \text{pan evap. } \times 0.8$). Monthly infiltrating precipitation was estimated assuming 15% of total is intercepted and evaporates directly from leaves. $I_c = ET_o - P$ (Equation 1). The drip-irrigation system would deliver about 2 L per minute (0.53 gpm) when activated. In July, for example, the irrigation system would run about 20 minutes per day (delivering 10.6 gal) to keep pace with stand transpiration.
Table 8-2  
Seasonal CPEC Mass Loading and Estimated Stand Uptake for Test Plots  
Feasibility Study Addendum  
Lakeside Reclamation Landfill

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Recovered groundwater</th>
<th>Mineral loading rate</th>
<th>Mineral content of grass stand</th>
<th>Mineral uptake by grass stand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/L</td>
<td>g/season</td>
<td>mg/kg DW</td>
<td>g/100 ft²/season</td>
</tr>
<tr>
<td>Ba</td>
<td>0.15</td>
<td>0.61</td>
<td>40</td>
<td>Markert, 1992</td>
</tr>
<tr>
<td>Ca</td>
<td>97</td>
<td>393</td>
<td>13,000</td>
<td>Smith et al., 1983</td>
</tr>
<tr>
<td>Cl</td>
<td>106</td>
<td>430</td>
<td>20,000</td>
<td>Garthwaite et al., 2005</td>
</tr>
<tr>
<td>Fe</td>
<td>17.5</td>
<td>71</td>
<td>150</td>
<td>Markert, 1992</td>
</tr>
<tr>
<td>Mg</td>
<td>45</td>
<td>182</td>
<td>5,000</td>
<td>Smith et al., 1983</td>
</tr>
<tr>
<td>Mn</td>
<td>4.1</td>
<td>16.6</td>
<td>200</td>
<td>Smith et al., 1983</td>
</tr>
<tr>
<td>N</td>
<td>0.7</td>
<td>2.8</td>
<td>40,000</td>
<td>Smith et al., 1983</td>
</tr>
<tr>
<td>K</td>
<td>2.5</td>
<td>10.1</td>
<td>35,000</td>
<td>Smith et al., 1983</td>
</tr>
<tr>
<td>Si</td>
<td>31.5</td>
<td>128</td>
<td>12,000</td>
<td>Marschner, 1995</td>
</tr>
<tr>
<td>Na</td>
<td>28.5</td>
<td>116</td>
<td>4,000</td>
<td>Smith et al., 1980</td>
</tr>
<tr>
<td>Zn</td>
<td>0.5</td>
<td>2.0</td>
<td>50</td>
<td>Smith et al., 1983</td>
</tr>
</tbody>
</table>

Notes:  
The mineral content in the recovered groundwater is assumed to be a 2-fold dilution of the average concentration in groundwater (Table 1). Biomass production for grass stand is assumed to be 23 kg/100ft²/season. It is assumed that the recovered groundwater would undergo pre-treatment for Fe removal, and that the excess Mn would precipitate in the root zone soil as amorphous Mn carbonate (rhodocrosite).
Figure 4-1. Effects of Increasing NaCl concentration in the Growth Medium of Barley.
Feasibility Study Addendum. Lakeside Reclamation Landfill

Notes:
Barley is a typical natrophile ("halophytic includer").

Levels of Na+ and Cl- increase in the aerial parts of the plant as the supply increases, and increase with leaf age. Symbols: circles, expanding leaf blade; triangles, youngest fully expanded leaf blade; square, 2nd youngest fully expanded leaf blade. Figure taken from Garthwaite et al., 2005.
Figure 4-2. Yield of first cutting of bromegrass and its N concentration as related to N applied from ammonium nitrate.

Feasibility Study Addendum, Lakeside Reclamation Landfill

Note:
Figure from Russell et al., 1954.
Figure 5-2. Approximate Land Application Area
Feasibility Study Addendum, Lakeside Reclamation Landfill
Figure 8-1. Pilot-Scale Groundwater Treatment
Feasibility Study Addendum, Lakeside Reclamation Landfill

Notes:
Groundwater will be extracted from three riverfront wells (EX1, MW-9 and MW-10) and aerated using a trickling filter system. One portion of the aerated water will be routed through a sand filter to remove suspended particles (e.g., Fe<sup>3+</sup>). The stream of aerated and filtered water will be used to supply water to each of three systems:
Treatment 1) Irrigation system for four plots of natrophilic grass.
Treatment 2) Compost sorption cell.
Treatment 3) Treatment wetland containing natrophilic plants.

The stream of aerated water and unfiltered water will be routed to either:

Treatment 4) Treatment wetland containing natrophilic plants or
Treatment 5) Filter system containing compost.

Water samples will be collected and analyzed for CPECs from sampling ports installed at the following locations:
ap  Up-stream of aerator
b  Effluent from sand filter
c  Effluent from compost sorption cell
d  Effluent from treatment wetland
e  Effluent from compost filtration/sorption cell
f  Effluent from filtration/treatment wetland cell
Figure 8-2. Alternative Groundwater Treatment Pilot Test Locations
Feasibility Study Addendum, Lakeside Reclamation Landfill

Notes:
Alternative 1 is on a relatively level bench on the southern slope of the landfill above the river. Alternative 2 is a flat area of fill between the southernmost irrigation storage pond and the river. Both area are approximately 0.3 acre.
In either case, the treatment wetland would be lined and loading to the irrigation areas would be controlled so that the hydraulic loading matched the evapotranspiration capacity.