Appendix G

Reactive Backfill Report

March 2023
Former Reynolds Metals Reduction Plant – Longview

Reactive Backfill Report

Prepared for
Northwest Alloys, Inc.
c/o Alcoa Corp.
201 Isabella Street
Pittsburgh, Pennsylvania 15212-5858

Prepared by
Anchor QEA, LLC
6720 South Macadam Avenue, Suite 125
Portland, Oregon 97219

Project Number: 220002-04.02
\\fuji\anchor\Projects\Alcoa\NW Alloys\Longview\Remediation\6_Design\4_EDR\Deliverables\07 Final EDR_working\03 Appendices\G_Reactive Backfill\Appendix G_Reactive Backfill_2023-03-31.docx

TABLE OF CONTENTS

1 Introduction 1

1.1 Site Description 1

1.2 Purpose 1

2 Basis of Design 2

2.1 Design Objectives and Criteria 3

3 Design of Reactive Backfill 4

3.1 Selection of Reactive Amendment for Backfill 4

3.2 Reactive Backfill Composition Evaluation Approach 4

3.3 Nominal Activated Alumina Dose Based on Fluoride Uptake Isotherms 5

3.4 Sensitivity Analysis 9

4 References 12

TABLES

Table G1 Current Fluoride Concentrations in Excavation Areas 3

Table G2 Nominal Activated Alumina Doses for Reactive Backfill 9

Table G3 Summary of Activated Alumina Dose Sensitivity Calculations 10

Table G4 Recommendations for Activated Alumina Dose in Reactive Backfill by SU 11

FIGURES

Figure G1 Groundwater Monitoring Wells Near SU2

Figure G2 Groundwater Monitoring Wells Near SU3, SU4, and SU5

GRAPHICS

Graphic G1 Fluoride Update Isotherms for Axens AA 6

Graphic G2 Geotechnical Soil Phase Relationships Diagram 7

ATTACHMENT

Attachment G1 Example Dose Calculations

ABBREVIATIONS

Axens AA	ActiGuard F 14×28 activated alumina obtained from Axens Canada Specialty Aluminas Inc.
Final EDR	*Final Engineering Design Report, Version 2*
Former Reynolds Plant	former Reynolds Metals Reduction Plant
kg	kilogram
L	liter
mg	milligram
mg/L	milligrams per liter
mg/kg	milligrams per kilogram
PDI	pre-design investigation
RI/FS	*Remedial Investigation and Feasibility Study*
SU	site unit

1 Introduction

This *Reactive Backfill Report* describes the design of reactive backfill for Site Unit (SU) 2, SU3, SU4, and SU5 at the former Reynolds Metals Reduction Plant (Former Reynolds Plant) in Longview, Washington. This report is an appendix to the *Final Engineering Design Report, Version 2* (Final EDR), prepared in accordance with the cleanup action as specified in the *Cleanup Action Plan* (Ecology 2018a) pursuant to Consent Decree No. 18-2-01312-08 (Ecology 2018b).

1.1 Site Description

The site is located at 4029 Industrial Way near Longview, Washington, in unincorporated Cowlitz County. The property includes about 460 acres and is currently operated as a multimodal bulk materials handling facility. The site is approximately 10 feet above mean sea level and bounded by the Columbia River to the south; Consolidated Diking Improvement District drainage ditches to the north, west, and east; Industrial Way along the northern boundary; and private property to the east.

1.2 Purpose

The purpose of this report is to present the basis of design and composition evaluation that supports the design of the reactive backfill below the waterline. The intent of the reactive backfill is to enhance natural recovery and attenuation processes that are already present at the site by providing fluoride removal capacity and to specifically support the Final EDR by providing the reactive media mixture.

2 Basis of Design

Reactive backfill will be placed in areas after waste is excavated to promote long-term reduction of residual groundwater fluoride concentrations. The amended backfill will enhance natural attenuation processes that are occurring at the site and potentially reduce the groundwater restoration time frame for the site. The reactive backfill design assumes that the fluoride concentrations in groundwater that will come in contact with the backfill will be similar to current fluoride concentrations in these areas. This is a conservative assumption because the current fluoride concentrations in the areas to be excavated are associated with the fluoride-impacted materials that will be removed, and the fluoride concentrations in the surrounding areas are lower.

During the 2019 pre-design investigation (PDI), groundwater samples were collected from monitoring wells RL-2S and PZ-5 for treatability testing and characterizing groundwater conditions in the excavation area (Anchor QEA 2019). These monitoring wells are located adjacent to the proposed locations of permeable reactive barriers in the West Groundwater Area and reactive backfill in the East Groundwater Area, respectively. Treatability testing, including groundwater characterization, batch testing, and column testing, was used to evaluate candidate reactive media for fluoride removal from groundwater and select reactive media for backfill.

The treatability test results are summarized in the *Treatability Study Report* located in Appendix I of the Final EDR.

As detailed in the *Remedial Investigation and Feasibility Study* (RI/FS; Anchor QEA 2015), groundwater within the Former Reynolds Plant was tested extensively for fluoride. Groundwater fluoride concentrations within most of the Former Reynolds Plant are below the groundwater cleanup level of 4.0 milligrams per liter (mg/L).[1] The exception to this is the shallow groundwater located within or immediately adjacent to the existing landfills and fill deposits. Therefore, representative fluoride concentrations were developed for each excavation area and are listed in Table G1. These concentrations were developed from the 2019 PDI sampling (PZ-5), groundwater samples collected in 2019 as part of the annual (RL-1D and R-3) and interim (RL-1S) groundwater monitoring programs,[2] and samples collected during the RI/FS in 2012 (RLSW-1, PZ-1, PZ-2, and PZ-4). The representative fluoride concentrations for SU3 and SU4/SU5 are the averages of the most recent data from monitoring wells in these areas. Because the fluoride concentrations in SU2 are relatively low, the maximum fluoride concentration among the data from monitoring wells in this area was used as

[1] The groundwater cleanup level is 4.0 mg/L fluoride, based on the State Drinking Water Maximum Contaminant Level. The screening level for protection of aquatic life in the shoreline bioactive zone porewater is 1.8 mg/L fluoride (Ecology 2018a).

[2] The groundwater samples collected in 2020 and 2021 at RL-1S were reviewed, and the fluoride concentration from the 2019 data is still considered to be representative.

the representative concentration for SU2. The groundwater monitoring wells listed in Table G1 are shown in Figures G1 and G2.

Table G1
Current Fluoride Concentrations in Excavation Areas

Excavation Area	Well	Sample Date[1]	Fluoride Concentration in Groundwater[2] (mg/L)	Representative Fluoride Concentration[3,4] (mg/L)
SU2	RL-1S	10/31/2019	8.28	51
	RL-1D	5/9/2019	0.287	
	RLSW-1	10/4/2012	50.7	
SU3	PZ-1	10/2/2012	222	574
	PZ-2	10/2/2012	471	
	PZ-4	10/2/2012	1,030	
SU4/SU5	R-3	8/19/2019	1,240	1,530
	PZ-5	10/31/2019	1,820	

Notes:
1. Sample date is the date when groundwater sample was collected for fluoride analysis. These concentrations were developed from the 2019 PDI sampling, groundwater samples collected in 2019 as part of the annual and interim groundwater monitoring programs, and samples collected during the RI/FS in 2012.
2. All fluoride concentrations are dissolved fluoride concentrations except for the concentration from well R-3, which is a total fluoride concentration.
3. The representative fluoride concentration for SU2 is the maximum of the most recent data.
4. The representative fluoride concentrations for SU3 and SU4/SU5 are the averages of the most recent data.

2.1 Design Objectives and Criteria

The design objectives and criteria are as follows:

- The reactive backfill will reduce the fluoride concentrations in groundwater rising into the backfilled excavation areas due to the seasonal fluctuation of the water table.
- The reactive backfill will have sufficient long-term fluoride uptake capacity to treat multiple annual cycles of water table fluctuation within the backfill area. Because fluoride source materials will be removed during excavation, the reactive backfill is only intended to provide treatment of fluoride for the finite volume of groundwater, immediately surrounding and beneath the excavation areas, that will enter the backfill.

3 Design of Reactive Backfill

The reactive backfill will consist of sand mixed with reactive media to immobilize dissolved fluoride from groundwater through adsorption and/or structural incorporation into the reactive material. The higher the percentage of reactive media in the backfill, the higher the removal efficiency in the short term due to adsorption and the higher the ultimate fluoride uptake capacity in the longer term.

3.1 Selection of Reactive Amendment for Backfill

Several reactive media were evaluated for fluoride removal in the *Treatability Study Report* (Appendix I of the Final EDR). The groundwater used in the treatability study was from the East and West Groundwater Areas and represented the highest fluoride concentrations within each area. Laboratory batch and column tests were performed to evaluate a number of candidate reactive media, including activated alumina, calcium phosphates (bone meal, bone char, and rock phosphate), carbonates (calcite and siderite), hydrotalcite, and magnesium oxide. Performance criteria included fluoride removal rates, removal efficiency, uptake capacity, stability of the sequestered fluoride, and potential secondary water quality effects from the reactive media. The conclusions of the *Treatability Study Report* include the following:

- Activated alumina was found to have the best fluoride removal performance overall for the range of site groundwater chemistry tested.
- Fluoride is strongly sequestered by activated alumina due to the formation of strong variable charge surface complexes and surface precipitates, and the potential for fluoride remobilization under reasonably anticipated future site conditions is very low.
- ActiGuard F 14×28 activated alumina obtained from Axens Canada Specialty Aluminas Inc. (Axens AA) was selected as the specific product for reactive backfill based on performance.

3.2 Reactive Backfill Composition Evaluation Approach

The following process was used to determine the required dose of Axens AA in the different reactive backfill areas:

1. The minimum dose of Axens AA (i.e., mass activated alumina per unit dry weight of reactive backfill) to achieve a 90% reduction in fluoride concentrations in each SU was calculated using the fluoride uptake isotherm determined for Axens AA with site groundwater (Appendix I of the Final EDR).
2. Sensitivity analyses were performed to assess if variations in post-construction soil conditions (i.e., porosity and density) and initial concentrations of fluoride in groundwater would result in significantly different dose values.

Conceptually, groundwater will initially be present in the excavation areas where removal of source materials extends below the water table. Fluoride concentrations in groundwater filling these excavated areas will be treated following placement of the clean amended backfill. Lateral migration of fluoride is limited by natural attenuation processes, as was documented in Appendix H of the RI/FS (Anchor QEA 2015). Therefore, the only ongoing residual source of fluoride to the reactive backfill after source removal will be groundwater that rises seasonally into the backfill. As the water table recedes, the treated groundwater within the backfill will move below the backfill and then move back into the backfill during the next seasonal rise of the water table. As a result of the seasonal water table fluctuation, some vertical mixing of the treated groundwater with deeper untreated groundwater will occur in the shallow zone due to dispersion processes.

3.3 Nominal Activated Alumina Dose Based on Fluoride Uptake Isotherms

Fluoride uptake from site groundwater on activated alumina and backfill soil was measured and fitted to empirical Freundlich isotherms (Graphic G1; Appendix I of the Final EDR). The Freundlich isotherm is defined as follows:

Equation G1

$$q_e = K_f (C_e)^{1/n}$$

where:

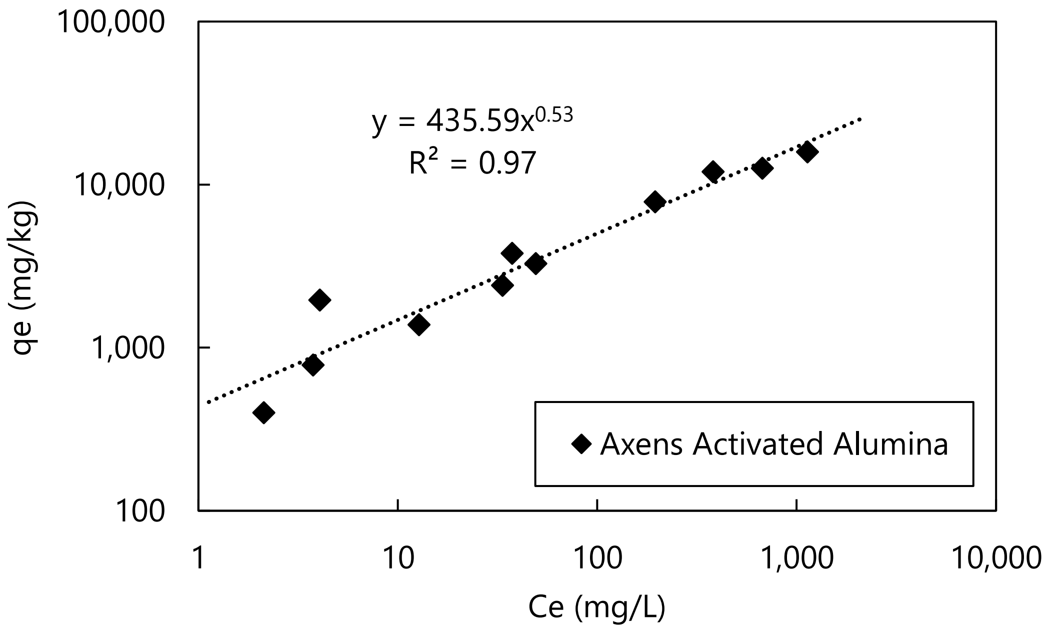
q_e	=	concentration of fluoride on the solid (milligrams per kilogram [mg/kg])
K_f	=	isotherm constant related to sorption capacity (435.59)
C_e	=	concentration of fluoride in solution (mg/L)
$1/n$	=	isotherm exponent related to sorption intensity (0.53)

Based on the empirical isotherm tests, the initial activated alumina dose can be calculated using the following steps (also demonstrated in Attachment G1):

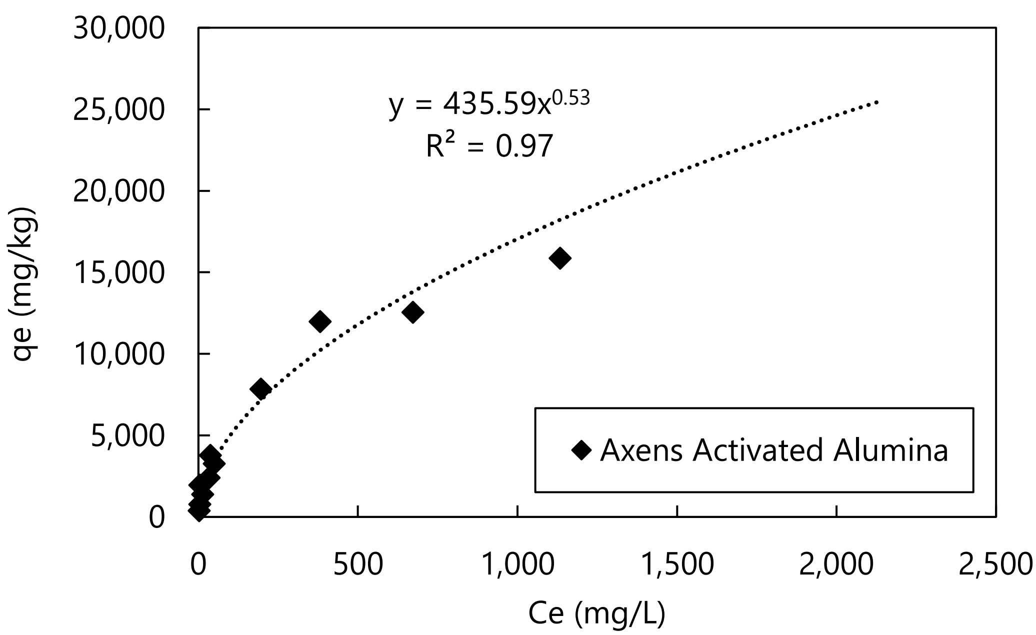
1. Using geotechnical soil phase relationships (Graphic G2) and Equation G2, calculate the mass of groundwater associated with the expected soil conditions after construction (i.e., porosity and density). Assume a 1-liter (L) cube of backfill and saturated conditions, such that the air phase can be omitted and the volume of voids is equal to the volume of water. Also calculate mass of solids in the backfill matrix.
2. Using Equation G3, calculate the mass of fluoride in groundwater that requires removal based on a target removal rate of 90%. Also calculate the resulting target concentration of fluoride in groundwater (C_e) after treatment.
3. Using Equation G1, calculate the fluoride update capacity per kilogram of activated alumina.

4. Using Equation G4, calculate the mass of activated alumina required to meet the given target treatment removal rate and associated dose per dry weight of backfill soil.

Graphic G1
Fluoride Update Isotherms for Axens AA

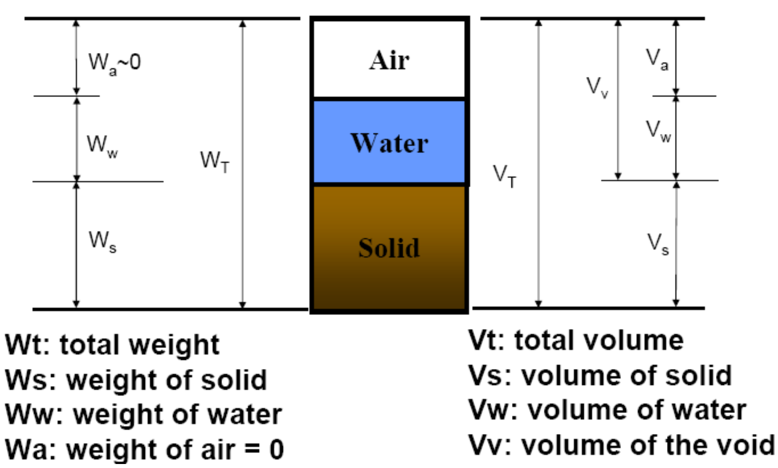


(a) logarithmic scale



(b) arithmetic scale

Graphic G2
Geotechnical Soil Phase Relationships Diagram



Equation G2

$$Vw = V_T * \eta$$

$$Ws = \gamma_T * V_T - Vw * \gamma_W$$

where:

V_W = total volume of groundwater to treat (L)

η = porosity, assumed initial value of 0.32 based on laboratory measurements

V_T = total volume of backfill, assumed 1 L

γ_T = bulk density of backfill, assumed 1.76 kilograms per liter (kg/L) based on compaction specs

γ_W = density of water, 1 kg/L

Equation G3

$$M_{F(Re)} = R_e * Vw * C_0$$

$$C_e = (1 - R_e) * C_0$$

where:

C_e	=	target concentration of fluoride in groundwater after treatment (mg/L)
C_o	=	initial fluoride concentration in groundwater (mg/L)
R_e	=	removal efficiency (%), assumed 90%
$M_{F(Re)}$	=	mass of fluoride to remove from groundwater at a given efficiency (milligrams)

Equation G4

$$M_{AA} = \frac{M_{F(Re)}}{q_e}$$

$$D_{AA} = 100 * \frac{M_{AA}}{(M_{AA} + Ws)}$$

where:

M_{AA}	=	mass of activated alumina required to achieve R_e (kilograms)
D_{AA}	=	dose of activated alumina in reactive backfill (% dry weight)

The activated alumina doses calculated with Equation G4 for 90% reduction in fluoride concentrations within SU2, SU3, SU4, and SU5 are shown in Table G2. Attachment G1 documents the base dose calculations.

Table G2
Nominal Activated Alumina Doses for Reactive Backfill

Area	Calculated Activated Alumina Dose (% by weight)[1]
SU2	1
SU3	3
SU4 and SU5	4.7

Note:
1. Dry weight basis

3.4 Sensitivity Analysis

Table G3 summarizes calculations that vary the expected compacted density and associated porosity and the starting groundwater concentration of fluoride to assess how sensitive the dose calculation is to these variations. Based on this assessment and the knowledge that a portion of SUs 3, 4, and 5 will not receive full compactive effort as material is placed below the groundwater table, doses in these areas were increased to account for the higher porosity at depth. A simple weighted average was used to calculate the dose increase.

Table G4 summarizes the recommended doses of activated alumina to be mixed with soil.

Table G3
Summary of Activated Alumina Dose Sensitivity Calculations

SU	γT (pcf)	γT (kg/L)	γW (kg/L)	Porosity	V_t (L)	V_w (L)	W_t (kg)	W_w (kg)	W_s (kg)	C_0 (mg/L)	R_e (%)	$M_{F(Re)}$ (mg)	C_e (mg/L)	q_e (mg/kg)	M_{AA} (kg)	D_{AA} (%)	Notes
SU2	105	1.68	1	0.4	1	0.4	1.68	0.4	1.28	51	0.90	18.36	5.1	1,032.98	0.018	1.4	All backfill placed above seasonal low groundwater level; high porosity assumption not applicable.
	110	1.76	1	0.32	1	0.32	1.76	0.32	1.44	51	0.90	14.688	5.1	1,032.98	0.014	1.0	Base dose from Section 3.3
	125	2.00	1	0.25	1	0.25	2.00	0.25	1.75	51	0.90	11.475	5.1	1,032.98	0.011	0.6	Dose is based on highest observed concentration, not average like in SUs 3, 4, and 5.
SU3	105	1.68	1	0.4	1	0.4	1.68	0.4	1.28	574	0.90	206.64	57.4	3,726.50	0.055	4.1	Up to 33% of reactive backfill in SU3 is expected below seasonal low water table.
	110	1.76	1	0.32	1	0.32	1.76	0.32	1.44	574	0.90	165.312	57.4	3,726.50	0.044	3.0	Base dose from Section 3.3
	125	2.00	1	0.25	1	0.25	2.00	0.25	1.75	574	0.90	129.15	57.4	3,726.50	0.035	1.9	
	105	1.68	1	0.4	1	0.4	1.68	0.4	1.28	222	0.90	79.92	22.2	2,252.40	0.035	2.7	
	110	1.76	1	0.32	1	0.32	1.76	0.32	1.44	222	0.90	63.936	22.2	2,252.40	0.028	1.9	
	125	2.00	1	0.25	1	0.25	2.00	0.25	1.75	222	0.90	49.95	22.2	2,252.40	0.022	1.2	
	105	1.68	1	0.4	1	0.4	1.68	0.4	1.28	1,030	0.90	370.8	103	5,080.21	0.073	5.4	
	110	1.76	1	0.32	1	0.32	1.76	0.32	1.44	1,030	0.90	296.64	103	5,080.21	0.058	3.9	
	125	2.00	1	0.25	1	0.25	2.00	0.25	1.75	1,030	0.90	231.75	103	5,080.21	0.046	2.5	
SU4/5	105	1.68	1	0.4	1	0.4	1.68	0.4	1.28	1,530	0.90	550.8	153	6,265.62	0.088	6.4	Up to 76% and 41% of reactive backfill in SU4 and SU5, respectively, is expected below seasonal low water table.
	110	1.76	1	0.32	1	0.32	1.76	0.32	1.44	1,530	0.90	440.64	153	6,265.62	0.070	4.7	Base dose from Section 3.3
	125	2.00	1	0.25	1	0.25	2.00	0.25	1.75	1,530	0.90	344.25	153	6,265.62	0.055	3.0	
	105	1.68	1	0.4	1	0.4	1.68	0.4	1.28	1,240	0.90	446.4	124	5,605.20	0.080	5.8	
	110	1.76	1	0.32	1	0.32	1.76	0.32	1.44	1,240	0.90	357.12	124	5,605.20	0.064	4.2	
	125	2.00	1	0.25	1	0.25	2.00	0.25	1.75	1,240	0.90	279	124	5,605.20	0.050	2.8	
	105	1.68	1	0.4	1	0.4	1.68	0.4	1.28	1,820	0.90	655.2	182	6,869.35	0.095	6.9	
	110	1.76	1	0.32	1	0.32	1.76	0.32	1.44	1,820	0.90	524.16	182	6,869.35	0.076	5.0	
	125	2.00	1	0.25	1	0.25	2.00	0.25	1.75	1,820	0.90	409.5	182	6,869.35	0.060	3.3	

Notes:
C_e: target fluoride concentration in groundwater
C_0: initial fluoride concentration in groundwater
D_{AA}: dose of activated alumina in reactive backfill
kg: kilogram
kg/L: kilograms per liter
L: liter
M_{AA}: mass of required activated alumina to achieve treatment
$M_{F(Re)}$: mass of fluoride to be removed from groundwater
mg: milligram
mg/kg: milligrams per kilogram
mg/L: milligrams per liter
pcf: pounds per cubic foot
q_e: concentration of fluoride on the solid
R_e: removal efficiency
SU: site unit
V_t: total volume
V_w: volume of water
W_s: weight of solid
W_t: total weight
W_w: weight of water
γT: bulk density
γW: density of water

Table G4
Recommendations for Activated Alumina Dose in Reactive Backfill by SU

Area	Recommended Activated Alumina Dose (% by weight)[1]	Notes
SU2	1	Dose not modified from base calculation
SU3	3.4	Dose increased to account for area at depth with lower compaction[2]
SU4	6	Dose increased to account for area at depth with lower compaction[2]
SU5	5.4	Dose increased to account for area at depth with lower compaction[2]

Notes:

1. Dry weight basis.
2. Refer to Attachment G1 for example calculation.

4 References

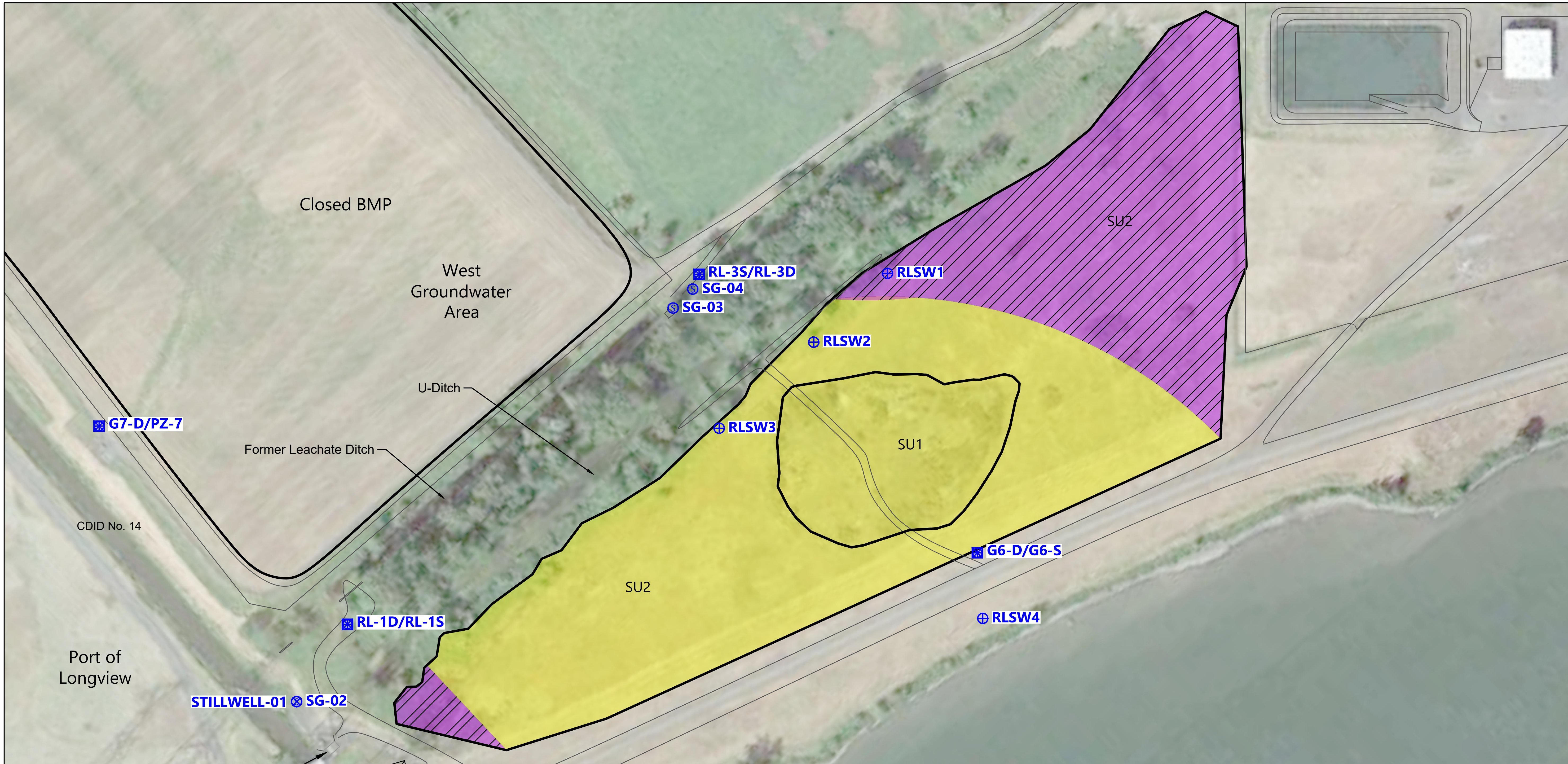
Anchor QEA (Anchor QEA, LLC), 2015. *Remedial Investigation and Feasibility Study*. Former Reynolds Metals Reduction Plant – Longview. Submitted on behalf of Northwest Alloys, Inc., and Millennium Bulk Terminals – Longview, LLC. January 2015.

Anchor QEA, 2019. *Pre-Design Investigation Work Plan*. Former Reynolds Metals Reduction Plant – Longview. Prepared for Northwest Alloys, Inc., and Millennium Bulk Terminals – Longview, LLC. March 2019.

Ecology (Washington State Department of Ecology), 2018a. *Cleanup Action Plan*. Former Reynolds Metals Reduction Plant – Longview. October 2018.

Ecology, 2018b. Consent Decree No. 18-2-01312-08. Former Reynolds Metals Reduction Plant – Longview. December 14, 2018.

Figures



SOURCE: Drawing prepared from ALTA Survey (Minister & Glaeser Surveying, Inc.) conducted on November 11, 2010. Aerial Image from Bing Maps.
HORIZONTAL DATUM: Washington State Plane South Zone, NAD83, U.S. Survey Feet
VERTICAL DATUM: NAVD88, Feet

LEGEND:

- Permanent Staff Gauge
- Low Permeability Cap
- Excavate and Consolidate on Site
- Reactive Backfill
- Groundwater Sampling Location
- Paired Shallow/Deeper Groundwater Sampling Location
- Temporary Stilling Well Instrumented for Tidal Study

0 200
Feet

Publish Date: 2023/03/22 9:50 PM | User: chewett
Filepath: 0730-RP-001 (GW Samples_G-1 and G-2).dwg Figure G-1

ANCHOR QEA

Figure G1
Groundwater Monitoring Wells Near SU2
Reactive Backfill Report
Former Reynolds Metals Reduction Plant – Longview

SOURCE: Drawing prepared from ALTA Survey (Minister & Glaeser Surveying, Inc.) conducted on November 11, 2010. Aerial Image from Bing Maps.
HORIZONTAL DATUM: Washington State Plane South Zone, NAD83, U.S. Survey Feet
VERTICAL DATUM: NAVD88, Feet

LEGEND:
- Permanent Staff Gauge
- Low Permeability Cap
- Excavate and Consolidate on Site
- Reactive Backfill
- Groundwater Sampling Location
- Paired Shallow/Deeper Groundwater Sampling Location

0 100
Feet

Publish Date: 2023/03/22 9:51 PM | User: chewett
Filepath: 0730-RP-001 (GW Samples_G-1 and G-2).dwg Figure G-2

ANCHOR QEA

Figure G2
Groundwater Monitoring Wells Near SU3, SU4, and SU5
Reactive Backfill Report
Former Reynolds Metals Reduction Plant – Longview

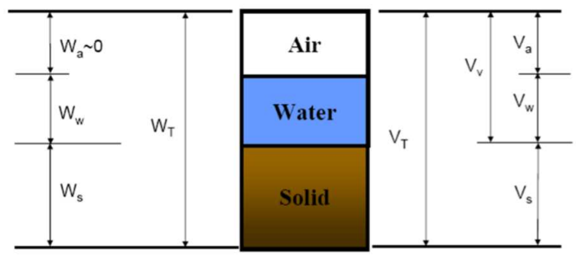
Attachment G1
Example Dose Calculations

ANCHOR QEA

Project: Longview Former Reynolds | Job No.: 220002-04.02
Subject: Reactive Backfill Base Dose Calculation for SU2 | Date: 3/13/23 Time:
~~Attendees:~~ | Page: Of:
Made By: R. Desrosiers
Route To:

☒ Calculations ☐ Telecon ☐ Meeting Notes

Soil Phase Relationships Diagram



Wt: total weight
Ws: weight of solid
Ww: weight of water
Wa: weight of air = 0

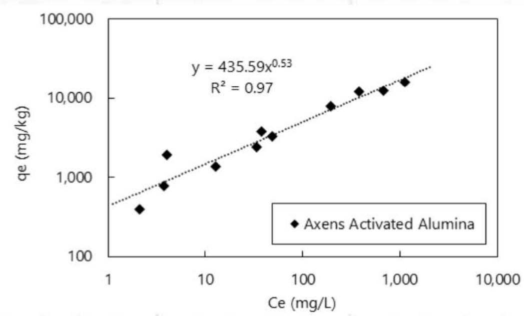
Vt: total volume
Vs: volume of solid
Vw: volume of water
Vv: volume of the void

<u>Assume</u>:
1. saturated conditions, Vv = Vw
2. porosity (η) = Vv/Vt = 0.32
3. bulk density (γt) = 1.76 kg/L (110 pcf)
4. total volume (Vt) = 1 L
5. density of water (γw) = 1 kg/L

<u>Phase Diagram Calculations</u>:
1. $Vw = V_T * \eta$ = 1 kg/L * 0.32 = 0.32 L
2. $Ws = \gamma_T * V_T - Vw * \gamma_W$
 = 1.76 kg/L * 1L - 0.32L * 1 kg/L = 1.44 kg

<u>Assume</u>:
1. initial concentration of F in groundwater (Co) = 51 mg/L
2. Removal efficiency = 90%

<u>Freundlich isotherm constants (see graph at right)</u>:
1. Kf = 435.59
2. 1/n = 0.53



<u>Dose Calculations</u>:
1. Mass of fluoride to be removed from groundwater,

$$M_{F(Re)} = R_e * Vw * C_0$$

= 0.9 * 0.32 L * 51 mg/L = 14.69 mg F

2. Target fluoride concentration after treatment,

$$C_e = (1 - R_e) * C_0$$

= (1 - 0.9) * 51 mg/L = 5.1 mg/L

3. Fluoride update capacity per kilogram of AA,

$$q_e = K_f (C_e)^{1/n}$$

= 435.59 * (5.1 mg/L)^0.53 = 1032.98 mg F / kg AA

4. Mass of required AA to achieve treatment,

$$M_{AA} = \frac{M_{F(Re)}}{q_e}$$

= (14.69 mg F) / (1032.98 mg F / kg AA) = 0.014 kg

5. Base Dose of AA,

$$D_{AA} = 100 * \frac{M_{AA}}{(M_{AA} + Ws)}$$

= 100 * [0.014 kg / (0.014 kg + 1.44 kg)] = 1.0 %

Project: Longview Former Reynolds | Job No.: 220002-04.02

Subject: Reactive Backfill Base Dose Calculation for SU3 | Date: 3/13/23 | Time:

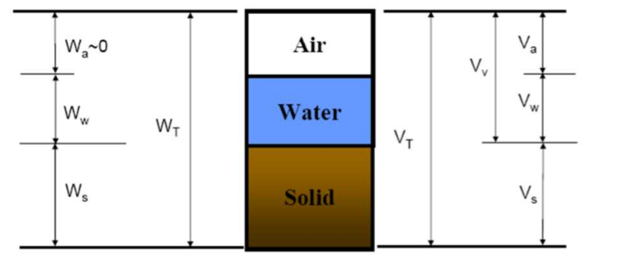
~~Attendees:~~ | Page: | Of:

Made By: R. Desrosiers

Route To:

☒ Calculations ☐ Telecon ☐ Meeting Notes

Soil Phase Relationships Diagram



Wt: total weight
Ws: weight of solid
Ww: weight of water
Wa: weight of air = 0

Vt: total volume
Vs: volume of solid
Vw: volume of water
Vv: volume of the void

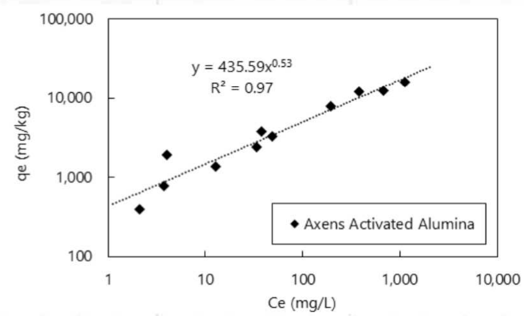
Assume:
1. saturated conditions, Vv = Vw
2. porosity (η) = Vv/Vt = 0.32
3. bulk density (γt) = 1.76 kg/L (110 pcf)
4. total volume (Vt) = 1 L
5. density of water (γw) = 1 kg/L

Phase Diagram Calculations:
1. $Vw = V_T * \eta$ = 1 kg/L * 0.32 = 0.32 L

2. $Ws = \gamma_T * V_T - Vw * \gamma_W$
   = 1.76 kg/L * 1L - 0.32L * 1 kg/L = 1.44 kg

Assume:
1. initial concentration of F in groundwater (Co) = 574 mg/L
2. Removal efficiency = 90%

Freundlich isotherm constants (see graph at right):
1. Kf = 435.59
2. 1/n = 0.53



Dose Calculations:
1. Mass of fluoride to be removed from groundwater,

$$M_{F(Re)} = R_e * Vw * C_0$$

= 0.9 * 0.32 L * 574 mg/L = 165.31 mg F

2. Target fluoride concentration after treatment,

$$C_e = (1 - R_e) * C_0$$

= (1 - 0.9) * 574 mg/L = 57.4 mg/L

3. Fluoride update capacity per kilogram of AA,

$$q_e = K_f(C_e)^{1/n}$$

= 435.59 * (57.4 mg/L)^0.53 = 3726.5 mg F / kg AA

4. Mass of required AA to achieve treatment,

$$M_{AA} = \frac{M_{F(Re)}}{q_e}$$

= (165.31 mg F) / (3726.5 mg F / kg AA) = 0.044 kg

5. Base Dose of AA,

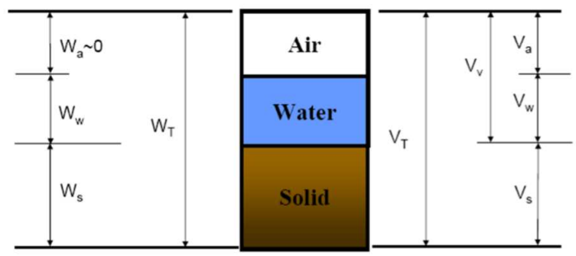
$$D_{AA} = 100 * \frac{M_{AA}}{(M_{AA} + Ws)}$$

= 100 * [0.044 kg / (0.044 kg + 1.44 kg)] = 3.0 %

Project:	Longview Former Reynolds	Job No.:	220002-04.02
Subject:	Reactive Backfill Base Dose Calculation for SU4/5	Date:	3/13/23 Time:
~~Attendees:~~		Page:	Of:
		Made By:	R. Desrosiers
		Route To:	

☒ Calculations ☐ Telecon ☐ Meeting Notes

Soil Phase Relationships Diagram



Wt: total weight
Ws: weight of solid
Ww: weight of water
Wa: weight of air = 0

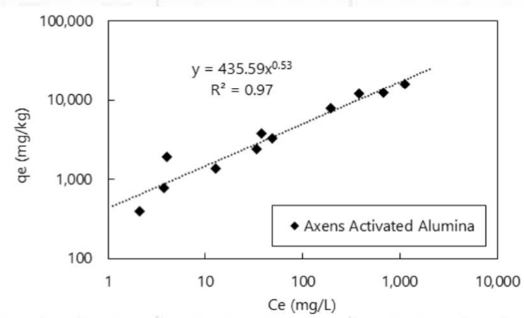
Vt: total volume
Vs: volume of solid
Vw: volume of water
Vv: volume of the void

<u>Assume</u>:
1. saturated conditions, Vv = Vw
2. porosity (η) = Vv/Vt = 0.32
3. bulk density (γt) = 1.76 kg/L (110 pcf)
4. total volume (Vt) = 1 L
5. density of water (γw) = 1 kg/L

<u>Phase Diagram Calculations</u>:
1. $Vw = V_T * \eta$ = 1 kg/L * 0.32 = 0.32 L

2. $Ws = \gamma_T * V_T - Vw * \gamma_W$
   = 1.76 kg/L * 1L - 0.32L * 1 kg/L = 1.44 kg

<u>Assume</u>:
1. initial concentration of F in groundwater (Co) = 1530 mg/L
2. Removal efficiency = 90%



<u>Freundlich isotherm constants (see graph at right)</u>:
1. Kf = 435.59
2. 1/n = 0.53

<u>Dose Calculations</u>:
1. Mass of fluoride to be removed from groundwater,

$$M_{F(Re)} = R_e * Vw * C_0$$

= 0.9 * 0.32 L * 1530 mg/L = 440.64 mg F

2. Target fluoride concentration after treatment,

$$C_e = (1 - R_e) * C_0$$

= (1 - 0.9) * 1530 mg/L = 153 mg/L

3. Fluoride update capacity per kilogram of AA,

$$q_e = K_f(C_e)^{1/n}$$

= 435.59 * (153 mg/L)^0.53 = 6265.62 mg F / kg AA

4. Mass of required AA to achieve treatment,

$$M_{AA} = \frac{M_{F(Re)}}{q_e}$$

= (440.64 mg F) / (6265.62 mg F / kg AA) = 0.070 kg

5. Base Dose of AA,

$$D_{AA} = 100 * \frac{M_{AA}}{(M_{AA} + Ws)}$$

= 100 * [0.070 kg / (0.070 kg + 1.44 kg)] = 4.7 %

ANCHOR QEA

Project: Longview Former Reynolds | Job No.: 220002-04.02

Subject: Reactive Backfill Base Dose | Date: 3/13/23 Time:

~~Attendees:~~ Example calculation for areas with backfill below the seasonal low groundwater table | Page: Of:

Made By: R. Desrosiers

Route To:

☒ Calculations ☐ Telecon ☐ Meeting Notes

Summary of Results from Table G-3

SU#	γT (pcf)	γT (kg/L)	Porosity	Co (mg/L)	Re (%)	Daa (%)	Notes
SU2	105	1.68	0.4	51	0.90	1.4	All backfill placed above seasonal low groundater level; high porosity assumption not applicable.
	110	1.76	0.32	51	0.90	1.0	Base dose from Section 3.3
	125	2.00	0.25	51	0.90	0.6	Dose is based on highest observed concentration, not average like in SUs 3, 4, and 5
SU3	105	1.68	0.4	574	0.90	4.1	Up to 33% of reactive backfill in SU3 is expected below seasonal low water table
	110	1.76	0.32	574	0.90	3.0	Base dose from Section 3.3
	125	2.00	0.25	574	0.90	1.9	
SU4/5	105	1.68	0.4	1530	0.90	6.4	Up to 76% and 41% of reactive backfill in SU4 and SU5, respectively, is expected below seasonal low water table
	110	1.76	0.32	1530	0.90	4.7	Base dose from Section 3.3
	125	2.00	0.25	1530	0.90	3.0	

<u>Calculate Percentage of Area below seasonal low groundwater table by depth (light blue line below)</u>:

1. SU4: 1 - (2.38' / 9.95') = 76.1%

2. SU5: 1 - (2.35' / 4') = 41.3%

<u>Calculate weighted dose</u>:

1. SU4: (0.761 * 6.4) + (0.239 * 4.7) = 6%

2. SU5: (0.413 * 6.4) + (0.588 * 4.7) = 5.4%