PolyMet Mining

ENGINEERED WETLANDS

PILOT SCALE TESTING WORKPLAN

DRAFT – Last Updated: October 12, 2016

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CONTENTS

TABLES

FIGURES

1 INTRODUCTION

This Pilot Test Work Plan (Work Plan) has been prepared to outline the design, construction, and operation of a pilot scale, non-mechanical engineered wetland water treatment system proposed to be located on the former LTV Steel Mining Company (LTVSMC) tailings basin.

Arcadis has drafted this Work Plan on behalf of Poly Met Mining, Inc. (PolyMet) in order to assess the effectiveness of a non-mechanical water treatment system; specifically, an engineered treatment wetland, in conjunction with the proposed NorthMet Project (Project). This document is intended to be a working document that will be updated based on findings of the recent proof-of-concept bench scale testing (described below), findings from similar projects (as applicable), and findings from the proposed bench-scale testing outlined later in this document.

The primary parameter of concern (POC) on the former LTVSMC tailings basin for this evaluation is sulfate. Other identified surface water POCs that may need to be addressed include mercury, total dissolved solids (TDS), specific conductance, alkalinity, and hardness. The focus of the proposed pilot test is to evaluate the potential applicability and effectiveness of an engineered treatment wetland to mitigate the POCs present in the seeps emanating from the LTVSMC tailings basin. Water from LTVSMC tailings basin seeps will be used in the pilot test to evaluate the effectiveness of treatment. As described in further detail below, the system will work primarily by reducing sulfate through biological reduction in a floating, subsurface flow, engineered wetland (i.e., the engineered wetland treatment cell will be installed within existing wetlands, an influent distribution system will be provided to disseminate flow within the media bed, will be hydraulically connected to the wetlands via an engineered outfall structure or structures, and will be equipped with a cover system to facilitate winter operations and prevent cycling of reduced sulfur compounds to sulfate). Reducing sulfate will likely also result in reductions in TDS and specific conductance since sulfate is a significant contributor to those parameters.

The pilot test will provide information on the potential applicability of engineered treatment wetlands in mitigating these POCs as well as any byproducts of the biological reduction process (e.g., alkalinity). In addition, the pilot test will provide valuable information on design and operational considerations that may need to be optimized for full scale application of the technology.

2 BACKGROUND DATA

The former LTVSMC tailings basin has several seeps that currently discharge from the tailings basin. Water flowing through the LTVSMC tailings basin results in the transport of weathered minerals and dissolved ions; the resulting effluent water quality has circumneutral pH but can contain elevated concentrations of sulfate, hardness (dominated by magnesium [Mg^{2+}]), and alkalinity. Together, these elevated salt concentrations contribute to elevated total dissolved solids (TDS) and specific conductance. A seep exists along the southern edge of the tailings basin, approximately ¾ of a mile upstream of permitted surface outfall SD026. This seep is considered representative of water chemistry conditions found along the basin seeps. This seep is currently being collected and pumped back to the tailings basin (SD026 Pumpback). A slip stream of the SD026 pumpback water will be used for pilot testing activities. Existing water quality data has been compiled and summarized for SD026 in an effort to characterize the potential pilot test influent water and is summarized in **Table 1**. SD026 pumpback water is expected to have similar water quality characteristics to SD026.

In 2011, a bench test was conducted by Barr Engineering to test the sulfate reduction potential of a floating wetland. This floating wetland bench test was completed using water from surface discharge SD033, which is an outfall from a former mining area east of the LTVSMC tailings basin. Compared to SD033 water, the water from the SD026 pumpback (from the LTVSMC tailings basin) that will be used as influent flow for pilot scale testing is lower in sulfate, hardness, and specific conductance water, while bicarbonate alkalinity is comparable.

The primary goal of the 2011 bench scale test was to evaluate a floating wetland technology for its ability to facilitate sulfate reduction in site-specific water. The 8-week pilot demonstrated that the floating wetland treatment effectively supported sulfate reduction when the reactors were established and maintained at approximately ideal conditions for microbial growth. Bench testing demonstrated nearly 90% reduction of sulfate at times during the test, with average reductions ranging between 62 – 76%.

The promising results from the 2011 bench scale test merit expansion of the test to a pilot scale. Testing biological sulfate reduction technology on a pilot scale will provide the opportunity to evaluate its treatment capabilities under site-specific conditions at the LTVSMC tailings basin.

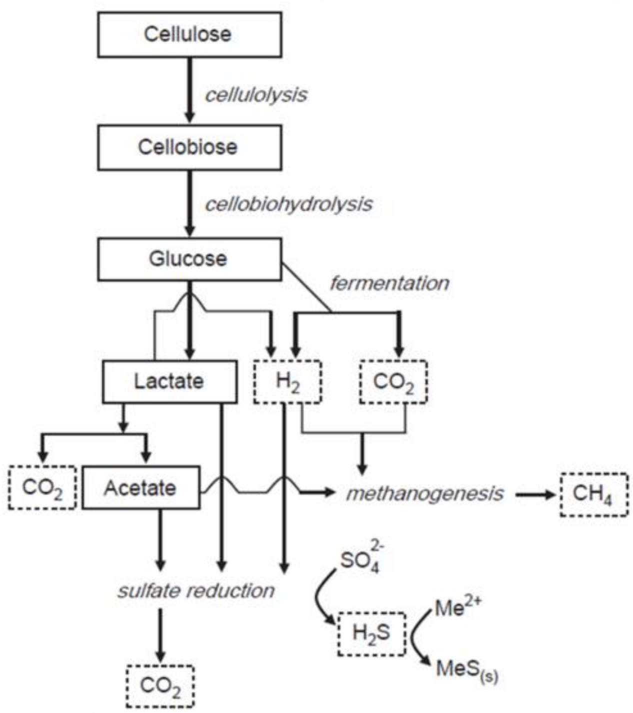
3 CONCEPTUAL TREATMENT TECHNOLOGY

3.1 Biological Sulfate Reduction

Sulfate reduction occurs via dissimilatory sulfate reduction by sulfate reducing bacteria (SRB). In general, this reaction can be summarized as follows:

Equation 1 $1/8\ SO_4^{2-} + 1/8\ CH_3OO^- + 3/16\ H^+ \rightarrow 1/16\ H_2S + 1/16\ HS^- + 1/8\ CO_2 + 2HCO_3^- + 1/8\ H_2O$

Organic matter (a carbon source) and anaerobic conditions are required to facilitate heterotrophic sulfate reduction. The organic matter can be provided by various methods, including naturally growing plant mass or it may be supplemented with either solid organic matter (manure, sawdust, woodchips, straw, peat, etc.) or a liquid feed source, such as methanol or ethanol. Acetate (depicted in Equation 1) is a carbon source utilized by SRB that is derived from various carbon sources (including carbohydrates such as cellulose) through microbial pathways as shown in the schematic below.



To remove the H_2S (hydrogen sulfide) generated by the SRB, dissolved metals can be added to precipitate metal sulfides. Iron, in forms ranging from iron oxide to zero valent iron (ZVI), is commonly used as a metal additive to facilitate this precipitation. A general reaction for the metal sulfide precipitation is:

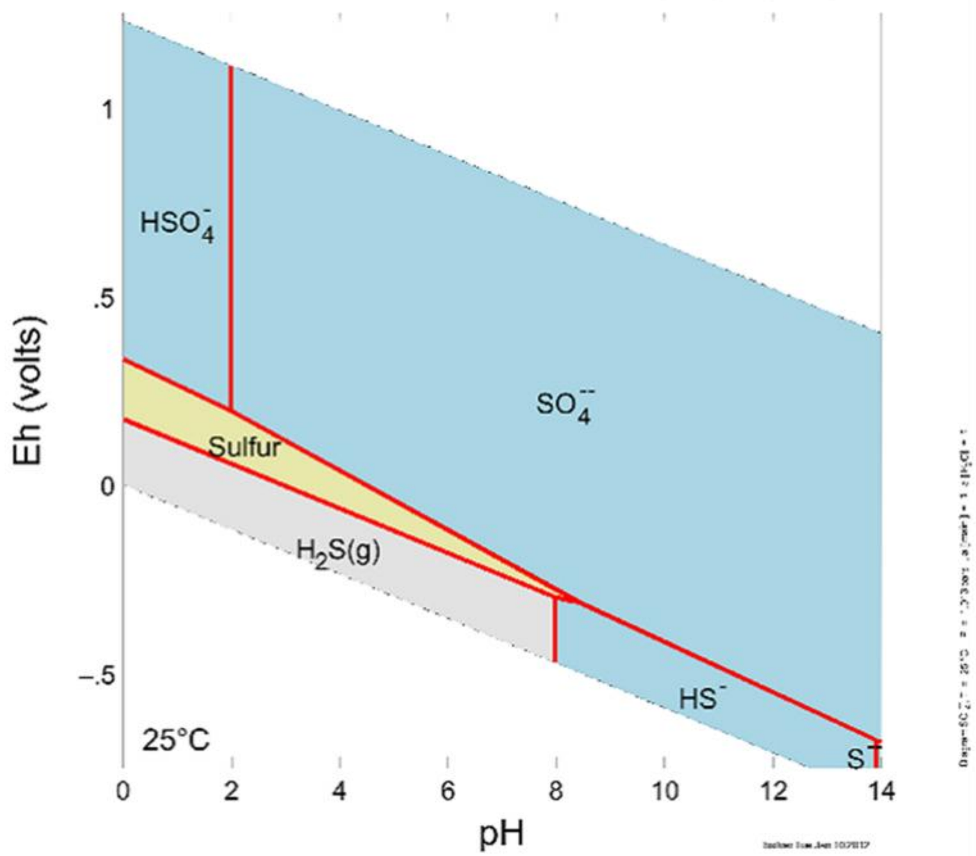
Equation 2 $H_2S + M^{2+} \rightarrow MS + 2H^+$

Therefore, the combined reaction for the reduction of sulfate by SRB and subsequent precipitation of metal sulfide is:

Equation 3 $SO_4^{2-} + 2CH_2O + M^{2+} \rightarrow MS + 2H_2CO_3$

The speciation of carbonic acid (H_2CO_3) will be dependent on the pH of the treatment system. For circumneutral or slightly alkaline waters, the bicarbonate ion (HCO_3^-) will dominate. As can be seen from Equation 3, metal ions (primarily iron and manganese) must be present in the same molar concentration as sulfate in order for complete metal sulfide precipitation. In the absence of sufficient concentration of metal ions, the reaction represented in Equation 1 would dominate, and hydrogen sulfide would be the primary sulfur-containing product.

As demonstrated in the Eh/pH diagram below, the fate of hydrogen sulfide (the primary reduced sulfur species generated in the absence of metals) when exposed to oxidants depends on the pH. At a pH greater than 8.0, hydrogen sulfide will be converted to sulfate. At pH less than 8.0, hydrogen sulfide will be converted to elemental sulfur. To avoid re-generation of sulfate as effluent is oxidized, it will be important to control the pH (i.e., maintain circumneutral pH).



3.2 Constructed Wetlands

Constructed treatment wetlands mimic biotic and abiotic processes that occur in natural wetlands and are able to remove pollutants through one or more mechanisms. These include biochemical oxidation and reduction, phytodegradation or immobilization, chemical precipitation, sedimentation, photodegradation, and volatilization. Constructed treatment wetlands have been used to treat mine influenced waters since at least the 1970s. Typical wetland configurations used in mining applications have been aerobic surface flow wetlands, anaerobic subsurface flow wetlands, and vertical flow wetlands. Aerobic wetlands have been effective at removing elevated concentrations of metals through oxidation and precipitation (Tarutis 1999; Watzlaf 2004). Effective metal removal rates in aerobic wetlands have been documented in Minnesota at the Dunka Mine in Babbitt (ITRC 2010) and have been the subject of numerous Minnesota Department of Natural Resources research projects (MDNR undated). Subsurface flow and vertical upflow wetlands are designed to limit atmospheric oxygen transfer and promote anaerobic conditions, limiting sulfate cycling in the wetlands and decreasing the potential for nuisance odor issues created by hydrogen sulfide emissions. These conditions should favor sulfate reducing bacteria and the formation of insoluble metal sulfides, which will be tested by PolyMet. However, the presence of alternate electron acceptors such as ferric iron, nitrate, and especially oxygen, would decrease the sulfate removal efficiency, as other microbial populations capable of utilizing these electron acceptors would out-compete the SRB.

3.3 Conceptual Field-Scale Pilot System

The intent of the field-scale pilot test is to confirm and further refine testing data obtained during previous proof-of-concept bench-scale testing of the anaerobic reduction process and to determine operational requirements for a full scale implementation. A conceptual field-scale pilot system test is shown in **Figure 1**.

Influent water will flow through a covered underflow, engineered wetland at a rate between 1-10 gallons per minute (gpm), with a steady state flow of 2.5 gpm (design flow). We will perform tests to achieve the maximum practical reduction for sulfate, which we expect to be approximately 100 mg/L. The system will be designed to target less than 100 milligrams per liter (mg/L) sulfate in the effluent. Drainage piping and stone will be installed to promote drainage of non-targeted water around the engineered wetlands. The pilot scale system will be lined with a 60-mil high density polyethylene (HDPE) liner (0.060-inch thickness) placed between layers of non-woven geotextile. Organic substrate with potential media amendments (e.g., zero valent iron, iron bearing rock/minerals, etc.) will be placed to a depth of four feet within the engineered wetland. Organic substrate will likely include hay, cow manure, nutshells, chitin, and woodchips, locally sourced as feasible. Additionally, use of fully digested bioreactor sludge as seed will be considered to enhance biological activity at the beginning of the pilot. Distribution laterals will be placed above the substrate to prevent short-circuiting of water through the system. A cover of mulch or woodchips, overlying an HDPE and geotextile liner, will be placed on top of the engineered wetland to provide freeze/thaw protection to the system. Additional benefits of the HDPE/geotextile liner will be to minimize cycling of sulfate by mitigating oxygen migration into the system, and to mitigate the potential for nuisance odors from hydrogen sulfide release. An outlet control structure will regulate water levels and effluent flow rates. It is likely that an aerobic polishing pond will be required to polish the engineered wetland effluent. The polishing pond will allow any residual iron or manganese to be oxidized, as well as to decrease biological oxygen demand (BOD) in the effluent prior to discharge from the treatment system.

3.4 Engineered Wetland Pilot Test

3.4.1 Objectives

The purpose of the engineered wetland pilot test is to determine the efficacy of the treatment approach for achieving sulfate load reduction at the LTVSMC tailings basin seeps.

The primary objectives of the engineered wetland pilot test include the following:

- Complete a supporting bench scale test prior to pilot-scale implementation in order to determine an effective blend of carbon substrate and inorganic media that will be used in subsequent pilot testing and to assess different non-metal reagents that may be used for sulfur capture to enhance long-term stability of the sequestered sulfur.
- Determine the extent of sulfate reduction through a range of flow and loading rates in a field-scale configuration under the operating conditions of climate/temperature and seasonality, as well as conditions that exceed design operating conditions (slug tests) to characterize performance under stress conditions.
- Refine key design parameters, such as contaminant mass loading rate and reduction capacity of the substrate, to refine the full-scale engineered wetland design.
- Assess wetland capacity and sustainability, including expected and potential organics demand, byproducts, life cycle considerations (e.g., carbon substrate depletion, iron media depletion, etc.), maintenance requirements, and generated constituent solid wastes.
- Assess reductions to other POCs, such as elevated TDS and alkalinity, which may be addressed by polishing steps as needed.
- Assess the dynamics of potential byproducts that could impact downstream water quality.
- Identify site-specific construction/implementation concerns and refine field-scale implementation approaches.
- Establish capital and operating costs associated with a full-scale implementation of the subsurface flow, engineered wetlands technology.

Pilot testing will include implementation within the LTVSMC tailings basin. The engineered wetland pilot test will be staged in an area to access a slip stream of water from SD026. The proposed schedule is summarized in **Table 2**.

3.4.2 Bench Testing

Prior to implementation of pilot testing, a supporting bench-scale test will be completed to determine an effective mix of carbon substrate and inorganic media for the engineered wetlands. Non-metal reagents may also be tested to enhance long-term stability of sequestered sulfur. This substrate and media blend will be able to achieve optimal pH and redox conditions within the engineered wetland in order to mitigate the cycling of sulfides back to sulfate.

Bench testing will occur in a controlled setting and should take no more than two months. A 30-day bench test window will allow sufficient time to observe steady state conditions at the bench scale. This testing will provide useful data that should support the optimization of the engineered wetland to achieve precipitation of sulfides with metals such as iron, or as elemental sulfur.

3.4.3 Engineered Wetland Pilot Test Design

The following preliminary design and operation parameters were assumed:

- The wetland will be engineered to target a sulfate removal rate of 0.04 moles per day per square meter of substrate, based on various benchmarks established in the literature for low metals concentration water chemistry (Wildeman 1993, Gusek 2013).
- A volume of approximately 75 feet (ft) by 55 ft by 7 ft depth (not including sloping factors) will be excavated prior to constructing the engineered wetland. Additionally, a vehicle turn-around area and other minor road improvements adjacent to the pilot testing area may be required to promote safe passage during construction, operation, and monitoring.
- The engineered wetland will include a drainage and liner system, a four-foot depth of blended substrate and media, a layer of distribution laterals, and a mulch or woodchip layer with geotextile cover to provide freeze/thaw protection and to minimize cycling of sulfate in the system. Refer to Figure 1 for a conceptual design of this system.
- Flow through the engineered wetland will run in a down-flow configuration, with distribution laterals installed to dispense inflows evenly across the substrate.

3.4.4 Pilot Test Operation

The engineered wetland pilot test operation will include three phases. The first phase will involve initial startup and troubleshooting of the system. During this time, the system flow rate will be brought up to 2.5 gpm in an incremental fashion in order to achieve steady state conditions. This phase is expected to take three months to complete. An Operations and Maintenance (O&M) manual will be developed at the end of phase one operation and will contain the following:

- Influent and Effluent flow control operations
- System maintenance procedures
- Performance monitoring and measurement
- Troubleshooting guidelines
- Final field design review
- Site and logistics review

The second phase will be steady state operations of the pilot system at approximately 2.5 gpm. This phase will determine the sulfate load reduction capacity of the substrate and lifespan of any media amendments used in the system. This phase is expected to take nine to twelve months of system operation, with the option to continue operating the system for another nine to twelve months if the performance of system is sufficiently promising Long term operation of the engineered wetland is required in order to determine seasonal/climatic effects on the system as well as identify any long term performance issues the system may face.

The third and final phase of system operation will be performance testing. This phase will increase the flow and/or sulfate loading rates to the engineered wetland in a series of slug tests. These slug tests will push the limits of system performance, identify key issues with system operation, and identify the flow and loading limits of stable system operation. This phase is expected to take 3 months to complete.

After the three phases of engineered wetland pilot testing are complete, the system will be drained and winterized or decommissioned as necessary. The media will be sampled for visual analyses, as well as measurements including alkalinity, sulfur content and speciation, degradation, and percent composition of volatile solids.

3.4.5 Performance Monitoring

Performance monitoring will be conducted during each phase of pilot system operation as summarized in the table below for both field parameters and a suite of analytical samples. Field parameters will include: pH, temperature, specific conductance, oxidation-reduction potential, and dissolved oxygen. The analytical samples are described in the table below. Analytical sample collection, packaging, and shipping will follow applicable standard operating procedures. Samples will be shipped to a qualified laboratory following chain-of-custody procedures.

Sample Location	Analytical Suite
Influent	Total/dissolved metals, sulfate, TDS, total suspended solids (TSS), alkalinity, hardness, BOD, total organic carbon, and dissolved organic carbon
Engineered Wetland	Total/dissolved metals, sulfate, TDS, TSS, alkalinity, hardness, BOD, total organic carbon, and dissolved organic carbon
Effluent	Total/dissolved metals, sulfate, TDS, TSS, alkalinity, hardness, BOD, total organic carbon, and dissolved organic carbon
Polishing step effluent (if implemented)	Total/dissolved metals, sulfate, TDS, TSS, alkalinity, hardness, BOD, total organic carbon, and dissolved organic carbon

During the various phases of pilot testing, samples will be taken at variable frequency, as detailed below:

- During phase one of pilot testing, analytical samples will be collected weekly and field parameters will be collected twice per week. Additionally, the media will be characterized visually, as well as analyzed for alkalinity, sulfur content and speciation, degradation, and percent composition of volatile solids.
- During phase two of pilot testing, analytical samples will be collected twice per month and field parameters will be collected weekly.
- During phase three of pilot testing, analytical samples will be collected twice per month and field parameters will be collected weekly. Additional sampling may be required based on the slug testing timelines.
- After the pilot testing is complete, the media will be characterized visually, as well as analyzed for alkalinity, sulfur content and speciation, degradation, and percent composition of volatile solids.

Additionally, site and system conditions will be documented at the time of sampling. Flow rates will be calculated and recorded during each site visit. Any maintenance or operational challenges will be documented and addressed. Precipitation will be documented throughout testing.

Finally, a data logger will be placed into the effluent sump drain to record conductivity and specific conductance, temperature, and water depth at regular intervals of 60 minutes. Data from the logger will be downloaded monthly during analytical sampling events.

3.4.6 Design Basis Assumptions

The engineered treatment wetland is designed to handle a flow of 2.0 gpm. This represents the nominal consistent flow rate expected to the pilot scale test. The engineered wetland influent will be supplied by a slip stream from the SD026 pumpback system. During later phases of the pilot testing program, influent flow rates will be increased to “push” the system for determination of limits of operation relative to hydraulic and mass loading.

The engineered wetland design is sized based on the average sulfate concentration at SD026 (183 mg/L), and a sulfate reduction rate based on the goal of reducing sulfate concentrations to 100 mg/L or less. The target sulfate reduction rate is 0.04 moles per day per square meter of substrate. Based on flow and loading calculations (Table 3), the dimensions of the pilot scale engineered wetlands are approximately 70 feet in length, 50 feet in width, and 4 feet of substrate depth (total wetland depth of approximately 7 feet). This sizing includes a 10% volume allowance for blending of inorganic amendments such as zero valent iron if bench testing indicates this step is necessary. A detailed basis of design calculation can be found in **Table 3**.

4 SCHEDULE AND REPORTING

A preliminary schedule for the construction, operation, and reporting tasks associated with the engineered wetland pilot test is presented below, with a more detailed schedule presented in Table 2.

Quarterly reports will be prepared and submitted to PolyMet for the periods when the pilot test is operational. Quarterly reports will include summaries of available data, preliminary interpretation of the data, and discussion of operation and maintenance issues or challenges. A final report will be submitted to PolyMet following the conclusion of the pilot test.

Pilot testing and follow-up sampling activities will occur according to the schedules outlined in Table 2 and summarized below:

Engineered Wetland Pilot Test Schedule	
Submittal of Engineered Wetland Pilot Test Work Plan:	Sep 2016
Agency approval of Work Plan:	Oct 2016
Finalize design; procurement of supplies:	Dec 2016 through Feb 2017
Supporting bench testing:	Jan through Feb 2017
Construction/startup of engineered wetland:	Apr through May 2017
Engineered wetland system operation:	Jun 2017 through Oct 2018
Phase One:	Jun through Aug 2017
Phase Two:	Aug 2017 through Aug 2018
Phase Three:	Aug through Oct 2018
Submittal of final engineered wetland pilot test report:	Dec 2018

4.1 Engineered Treatment Wetlands in Mine Planning

PolyMet plans to implement this work plan in the spring of 2017. The test work under this plan will occur in parallel with the permitting process, and potentially also in parallel with construction of the project, which is estimated to last for two years once permits are received. If engineered wetland treatment is demonstrated to be successful one year prior to the commencement of operations, PolyMet will propose a transition from mechanical water treatment to non-mechanical water treatment in its contingency reclamation estimate.

5 REFERENCES

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TABLES

Table 1 - SD026 Historical Water Quality (2005 - 2011)

	Parameter	Units	# of Samples	Minimum	Maximum	Average
Required Monitoring Parameters	Cis-1,2-Dichloroethylene	ug/L	6	<0.5	<1	<0.83
	Benzene	ug/L	6	<.5	<1	<.83
	Bicarbonates (Alkalinity as CaCO3)	mg/L	58	254	687	454
	Boron	ug/L	26	140	286	238
	Calcium	mg/L	54	53.2	96	81
	Cations, Total	meq/L	7	13.9	16	15
	Chloride	mg/L	48	7.5	16.7	12.6
	Chloroform	ug/L	6	<1	<2	<1.2
	Cobalt	ug/L	26	<.2	2.5	0.18
	Ethyl Benzene	ug/L	6	<1	<1	<1
	Flow	mgd	83	0	1.82	0.64
	Fluoride	mg/L	26	1.28	3.4	2.23
	Hardness, Carbonate (as CaCO3)	mg/L	37	294	537	463
	Magnesium	mg/L	54	55.5	121	100
	Manganese	ug/L	26	161	2190	636
	Mercury, Low Level	ng/L	26	<.05	2.1	0.53
	Molybdenum	ug/L	26	14.2	52.8	26.6
	Organics, Diesel Range	mg/L	78	<0.08	0.4	<.02
	pH	Std Units	83	7.3	8.4	8.0
	Potassium	mg/L	9	6.39	14.8	9.5
	Sodium, % of Total Cations	%	7	16	22.8	18.8
	Sodium	mg/L	7	35.7	52.9	46.9
	Solids, Total Dissolved (TDS)	mg/L	48	483	866	730
	Solids, Total Suspended (TSS)	mg/L	64	<1	16	2.96
	Specific Conductance	umh/cm	83	728	1350	1115
	Sulfate	mg/L	58	115	360	183
	Tetrachloroethylene	ug/L	6	<1	<1	<1
	Toluene	ug/L	6	<1	<1	<1
	Trichloroethylene	ug/L	6	<1	<1	<1
	Xylene, M&P	ug/L	6	<1	<2	<1.6
	Xylene, O	ug/L	6	<1	<1	<1
Non-Required Monitoring Parameters	Arsenic	ug/L	1	<2	<2	<2
	Bromide	mg/L	2	<.5	<.5	<.5
	Copper	ug/L	2	<2	<2	<2
	Hardness, Total, as CaCO3	mg/L	58	361	780	610
	Iron	mg/L	1	0.048	0.048	0.048
	Nickel	ug/L	1	<2	<2	<2
	Nitrogen, Ammonia as N	mg/L	1	0.15	0.15	0.15
	Nitrogen, Nitrate+Nitrite as N	mg/L	1	<.1	<.1	<.1
	Phosphorous, Total as P	mg/L	1	0.014	0.014	0.014
	Salinity	Std Units	10	0.3	0.6	0.5
	Selenium	ug/L	1	<2	<2	<2
	Surrogate 1,2-Dichloroethane-d4	%	4	99.2	109	106
	Surrogate Bromofluorobenzene	%	4	98.9	104	101
	Surrogate Toluene-d8	%	4	97.9	107	101
	Total Organic Carbon	mg/L	2	4.4	4.4	4.4
	Trans-1,2-Dichloroethylene	ug/L	1	<1	<1	<1
	Zinc	ug/L	1	<25	<25	<25

Table 2 - Engineered Wetland Pilot Test Schedule

Engineered Wetland Pilot Test Schedule - 2016 & 2017	2016				2017											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Engineered Wetland Pilot Test Work Plan																
Submittal of Engineered Wetland Pilot Test Work Plan																
Agency approval of Work Plan																
Finalize design; procurement of supplies:																
Supporting bench testing:																
Construction/startup of engineered wetland:																
Engineered wetland system operation:																
Phase One:																
Phase Two:																
Phase Three:																
Submittal of final engineered wetland pilot test report:																

Engineered Wetland Pilot Test Schedule - 2018	2018											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Engineered wetland system operation:												
Phase Two:												
Phase Three:												
Submittal of final engineered wetland pilot test report:												

Table 3 - Detailed Design Basis Calculations

Preliminary Sulfate Reducing Engineered Wetland (SREW) Sizing
Polymet
Tailings Basin

Prepared By:	L. Weidemann
Checked By:	J. Forbort
Revision No.:	001
Date:	9/25/2016

Piped Seep Flow Rate

Slip stream of tailings basin seep water ranging from 1-10 gpm.

Estimated Flow Rate =	2.5	gpm
	14,000	L/day

Calculate Minimum Volume of Organic Substrate Required

Volume of Organic Substrates Based on the Following Loading Rate (Gusek et. al, 2013)
Ranging from 0.04 to 0.08 moles/day/m^3

Target Metals Loading Rate =	0.04	mol/day/m^3

Volume of Organic Substrates Based on Sulfate Concentration

Sulfate Concentration =	183	mg/L
Sulfate Loading =	2,560,000	mg/day
	2,560	g/day

Sulfate Removal Targets

Sulfate Concentration =	183	mg/L
Sulfate Effluent Target =	90	mg/L
Sulfate Target Removal =	93	mg/L
Sulfate Target Removal =	1,300	g/day
Molecular Weight of Sulfate =	96.06	g/mol
Sulfate Loading Molar Basis =	13.5	mol/day
Volume of Organics =	338	m^3
	11,900	ft^3
Empty Bed	24	days

Calculate Combined Volume of Organic Substrate and Zero Valent Iron

Substrate will be a Mixture of 90% Organic Material and 10% Zero Valent Iron (or similar amendment)

Volume of Iron =	1,322	ft^3
Total Combined Volume =	13,200	ft^3

Calculate Base Area of SRBR Based on Substrate Volume

Min. Substrate Thickness =	4	feet
Total Area (Volume Based) =	3,300	ft^2

SRBR Sizing Summary

Minimum Substrate Volumes

Volume of Organics =	11,900	ft^3
Volume of Limestone =	1,322	ft^3
Minimum Substrate Volume =	13,200	ft^3

Minimum Base Area for SRBR

Total Area (Volume Based) =	3,300	ft^2
Factor of Safety =	1.0	unitless
Total Base Area of SRBR =	3,300	ft^2
Depth Substrate =	4	ft
Length =	70	ft
Width =	47	ft

References

Gusek, J.J., Buchanan, R.J. Jr., and Sorells, D. (2013). Infiltration-Diverting Cap and Full-Scale Biochemical Reactor Operation at the Iron King/Copper Chief Mine, Arizona. Proceedings, Internation Mine Water Association Annual Conference, pg. 581-586.

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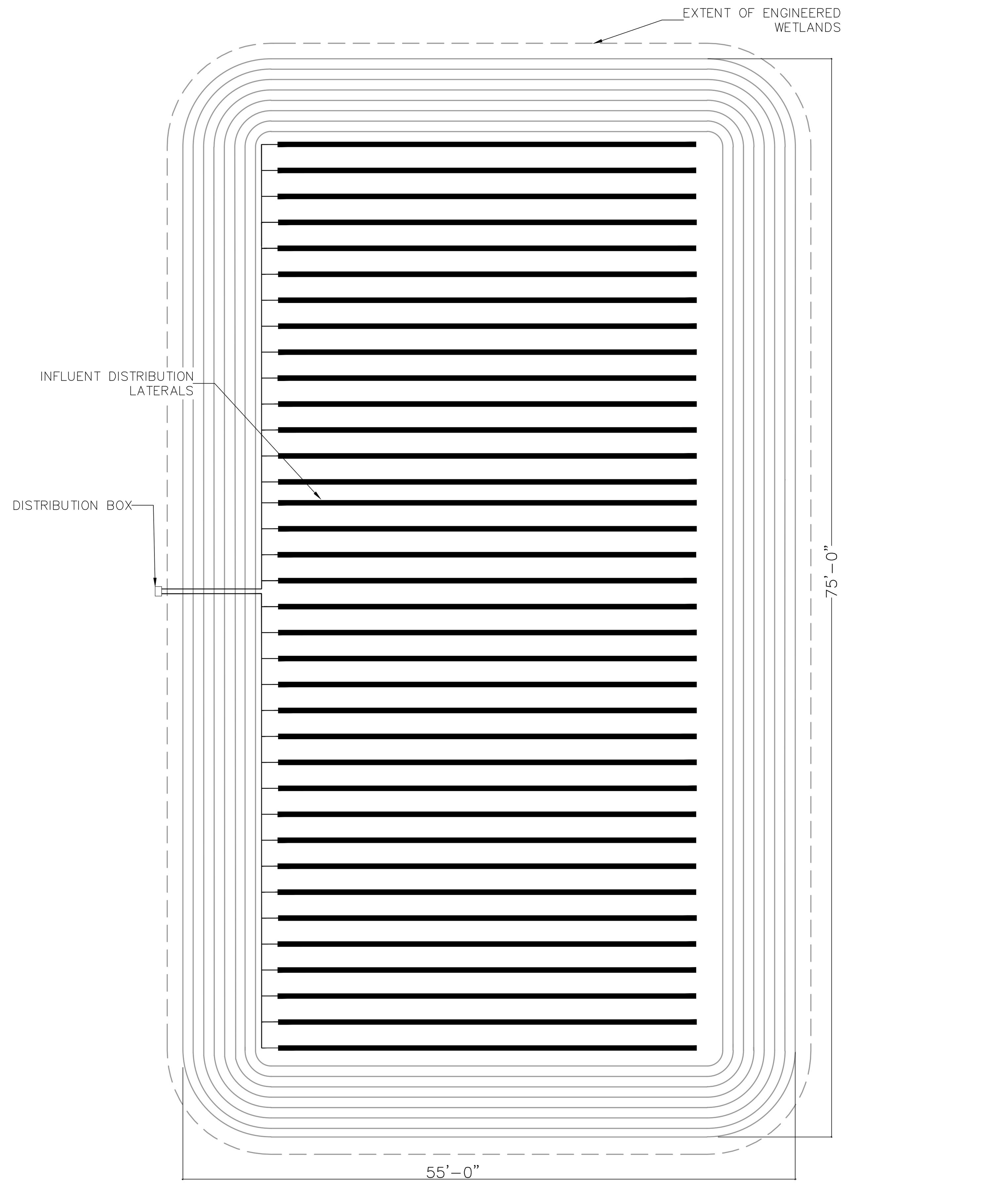
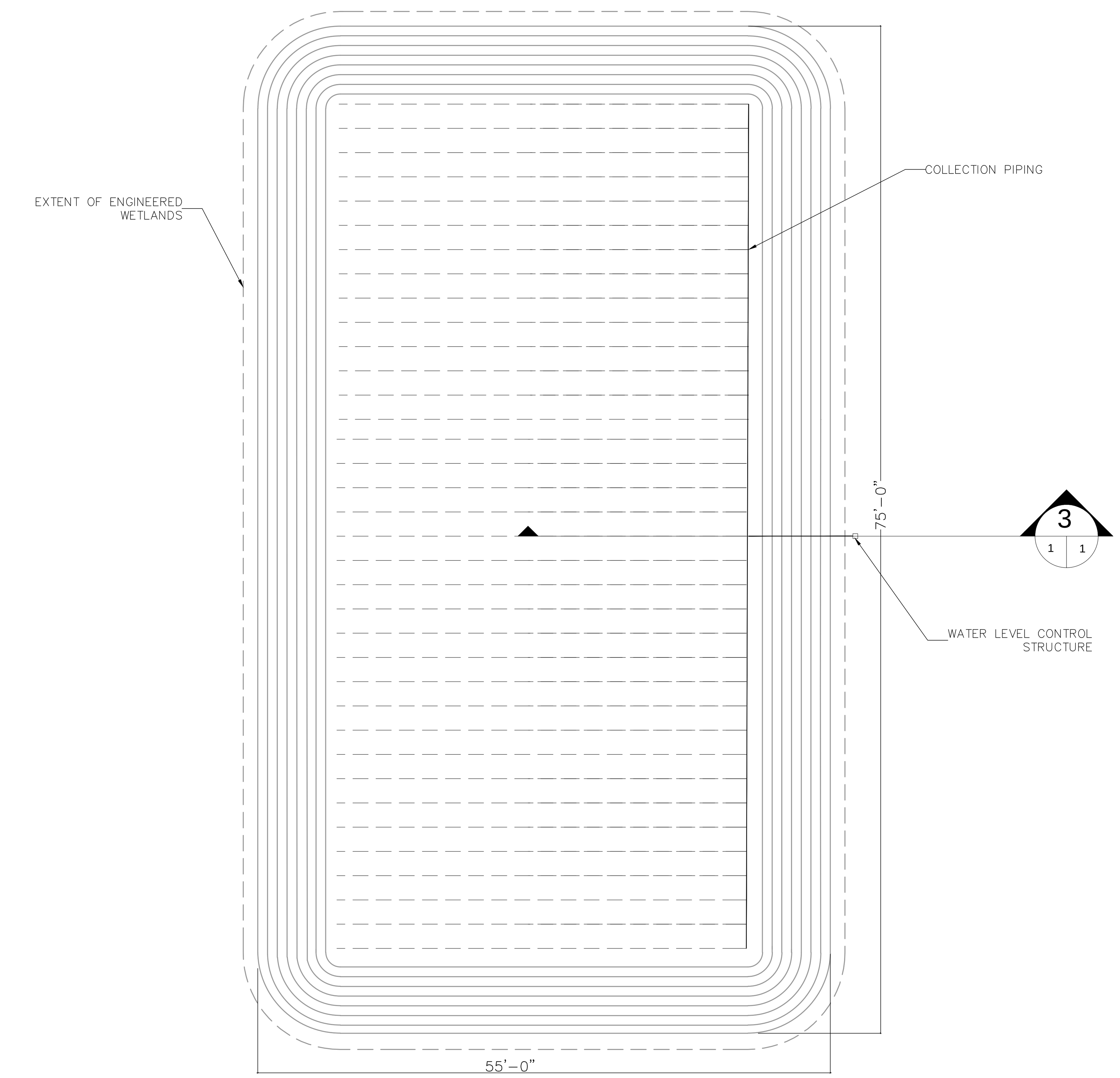
FIGURES



1 ENGINEERED WETLANDS INFILTRATION SYSTEM

NOT TO SCALE

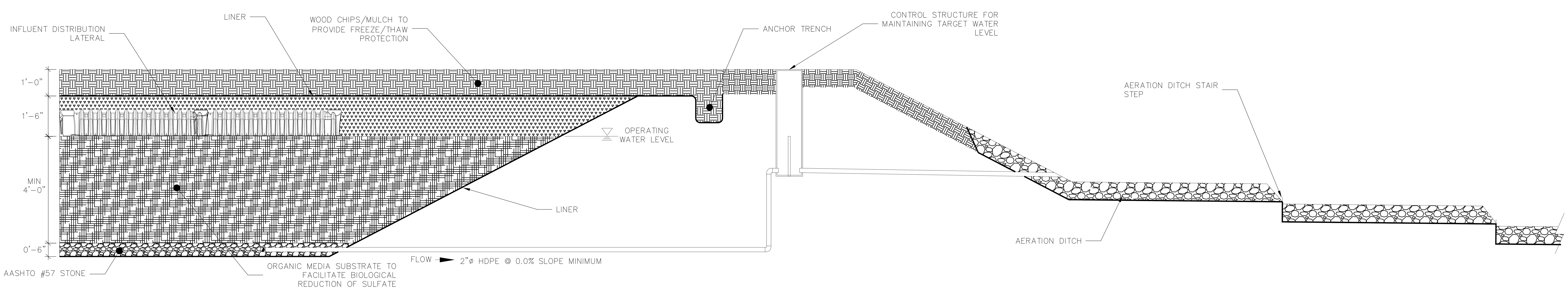


2 ENGINEERED WETLANDS DRAINAGE SYSTEM

NOT TO SCALE

NOTES:

1. FIELD SCALE PILOT DESIGN INTENDED FOR IMPLEMENTATION ON THE TAILINGS IMPOUNDMENT. DESIGN INCLUDES LINERS TO PREVENT SLIP STREAM OF WATER FROM THE EXISTING PUMP BACK SYSTEM FROM PERCOLATING INTO TAILINGS.
2. FULL-SCALE DESIGN WOULD BE INSTALLED TO RECEIVE WATER FROM THE TAILINGS BASIN THROUGH A FUNNEL AND GATE APPROACH WITH THE HYDRAULIC BARRIER.
3. THIS DESIGN IS ONLY INTENDED FOR THE FIELD SCALE PILOT SYSTEM. FULL-SCALE DESIGN WILL BE LARGER AND WILL CONSIST OF MORE ROBUST COMPONENTS.



3 TYPICAL ENGINEERED WETLANDS PROFILE

1/2" = 1'

SCALE(S) AS INDICATED

THIS BAR REPRESENTS ONE INCH ON THE ORIGINAL DRAWING: USE TO VERIFY FIGURE REPRODUCTION SCALE

No.	Date	Revisions	By	Ckd

Professional Engineer's Name

Professional Engineer's No.

State	Date Signed	Project Mgr.
		JEF
Designed by	Drawn by	Checked by
JEF	JVA	JEF

NOT FOR CONSTRUCTION

ARCADIS Design & Consultancy for natural and built assets

ARCADIS U.S., INC.

POLYMET MINING
NORTHMET MINING PROJECT

FIELD SCALE PILOT SYSTEM

ARCADIS Project No.
MN000643.0001.00002

Date
SEPTEMBER 2016

ARCADIS
430 First Avenue North
Suite 720
Minneapolis, Minnesota 55401
TEL.612.339.9434

Arcadis U.S., Inc.

630 Plaza Drive

Suite 100

Highlands Ranch, Colorado 80129

Tel 720 344 3500

Fax 720 344 3535

www.arcadis.com