APPENDIX K
GEOMEMBRANE PUNCTURE PROTECTION

TECHNICAL MEMORANDUM

DATE: September 10, 2014

FROM: Tony Donovan, P.E.

REVIEWED: Mark Peters, P.E.

SUBJECT: Cap System Design and Membrane Puncture Evaluation
Callahan Mine Superfund Site
Brooksville, Maine

PROJECT: 3612-11-2201

1.0 Introduction

AMEC Environment & Infrastructure, Inc. (AMEC) has performed an evaluation of the proposed low permeable cap system and cover soils for remediation of the Tailings Impoundment at the Callahan Mine Superfund Site (Site) in the Town of Brooksville Maine. This evaluation has been completed to demonstrate the proposed cap system meets the remedial action objectives as described in the Record of Decision (ROD) and listed below:

- Minimize acid rock drainage from the Tailings Impoundment
- Develop structural stability of the Tailings Impoundment through dewatering

In addition this evaluation has been completed to demonstrate the proposed crushed stone cover will not subject the geomembrane to puncturing during or after remedial construction activities.

2.0 Project Background

The Site was subject to intermittent exploration and mining of copper, lead, and zinc from the 1880s to the 1970s. Callahan Mining Corporation (Callahan) implemented the most extensive mining operations from 1968 through 1972. During this time, Callahan mined approximately five million tons of waste rock and 800,000 tons of ore-bearing rock from an open-pit mine. The waste rock was disposed of on the Site and also utilized to construct a starter dike and subsequent lifts at the Tailings Impoundment. The ore-bearing rock was pulverized producing slurry comprised of water, fine sand, silt, and clay-sized rock particles. Copper, lead, and zinc were separated from the slurry utilizing a floatation process and the remaining slurry was discharged to the Tailings Impoundment.

2.2 Planned Remedial Action

The design objectives for the Tailings Impoundment remedy include reducing the contaminant load to adjacent Goose Pond and improve both static and seismic stability in order to minimize the potential for a slope failure to occur. A low permeability cover system is proposed to reduce the runoff and discharge of metals-laden surface water and seepage of metals-contaminated groundwater from the Tailings Impoundment. These waters currently discharge to the Goose Pond estuary. The cover system will also reduce infiltration and allow for dewatering of the Tailings Impoundment to improve overall stability.

To the extent possible, materials for the cover system will be generated from on-site resources. The roads leading to the site are narrow and winding and local residents have expressed concerns about the amount of truck traffic generated by the remediation project. Therefore, a concerted effort has been made to minimize the amount of imported materials. A rock quarry is proposed to provide for crushed stone and rip rap needed for cap cover soils, road construction, and drainage stabilization.

A groundwater model has been developed for the Site to evaluate dewatering options within the Tailings Impoundment both during construction and after remedial activities are complete. The evaluation indicated that a series of horizontal wells at various depths would be an effective method of dewatering the Tailings Impoundment. Discharge from the horizontal wells will be transferred to an engineered treatment wetland through a series of collection pipes and structures with valves to monitor and control flow rates.

2.2 Tailings Impoundment Cap Design

The Tailings Impoundment will be remediated pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). The remediation will incorporate a low-permeable geosynthetic cap system to reduce acid rock drainage and increase overall stability of the Tailings Impoundment.

The following table and figure summarize the proposed cap components within the Tailings Impoundment.

Table 1. Cap Design Summary

Cap Component	Proposed Material
Soil Cover	15-inches (38 cm)
Geocomposite Drainage Layer	Transmissivity ≥ 1.7 x 10^{-3} cm^2/s
Two-Layer Low Permeability Layer	60-mil Linear Low Density Polyethylene (LLDPE) Membrane Geosynthetic Clay Liner Hydraulic Conductivity ≤ 5 x 10^{-9} cm/s

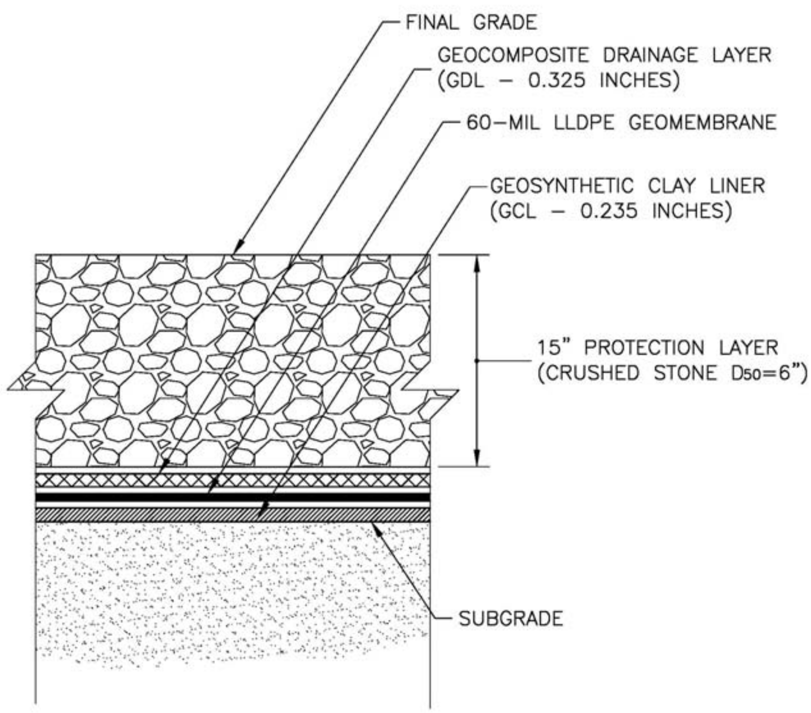

Figure 1. Proposed Tailings Impoundment Cap Cross Section

The proposed cap components for the Tailings Impoundment are consistent with appropriate regulations and guidance documents with the exception of soil cover overlying the geosynthetic cap materials. An objective in the remedial design was to minimize the volume of truck traffic to the Site due to narrow and winding roads as well as concerns expressed by the local residents. Based on these criteria, a final cover consisting of crushed stone was selected for the Tailings Impoundment as this material can be generated through an on-site quarry operation and eliminate the need for importing material capable of supporting vegetative growth.

The total required thickness of crushed stone over the low-permeable geosynthetic cap system was determined based on a D_{50} stone size of 6-inches and a maximum particle size of 9-inches. A total crushed stone thickness of 15-inches was selected based on providing a minimum lift thickness of 1.5 times the maximum stone size.

2.3 Geomembrane Puncture Evaluation

The crushed stone cover material will be placed in a single lift directly on the Geocomposite Drainage Layer (GDL) with a low ground pressure dozer. However, construction trucks delivering material for placement will exert a larger force on the geomembrane when driven directly on the installed 15-inch stone layer. An analysis was completed to evaluate the puncture resistance of the geomembrane during the described construction loading and is attached at the end of this technical memorandum. The puncture resistance index property determined by ASTM D 4833 was reduced by a factor of four for the analysis to provide a conservative factory of safety against puncture. Additionally, the protective effects of the overlying Geocomposite Drainage Layer (GDL) have been ignored in this evaluation.

2.4 Conclusion

The proposed low-permeability geosynthetic cap system with a 15-inch layer of D_{50}
crushed stone cover soil will satisfy the required remedial objectives. The factor of safety against puncture of the geomembrane during construction has been conservatively determined to be 2.14. In addition, the allowable puncture resistance of the geomembrane was reduces by a factor of two and the protective effects of the GDL were not included in the evaluation. The proposed cap system will significantly reduce infiltration into and assist with lowering the groundwater level within the Tailings Impoundment which in affect will increase the overall static and seismic stability.

ATTACHMENT

GEOMEMBRANE PUNCTURE PROTECTION EVALUATION

Project:	Callahan Mine Superfund Site	Created by:	T Donovan
	OU3 Tailings Impoundment Remedial Design	Date:	07/22/14
	Brooksville, Maine	Checked by:	M Peters
Job No:	3612-11-2201	Date:	7/23/2014
Evaluation:	Geomembrane Puncture Protection	Sheet:	1 of 3

Problem Statement:

Evaluate the puncture resistance of the 60-mil linear low density polyethylene (LLDPE) geomembrane assuming the overlying crushed stone protection layer is placed directly on the LLDPE during construction. The evaluation ignores the geocomposite draignae layer (GDL) to be placed directly above the LLDPE liner to assist in cap drainage and protect the liner from puncturing during construction.

Method:

Based on the Puncture Resistance evaluation method defined in *Designing with Geosynthetics*, 4th Edition, by Robert M. Koerner, dated 1998.

Assumptions:

The maximum particle size of the crushed stone collection layer is 9-inches with the potential for 75% of the particle to protrude beyond the bottom plane of the layer in the absence of the linear low density polyethelne liner

The LLDPE geomembrane is installed on a fine grain soil layer consisting of 3/8-inch minus material.

To account for reduction factors in the long term material performance and factors of safety, the puncture resistance index property determined by ASTM D 4833 is reduced by a factor of 4 for the purpose of this evaluation.

The crushed stone protection layer will be installed in a single 15-inch lift by a low ground pressure dozer with a maximum ground pressure of 5 psi. However, construction trucks delivering material for placement will exert a larger load on the geomembrane when driven directly on the 15-inch installed layer. Of all the construction equipment utilized, the pressure from a loaded tri-axle dump truck is the greatest, and is used as the worst case construction short-term loading scenario for this evaluation.

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$F_{reqd} = p' \times d_a^2 \times S_1 \times S_2 \times S_3$

- F_{reqd} = required vertical force to be resisted
- d_a = average diameter of the puncturing aggregate, in
- p' = pressure exerted on the GM, psi
- S_1 = protrusion factor = H_h/d_a
- H_h = Protrusion height $\leq$ d_a, in
- S_2 = scale factor to adjust the ASTM D48933 puncture test value (uses an 8.0 mm diameter puncture probe) to the diameter of the puncturing object (= d_{probe}/d_a)
- S_3 = shape factor to adjust the ASTM D4833 flat puncture probe to the actual shape of the puncturing object = $1-A_p/A_c$
- A_p = projected area of the puncturing object
- A_c = area of the smallest circumscribed circle around the puncturing object
- F_{D4833} = puncture resistance force of 60-mil LLDPE per ASTM D4833 and reported as the minimum allowable index property in GRI-GM17, lb

Given:

d_a =	4.00	in
H_h =	3.00	in
A_p/A_c =	0.80	rounded sand
	0.70	bank gravel
	0.40	crushed rock
	0.30	shot rock
d_{probe} =	0.31	in
F_{D4833} =	84.00	lb
	See attached Spec	

Calculate:

$S_1 = H_h/d_a$

0.75

$S_2 = d_{probe}/d_a$

0.08

$S_3 = 1 - A_p/A_c$

0.60

Scenario No. 1: Short-term loading during construction due to a tri-axle dump truck

p' = 31 psi

Assuming 15 inches of Crushed Stone Cover above Membrane
See Table 1, "Contact Pressure on GM for Wheeled Vehicle Loads"

$F_{reqd} = p' \times d_a^2 \times S_1 \times S_2 \times S_3$

= 17.57 lbs

$F_{allow} = F_{D4833} / 2$

Allowable puncture resistance force conservatively reduced by a factor of 4

= 21.00 lbs

Factor of Safety, FS

FS = F_{allow}/F_{reqd}

FS = **1.19** therefore, loading does not approach the puncture resistance of the 60-mil LLDPE Geomembrane

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Table 1: Contact Pressure on Geomembrane for Wheeled Vehicle Loads

Soil Cover Depth (in)	Soil P (psi)	Tri-Axle Dump Truck		Articulated Dump Truck	
		Contact Tire P (psi)	Total Contact P (psi)	Contact Tire P (psi)	Total Contact P (psi)
6	0.38	39.33	39.71	23.77	24.15
8	0.51	27.52	28.03	18.26	18.77
10	0.64	20.35	20.99	14.47	15.11
12	0.76	15.66	16.42	11.75	12.52
14	0.89	12.43	13.32	9.73	10.62
15	1.13	29.91	**31.04**	8.91	10.04
16	1.02	10.10	11.12	8.19	9.21
18	1.15	8.37	9.52	6.99	8.14
20	1.27	7.05	8.33	6.03	7.31
22	1.40	6.02	7.42	5.26	6.66
24	1.53	5.20	6.73	4.63	6.16
30	1.91	3.55	5.46	3.29	5.20
36	2.29	2.57	4.86	2.46	4.75
48	3.06	1.53	4.58	1.52	4.58

Notes:
1. P = Pressure measured in pounds per square inch (psi).
2. Total contact pressure is the sum of soil pressure and tire contact pressure.
3. Assumes a 1:1 load distribution through the depth of soil cover.
4. Assumes that the tri-axle dump truck has dual tires on the rear axle inflated to a maximum tire pressure of 120 psi with a contact area of 70 in^2. See the attached calculations.
5. Assumes that the articulated dump truck has a maximum tire pressure of 71 psi with a contact area of 270 in^2. See the attached calculations.

Figure 1: Contact Pressure on Geomembrane