



Technical Memorandum

To:	<u>Kathy Arnold</u>	From:	<u>Mike Thornbrue</u>
Company:	<u>Rosemont Copper Company</u>	Date:	<u>August 31, 2010</u>
Re:	<u>Rosemont Settling Basin BADCT Analysis</u>	Doc #:	<u>238/10-320877-5.3</u>
CC:	<u>David R. Krizek, P.E. (Tetra Tech)</u>		

1.0 Introduction

This Technical Memorandum provides an analysis of the Best Available Demonstrated Control Technology (BADCT) alternatives for the Settling Basin at the Rosemont Copper Project (Project) in Pima County, Arizona. This information is in response to the April 14, 2010 Comprehensive Request for Additional Information from the Arizona Department of Environmental Quality (ADEQ) to Rosemont Copper Company (Rosemont). Specifically, this Technical Memorandum provides partial answers to item no. 26 on page 12 of 18.

(p.4) - The Settling Basin Embankment has a maximum height of 65 feet and a total storage capacity of 180 acre-feet.

Pursuant to A.C.C. R12-15-1206(B)(2)(a), the Settling Basin, with 65 feet embankment height and a total storage capacity of 180 acre-feet appears to be a jurisdictional dam. The applicant is advised to obtain ADWR approval for the construction and operation of Settling Basin Embankment.

Additionally, please provide the following information concerning facility design and estimated performance (aquifer loading calculation):

- *maximum operating depth and design freeboard;*
- *design capacity of the Settling Basin (maximum tonnage of tailings - solids that can be stored in the basin;*
- *longitudinal cross-section of the Settling Basin showing anchor trench or alternative method to secure GCL;*
- *demonstration that the downward thrust of stored tailings will not cause damage or puncture the GCL at the interface of 1.5-inch minus protective layer of rock material; and*
- *aquifer loading calculation for the preferred BADCT alternative and comparison with other feasible alternatives for cost vs. discharge reduction.*

This Technical Memorandum addresses the last two (2) items from the list above. The remaining items have been, or will be, addressed separately as follows:

- Rosemont acknowledged that the Settling Basin Embankment may be an ADWR Jurisdiction Dam in a letter prepared by Kimberlite Water Quality Permitting and Compliance Services L.L.C. (Kimberlite) dated July 15, 2010 (Kimberlite, 2010);
- M3 Engineering & Technology Corp. (M3) is addressing the following items:
 - Maximum operating depth and design freeboard;
 - Design capacity of the Settling Basin (maximum tonnage of tailings – solids that can be stored in the basin; and
 - Longitudinal cross-section of the Settling Basin showing anchor trench or alternative method to secure GCL.

2.0 Puncture of the GCL by the Protective Rock

The liner system for the Settling Basin, as presented in the APP application (Tetra Tech, 2009) and in the *Process Water Pond, Temporary Storage Pond, and Settling Basin Design Report* (M3, 2009), has been modified. The liner system no longer will be comprised of a geosynthetic clay liner (GCL) overlain by a protective rock layer. The new design will consist of a high-density, polyethylene (HDPE) liner underlain by a GCL. The updated design of the Settling Basin is provided in *PWTS Pond and Settling Basin Design Revisions* (M3, 2010) dated August 27, 2010.

Based on this design modification, a demonstration is no longer required showing that the downward thrust of the tailings would not cause damage to the GCL at the interface of 1.5-inch minus protective layer of rock material.

Heavy equipment will no longer be employed as a measure to clean-out the basin. The Settling Basin has been designed such that tailings will be removed using a slurry pump lowered into the pond by a jib crane.

3.0 Design Information

The Settling Basin for the Project is intended for temporary storage of unfiltered tailings slurry during process upsets related to the Tailings Filter Plant. The tailings slurry will be the underflow from the tailings thickeners and will be about 65% tailings solids and 35% water.

The following sections will address the following liner system designs:

- The initial design of the Settling Basin;
- A modified BADCT liner system for a non-stormwater pond;
- A prescriptive BADCT liner system for a non-stormwater pond; and
- A geomembrane/GCL (GM/GCL) one-product liner system.

3.1 Initial Design

The Settling Basin was designed by M3 as documented in the design report titled *Process Water Pond, Temporary Storage Pond, and Settling Basin Design Report* (M3, 2009).

The initial design of the Settling Basin liner system consisted of the following (from bottom to top):

- A prepared subgrade compacted to 95% of the maximum dry density as determined by ASTM D-698;
- A sodium bentonite GCL;
- A 1.5-foot thick layer of 1.5-inch minus protective rock;
- A wire mesh screen, anchored vertically through the protective rock layer to prevent displacement of the protective rock; and
- An additional 1.5-foot thick layer of protective rock sized to six (6) inch < D₅₀ < 12-inch.

3.2 Modified BADCT Liner System for a Non-Stormwater Pond

The design has now been revised to be similar to other non-stormwater pond designs at the Project and will include the following liner system (from bottom to top):

- A prepared subgrade;
- A sodium bentonite GCL; and
- A minimum 60-mil high density, polyethylene (HDPE) geomembrane liner.

3.3 Prescriptive BADCT Liner System for a Non-Stormwater Pond

The Prescriptive BADCT design guidance for a non-stormwater pond includes the following liner system (from bottom to top):

- A 3/8-inch minus prepared subgrade compacted to a minimum of 95% of the maximum dry density as determined by ASTM-D698; and
- A minimum 60-mil HDPE geomembrane liner.

4.0 Equations

The calculations used in this memorandum are based on Darcy's Law, Giroud's Equation, or Bernoulli's Equation for free flow through an opening.

4.1 Darcy's Law

The leakage through a low permeability soil layer can be calculated using Darcy's Law:

$$Q = \frac{k * A * h}{t}$$

Where:

- Q = Rate of liquid migration or Total Potential Leakage (TPL) [cubic meters per second (m³/s)];
- A = Area of the pond [square meters (m²)];
- k = Hydraulic conductivity of the low permeability component (m/s);
- h = Height of liquid above the low permeability soil layer (m); and
- t = Thickness of the low permeability soil layer (m).

4.2 Giroud's Equation

The leakage through a circular defect in a liner system that includes a low permeability component (soil or geosynthetic clay liner) along with a geomembrane liner was estimated using Giroud's Equation (Giroud, 1997):

$$Q = 0.976C_{qo} \left[1 + 0.1 \left(\frac{h}{ts} \right)^{0.95} \right] d^{0.2} h^{0.9} k_s^{0.74}$$

Where:

Q = Rate of liquid migration or potential leakage rate (PLR) [cubic meters per second per defect (m³/s/defect)];

C_{qo} = Contact quality factor that represents the contact interface between the low permeability component and the geomembrane liner (dimensionless);

This factor is dimensionless and is defined as follows:

- Poor contact: 1.15;
- Good contact: 0.21; and
- Intimate contact: 0.01.

h = Height of liquid on top of geomembrane (m);

Giroud's Equation assumes that the hydraulic head on the liner to be less than or equal to three (3) meters (m). The empirical investigations published by Giroud and Bonaparte (1989) showed that permeation, leakage through a geomembrane liner without holes may not be negligible in scenarios with more than three (3) meters of hydraulic head. Giroud's Equation does not take permeation into account.

t_s = Thickness of the low permeability component (m);

d = Diameter of circular defect (m); and

Giroud's Equation assumes a circular defect in the geomembrane liner having a diameter between 0.0005 m and 0.025 m. A single, two (2) millimeter (mm) diameter [area (a) = 3.14 mm²] hole per acre allows for seam defects that still may exist after intensive quality assurance resulting from fabrication or installation factors (Giroud and Bonaparte, 1989).

k_s = Hydraulic conductivity of the low permeability component (m/s).

A standard GCL permeability of 5x10⁻⁹ cm/s was selected for the GCL calculations (Cetco, 2009).

Once the PLR (m³/s/defect) is determined, it is multiplied by the Lined Surface Area (LSA) of the pond (in acres) and multiplied by the number of defects per acre to calculate the TPL.

$$TPL = PLR \frac{m^3}{s * defect} \times \frac{defects}{acre} \times LSA(acres) = TPL \frac{m^3}{s}$$

4.3 Bernoulli's Equation for Free Flow Through an Opening

The rate of liquid migration or PLR through a geomembrane liner that is not placed directly on a low permeability component can be calculated using Bernoulli's Equation for free flow through an opening.

$$Q = C_B a \sqrt{2gh_w}$$

Where:

- Q = rate of liquid migration or PLR through a geomembrane hole (m³/s/defect);
- C_B = Dimensionless coefficient related to the shape of the edges of the hole (for sharp edges C_B = 0.6);
- a = Hole area (m²);
- g = Acceleration due to gravity (m/s²); and
- h_w = Liquid depth on top of the geomembrane (m).

Once the PLR (m³/s/defect) is determined, it is multiplied by the Lined Surface Area (LSA) of the pond (in acres) and multiplied by the number of defects per acre to calculate the TPL.

$$TPL = PLR \frac{m^3}{s * defect} \times \frac{1 defect}{acre} \times LSA(aces) = TPL \frac{m^3}{s}$$

This equation was used to calculate the Alert Levels for the double-lined solution ponds. This equation can also be used to calculate the PLR through liner systems that do not utilize a GCL or low permeability soil layer beneath a geomembrane liner.

5.0 GCL with Protective Rock Liner System (Initial Design)

This section addresses the total potential leakage through a liner system consisting of the following (from bottom to top):

- A prepared subgrade;
- A GCL; and
- A protective rock layer that consists of:
 - 18-inches of 1.5-inch minus rock;
 - a wire mesh; and
 - 18-inches of protective run-of-mine (ROM) rock.

The leakage through this liner system can be approximated using Darcy's Law.

$$Q = \frac{k * A * h}{t}$$

Where:

- Q = Rate of liquid migration or PLR [cubic meters per second (m³/s)];
- A = Area of the pond [square meters (m²)];
- K = Hydraulic conductivity of the low permeability component (m/s);

- h = Height of liquid above the low permeability soil layer (m); and
- t = Thickness of the low permeability soil layer (m).

The PLR calculation results are expressed as cubic meters per second per defect (m³/s). This value is then converted to gallons per day (gpd).

For the Settling Basin, the maximum head on the liner would be about 35 feet and the total area of the pond would be 324,396.1 square feet (30,137.4 m² or 7.45 acres) at maximum build out. Therefore, the TPL can be calculated as follows:

$$TPL = \frac{5E - 11 \times 30,137.4 \times 10.67}{0.006} = \frac{0.0027m^3}{s}$$

$$TPL = \frac{0.0027m^3}{s} \times \frac{264.17 \text{ gallons}}{m^3} \times \frac{3600s}{hour} \times \frac{24hours}{day} = 61,162.6gpd$$

However, this calculation is not accurate because the head on the GCL is not 35 feet over the entire area of the pond. Therefore, it is appropriate to calculate the leakage using a modified approach where the leakage is calculated using the variable pond depths and the area of the pond that is below that depth. Table 1 (below) presents the revised calculations.

Table 1 Adjusted Settling Basin Leakage with GCL Only

Elevation	Depth (Feet)	Area at Depth (Acres)	h _w (Meters)	PLR (gpd/acre)	TPL (gpd/Interval)
4915	35	2.30	10.67	8,211.4	18,850
4920	30	0.44	9.14	7,038.3	3,088
4930	20	1.46	6.1	4,692.2	6,869
4940	10	1.57	3.1	2,346.1	3,690
4950	0	1.68	0	0	0
Total	35	7.45	10.67		32,497

Based on the adjusted calculations, the TPL for the Settling Basin would be 32,497 gpd or 22.6 gallons per minute (gpm) for a liner system consisting only of GCL.

It should be noted that these calculations are based on the behavior of a water solution. The tailings are anticipated to be 65% fine-grained solids. Therefore, the solids will tend to settle to the bottom of the pond with the water rising to the top.

Additionally, it is anticipated that the first time the Settling Basin is utilized, most likely early in the mine life during commissioning of the Tailings Filter Plant, tailings will settle into the protective rock on top of the GCL associated with this design. As stated in Section 7.2 of the APP application (Tetra Tech, 2009a), the tailings are anticipated to have a permeability of 10⁻⁶ cm/s, making them comparable with low permeability soil. Thus, once tailings would have settled into the protective rock, it would dry to form an additional low permeability layer, providing an additional degree of engineering control.

6.0 Modified BADCT Liner System

This section will assess the potential leakage through a liner system that consists of the following (from bottom to top):

- A prepared subgrade;

- A sodium bentonite GCL; and
- An HDPE geomembrane liner.

The leakage through a circular defect (puncture) in a liner system that includes a low permeability component (soil or GCL), along with a geomembrane liner, was estimated using Giroud's Equation (Giroud, 1997).

The following values were established to represent the variables of the equation.

- Height of liquid on top of geomembrane: The maximum head allowed by the design (10.67 meters) was selected;
- Contact quality factor (C_{qo}): The contact quality factor for good contact was used to represent the HDPE/GCL interface;
- Diameter of circular defect: A defect rate of one (1) hole per acre that is two (2) millimeters (mm) in diameter was selected. This defect rate is based on empirical investigations published by J.P. Giroud and Bonaparte (1989);
- Thickness of GCL: The calculation used a GCL having a thickness of six (6) mm underneath the geomembrane liner; and
- Hydraulic conductivity: A GCL permeability of 5×10^{-9} cm/s was selected for the GCL layer (Cetco, 2009).

Table 2 presents the PLR for a puncture in an HDPE/GCL liner system.

Table 2 PLR for a HDPE/GCL liner system

C_{qo} =	0.21	(dimensionless)
h =	10.67	(m)
d =	0.002	(m)
t_s =	0.0060	(m)
k_s =	5.0E-11	(m/s)
Q =	1.46E-06	PLR ($m^3/s/defect$)

The calculations yielded a PLR of $Q = 1.46E-6$ $m^3/s/defect$. This can be converted to gallons per day (gpd) per defect as follows:

$$\frac{1.46E-6 \text{ m}^3/s}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60s}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{33.40 \text{ gpd}}{\text{defect}}$$

To establish the TPL, the PLR is multiplied by the defect rate and the LSA of the pond in acres. The Settling Basin has a total LSA of 324,396.1 square feet or 7.45 acres. A defect rate of one (1) hole per acre was selected. A single, small hole per acre allows for seam defects resulting from fabrication or installation factors that still may exist after intensive quality assurance (Giroud and Bonaparte, 1989).

$$TPL = \frac{33.4 \text{ gpd}}{\text{defect}} \times \frac{1 \text{ defect}}{\text{acre}} \times 7.45 \text{ acres} = 248.83 \text{ gpd}$$

The calculations indicate that the Settling Basin could potentially discharge 249 gpd through incidental punctures in the liner system. However, this method of calculation indicates that each hole is located at the base of the pond. Therefore, it is appropriate to calculate the leakage

using a modified approach where the leakage is calculated using the variable pond depths and the area of the pond that is below that depth. Table 3 (below) presents the revised calculations.

Table 3 Adjusted Settling Basin Leakage through Incidental Punctures

Elevation	Depth (Feet)	Area at Depth (Acres)	h_w (Meters)	PLR (gpd/defect)	TPL (gpd/Interval)
4915	35	2.30	10.67	33.40	76.67
4920	30	0.44	9.14	25.15	11.03
4930	20	1.46	6.1	11.93	17.46
4940	10	1.57	3.1	3.35	5.27
4950	0	1.68	0	0.00	0.00
Total	35	7.45	10.67		110.44

The adjusted approach indicates that the Settling Basin could discharge 110.44 gpd through incidental punctures assuming a modified liner system.

7.0 Prescriptive BADCT Liner System

This Section will address a liner system that consists of the following (from bottom to top):

- A prepared subgrade; and
- An HDPE geomembrane liner.

This liner system is for a prescriptive BADCT non-stormwater pond. Because a low permeability component is not required for prescriptive BADCT design of a non-stormwater pond, i.e., for an overflow pond that will contain process solution for short periods of time due to process upsets or rainfall events, the PLR for the Settling Basin could be estimated using Bernoulli's equation for free flow through an opening. This assumes a prescriptive BADCT design is applied to the Settling Basin.

The following values were established to represent the variables of the equation.

- Dimensionless coefficient (CB): related to the shape of the edges of the hole (for sharp edges CB = 0.6);
- The hole area (a): A single two (2) mm diameter ($a = 3.14 \text{ mm}^2$) hole per acre allows for seam defects resulting from fabrication or installation factors that still may exist after intensive quality assurance (Giroud and Bonaparte, 1989); and
- Liquid depth on top of the geomembrane (h_w): The maximum hydraulic head allowed by the design (10.67 meters) was used to estimate the PLR.

Table 4 presents the PLR for a prescriptive BADCT lined Settling Basin.

Table 4 PLR for a Prescriptive BADCT Settling Basin

C_B =	0.6	(dimensionless)
a =	3.14	(mm ²)
g =	9.81	(m/s ²)
h_w =	10.67	(m)
Q =	2.73E-05	PLR (m³/s/defect)

The calculations yielded a PLR of Q = 2.73E-5 m³/s/defect. This can be converted to gpd per defect as follows:

$$\frac{2.73E-5 \text{ m}^3 / \text{s}}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{622.11 \text{ gpd}}{\text{defect}}$$

To establish the TPL, the PLR is multiplied by the defect rate and the LSA of the pond in acres. A defect rate of one (1) hole per acre was selected. This defect rate is based on empirical investigations published by J.P. Giroud and Bonaparte (1989). The LSA of the Settling Basin is 324,396.1 square feet (30,137.4 m² or 7.45 acres).

$$TPL = \frac{622.11 \text{ gpd}}{\text{defect}} \times \frac{1 \text{ defect}}{\text{acre}} \times 7.45 \text{ acres} = 4,634.7 \text{ gpd}$$

Therefore, the TPL through a prescriptive BADCT lined Stormwater Pond is approximately 4,635 gpd.

However, this method of calculation indicates that each hole is located at the base of the pond. Therefore, it is appropriate to calculate the leakage using a modified approach where the leakage is calculated using the variable pond depths and the area of the pond that is below that depth. Table 5 (below) presents the revised calculations.

Table 5 Adjusted Settling Basin Leakage

Elevation	Depth (Feet)	Area at Depth (Acres)	h_w (Meters)	PLR (gpd/defect)	TPL (gpd/Interval)
4915	35	2.30	10.67	622.11	1,428.1
4920	30	0.44	9.14	576.0	252.7
4930	20	1.46	6.1	470.3	688.5
4940	10	1.57	3.1	332.5	523.0
4950	0	1.68	0		
Total	35	7.45	10.67		2,892.3

The adjusted approach indicates that the Settling Basin could discharge 2,892 gpd through incidental punctures assuming a prescriptive liner system.

8.0 BADCT Alternatives Cost Comparison

Comparative costs for installing the three (3) lining systems discussed above are provided in Table 8. These costs are not intended to be all inclusive and should not be used for budgeting or bidding purposes. Costs considered equal for all scenarios, such as subgrade preparation, were not included. Estimated costs include delivery and installation and were based on the basin's lined surface area (LSA) of 354,537 square feet (sf). In order to accurately estimate the amount of lining material needed, a waste factor of 10% was applied to the GCL and HDPE liner quantities to account for variables such as seam overlaps, material placed in anchor trenchers, etc.

Table 8 BADCT Alternatives Cost Analysis

Item	Units	Quantity	Unit Cost	Total Cost	TPL (gpd)
GCL with Protective Rock					
GCL	sf	389,991	\$ 0.70	\$ 272,994	32,497
Protective Rock (-1.5")	CY	19,697	\$ 12.40	\$ 244,243	
Wire Mesh Interface	sf	389,991	\$ 0.20	\$ 77,998	
Protective Rock (ROM)	CY	19,697	\$ 1.50	\$ 29,546	
Estimated Cost				\$ 624,781	
Modified BADCT Liner System					
GCL	sf	389,991	\$ 0.70	\$ 272,994	110
HDPE Liner	sf	389,991	\$ 0.72	\$ 280,794	
Estimated Cost				\$ 553,788	
Prescriptive BADCT Liner System					
HDPE Liner	sf	389,991	\$ 0.72	\$ 280,794	2,892
Estimated Cost				\$ 280,794	

As indicated in Table 8, an HDPE liner without a low permeability soil or GCL is the most economical BADCT alternative while an HDPE with a low permeability soil or GCL provides the highest degree of engineering control against seepage.

In the option consisting of the GCL and protective rock layer, cleanout of the Settling Basin would be by mechanical means (heavy equipment). In the HDPE lined options, slurry pumps would need to be used for tailings removal.

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