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## Technical Memorandum

<b>To:</b>	Kathy Arnold	<b>From:</b>	Mike Thornbrue
<b>Company:</b>	Rosemont Copper Company	<b>Date:</b>	August 20, 2010
<b>Re:</b>	Rosemont Heap Leach Facility Permit Design Liner Leakage Calculations	<b>Doc #:</b>	221/10-320877-5.3
<b>CC:</b>	Joel Carrasco (Tetra Tech) David R. Krizek, P.E. (Tetra Tech)		

### 1.0 Introduction

This Technical Memorandum supersedes any previous liner leakage estimates submitted in the *Aquifer Protection Permit (APP) Application* (Tetra Tech, 2009a), the *Rosemont Heap Leach Facility Permit Design Report* (Tetra Tech, 2009b), and the feasibility level *Heap Leach Facilities Design* (Tetra Tech, 2007) for the proposed Heap Leach Facility (HLF) at the proposed 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 answers item no. 27 on page 12 of 18.

- Item 27 - Technical Memorandum, Rosemont Heap Leach Facilities – Liner Leakage Calculations April 27, 2009

*The alert level AL2 (Rapid and Large Leakage) for each of the Raffinate Pond and the PLS Pond is calculated at 15,272 gpd and 46,812 gpd, respectively.*

*Rosemont's proposed alert level for each of the Raffinate Pond and the PLS Pond appears to be excessively high and shall be revised. Analytical calculations shall be based on system components, taking into account geomembrane defects, transmissivity of the drainage medium, design capacity of the leak collection and removal system (LCRS) rather than discharging capability of the pumping system alone at the LCRS. Please provide revised calculations.*

The purpose of this Technical Memorandum is to document the calculations used to evaluate the level of engineering control achieved for various liner systems as part of the Best Available Demonstrated Control Technology (BADCT) analysis for the Heap Leach Facility at the proposed Rosemont Copper Project (Project). The calculations were used to estimate potential leakage rates (PLRs) through geomembrane liner systems for the proposed facilities. Additionally, calculations were performed to determine Alert Level (AL) liner leakage rates for

potential flow to the Leak Collection and Removal System (LCRS) in the Raffinate and PLS Ponds. This memorandum is organized as follows:

- Section 2.0 presents the equations used for the liner leakage calculations;
- Section 3.0 presents the BADCT analysis of alternative liner systems for the Stormwater Pond;
- Section 4.0 presents the BADCT analysis of alternative liner systems for the Heap Leach Pad;
- Section 5.0 presents the BADCT analysis of alternative liner systems Raffinate and PLS Ponds;
- Section 6.0 presents the calculations used to determine the proposed Alert Level 1 (AL1) and Alert Level 2 (AL2) for the Raffinate Pond;
- Section 7.0 presents the calculations used to determine the proposed AL1 and AL2 for the PLS Pond; and
- Section 8.0 presents a summary of the previous sections.

The configuration and location of the Raffinate Pond has been updated from the design shown in the *Rosemont Heap Leach Facility Permit Design Report* (Tetra Tech, 2009b) dated May 2009. The BADCT and liner leakage calculations are based on this new design. A stability analysis (Tetra Tech, 2009c) was also performed on the new pond location (see Attachment 1).

## 2.0 Equations

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

### 2.1 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):

$$Q = 0.976 C_{qo} [1 + 0.1(h/t_s)^{0.95}] d^{0.2} h^{0.9} k_s^{0.74}$$

Where:

Q = Rate of liquid migration or PLR [cubic meters per second (m<sup>3</sup>/s)];

The PLR is represented as the rate of liquid migration through a composite liner system. This is an accurate representation of the degree of engineering control achieved by a BADCT liner system. By maximizing the degree of engineering control, the rate of liquid migration or PLR is minimized.

$C_{qo}$  = Contact Quality Factor (CQF) that represents the contact interface between the low permeability component and the geomembrane liner (dimensionless);

This factor is dimensionless and ranges from 0.21 for good contact and 1.15 for poor contact. Typically, a GCL/geomembrane interface has a better CQF than a soil/geomembrane interface. However, a good CQF was used for all systems to provide a uniform comparison.

$h$  = 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);

The thickness of the low permeability component directly affects the amount of time necessary for a fluid to flow through the material.

$d$  = 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 mm<sup>2</sup>] 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).

The prescriptive BADCT permeability standard of  $1 \times 10^{-6}$  cm/s was used for the low permeable soil (LPS) calculations. A standard geosynthetic clay liner (GCL) permeability of  $5 \times 10^{-9}$  cm/s was selected for the GCL calculations (Cetco, 2009).

## 2.2 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. This equation was used to calculate the Alert Levels for the double-lined solution ponds. This equation can also be used to calculate the rate of liquid migration or PLR through liner systems that do not utilize a LPS or GCL beneath a geomembrane liner.

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

Where:

$Q$  = rate of liquid migration or PLR through a geomembrane hole (m<sup>3</sup>/s);

- $C_B$  = Dimensionless coefficient related to the shape of the edges of the hole (for sharp edges  $C_B = 0.6$ );
- $a$  = Hole area ( $m^2$ );
- $g$  = Acceleration due to gravity ( $m/s^2$ ); and
- $h$  = Liquid depth on top of the geomembrane (m).

### **3.0 BADCT Analysis for the Stormwater Pond**

As stated in Section 2.0, Giroud's Equation assumes the hydraulic head on the liner to be less than or equal to three (3) meters and therefore does not account for permeation of liquids through the liner. The Stormwater Pond is designed with a maximum capacity in excess of three (3) meters of hydraulic head. Because of this, the calculations used in this section to estimate the potential leakage rates do not account for permeation of liquids through the liner.

The maximum hydraulic head on the liner in the Stormwater Pond was determined using the total depth of the pond (20 feet) and subtracting the required freeboard (3 feet). This results in an overall maximum hydraulic head of 17 feet (5.18 meters). The total lined surface area (LSA) of the pond was estimated to be approximately 246,325 square feet (sf) or 5.65 acres. This area does not include the potential expansion of the pond as shown on the design drawings.

#### **3.1 Stormwater Pond with a Low Permeability Soil Layer**

The PLR for the Stormwater Pond having a composite liner system consisting of LPS and a single geomembrane liner was calculated using Giroud's Equation as presented in Section 2.0. 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 (5.18 meters) was selected;
- 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 LPS: The calculation used a LPS layer having a thickness of six (6) inches (0.1524 meters) underneath the geomembrane liner; and
- Hydraulic conductivity of low permeability component: The prescriptive BADCT permeability standard of  $1 \times 10^{-6}$  cm/s was used for the LPS layer (ADEQ, 2004).

Table 3.1 presents the PLR through a composite liner system comprised of a six (6) inch thick layer of LPS and a geomembrane liner.

**Table 3.1 PLR for the Stormwater Pond (LPS and Geomembrane)**

<b>C<sub>go</sub> =</b>	0.21	(dimensionless)
<b>h =</b>	5.18	(m)
<b>d =</b>	0.002	(m)
<b>t<sub>s</sub> =</b>	0.1524	(m)
<b>k<sub>s</sub> =</b>	1.0E-8	(m/s)
<b>Q =</b>	1.20E-06	PLR (m <sup>3</sup> /s/defect)

The calculation yielded a PLR of Q = 1.20E-6 m<sup>3</sup>/s/defect. This can be converted to gallons per day (gpd) per defect as follows:

$$\frac{1.20E-6 \text{ m}^3 / \text{s}}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{27.39 \text{ gpd}}{\text{defect}}$$

To establish the total potential leakage (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 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). The Stormwater Pond has an LSA of 246,325 square feet (sf) or 5.65 acres.

$$TPL = \frac{27.39 \text{ gpd}}{\text{defect}} \times \frac{1 \text{ defect}}{\text{acre}} \times 5.65 \text{ acres} = 154.7 \text{ gpd}$$

Therefore, the TPL through the liner system of the Stormwater Pond using LPS as the low permeability component is approximately 155 gpd.

### 3.2 Stormwater Pond with a Geosynthetic Clay Liner

The PLR for the Stormwater Pond having a composite liner system consisting of a GCL and a single geomembrane liner was calculated using Giroud's Equation as presented in Section 2.0. 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 (5.18 meters) was selected;
- 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 of low permeability component: A GCL permeability of 5x10-9 cm/s was selected for the GCL layer (Cetco, 2009).

Table 3.2 presents the PLR through a composite liner system comprised of a GCL and a geomembrane liner.

**Table 3.2 PLR for the Stormwater Pond (GCL and Geomembrane)**

<b>C<sub>qo</sub> =</b>	0.21	(dimensionless)
<b>h =</b>	6.4	(m)
<b>d =</b>	0.002	(m)
<b>t<sub>s</sub> =</b>	0.0060	(m)
<b>k<sub>s</sub> =</b>	5.0E-11	(m/s)
<b>Q =</b>	3.88E-07	PLR (m <sup>3</sup> /s/defect)

The calculation yielded a PLR of Q = 3.88E-7 m<sup>3</sup>/s/defect. This can be converted to gpd per defect as follows:

$$\frac{3.88E-7 m^3 / s}{defect} \times \frac{264.17 gallons}{m^3} \times \frac{60s}{min} \times \frac{60 min}{hr} \times \frac{24hr}{day} = \frac{8.96 gpd}{defect}$$

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 Stormwater Pond has an LSA of 246,325 square feet (sf) or 5.65 acres.

$$TPL = \frac{8.96 gpd}{defect} \times \frac{1 defect}{acre} \times 5.65 acres = 50.62 gpd$$

Therefore, the TPL through the liner system of the Stormwater Pond using GCL as the low permeability component is approximately 51 gpd.

### 3.3 Prescriptive BADCT Liner System for the Stormwater Pond

Because a low permeability component (GCL or LPS) 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 of rainfall events, the PLR for the Stormwater Pond could be estimated using Bernoulli's equation for free flow through an opening as presented in Section 2.0. This assumes a prescriptive BADCT design is applied to the Stormwater Pond.

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 mm<sup>2</sup>) 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 (hw): The maximum hydraulic head allowed by the design (5.18 meters) was used to estimate the PLR.

Table 3.3 presents the PLR for a prescriptive BADCT lined Stormwater Pond.

**Table 3.3 PLR for a Prescriptive BADCT Stormwater Pond**

<b>C<sub>B</sub> =</b>	0.6	(dimensionless)
<b>a =</b>	3.14	(mm <sup>2</sup> )
<b>g =</b>	9.81	(m/s <sup>2</sup> )
<b>h<sub>w</sub> =</b>	6.4	(m)
<b>Q =</b>	1.90E-05	PLR (m <sup>3</sup> /s/defect)

The calculations yielded a PLR of Q = 1.90E-5 m<sup>3</sup>/s/defect. This can be converted to gpd per defect as follows:

$$\frac{1.90E-5 \text{ m}^3 / \text{s}}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{433.66 \text{ gpd}}{\text{defect}}$$

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 Stormwater Pond has an LSA of 246,325 square feet (sf) or 5.65 acres.

$$TPL = \frac{433.66 \text{ gpd}}{\text{defect}} \times \frac{1 \text{ defect}}{\text{acre}} \times 5.65 \text{ acres} = 2,450.18 \text{ gpd}$$

Therefore, the TPL through a prescriptive BADCT lined Stormwater Pond is approximately 2,450 gpd.

### 3.4 Conclusions

As indicated in Sections 3.1 through 3.3, the minimum TPL through the Stormwater Pond would be:

- 155 gpd for a geomembrane/LPS composite liner system;
- 51 gpd for a geomembrane/GCL composite liner system; and
- 2,450 gpd for a prescriptive BADCT liner system for a non-stormwater pond.

As stated by Giroud and Bonaparte (1989), “It also appears that unitized leakage rates due to permeation through the geomembrane may not be negligible in the case of liquid impoundments; however, additional research is needed in this area before firm conclusions are drawn.” The permeation of fluid through the geomembrane is therefore not included in the calculated rates shown above.

Calculations were performed for the purpose of evaluating BADCT for different liner designs and to establish the degree of engineering control for each design. The proposed liner system for the Stormwater Pond is a geomembrane/GCL composite liner system. The BADCT comparison indicated that this liner system achieves a greater degree of engineering control when compared to that achieved by the prescriptive BADCT design for a non-stormwater pond.

#### 4.0 BADCT Analysis for the Heap Leach Pad

This section presents calculations for the estimated TPL through the Heap Leach Pad Liner system. TPLs were calculated for two (2) liner systems.

- A composite liner system consisting of one (1) foot of LPS ( $10^{-6}$  cm/sec material) and a geomembrane liner; and
- A composite liner system consisting of a GCL and a geomembrane liner.

Both systems were evaluated with a liner defect rate of one (1) hole per acre that is 11.3 mm in diameter. According to Giroud and Bonaparte (1989), a failure of the geomembrane due to accidental punctures may be represented by a single 11.3 mm diameter ( $a = 100 \text{ mm}^2$ ) hole per acre.

The PLR through a Heap Leach Pad liner can be estimated using the Giroud's Equation (Giroud, 1997) as described in Section 2.0. The following values were established to represent the variables of the equation for the Heap Leach Pad liner leakage calculation.

- CQF (C<sub>qo</sub>): Typically, a GCL/geomembrane interface has a better CQF than a soil/geomembrane interface. For these calculations, a CQF of 0.21 (the appropriate CQF associated with GCL) was selected for both liner systems. Typically, a GCL/geomembrane interface has a better CQF than a soil/geomembrane interface. However, a good CQF was used for both systems to provide a uniform comparison;
- Height of liquid on top of geomembrane (h): An average hydraulic head of two (2.0) feet (0.6096 meters) allowed on a Heap Leach Pad Liner by prescriptive BADCT was selected (ADEQ, 2004);
- Diameter of circular defect (d): A single 11.3 mm diameter hole per acre of liner was selected. This defect rate allows for damage incurred during placement of overliner materials or accidental punctures;
- Thickness of LPS or GCL (t<sub>s</sub>): The prescriptive BADCT standard of one (1) foot (0.3048 meters) of LPS was selected for the scenario presented in Table 4.1 (ADEQ, 2004). A standard GCL thickness of six (6) mm was selected for the GCL scenario presented in Table 3.02 (Cetco, 2009);
- Hydraulic conductivity of low permeability component (k<sub>s</sub>): The prescriptive BADCT permeability standard of  $1 \times 10^{-6}$  cm/s was selected for the LPS scenario presented in Table 4.1 (ADEQ, 2004). A standard GCL permeability of  $5 \times 10^{-9}$  cm/s was selected for the GCL scenario presented in Table 4.2 (Cetco, 2009); and
- LSA: The LSA for phases 1 and 2, including the area of the expanded phase 1 pad, is estimated to be 9,438,077 sf or 217 acres.

#### 4.1 Potential Leakage through a Geomembrane/LPS lined Heap Leach Pad

Table 4.1 presents the PLR through a heap leach pad liner system consisting of a one (1) foot thick LPS layer and a geomembrane liner.

**Table 4.1 PLR for the Heap Leach Pad (LPS and Geomembrane)**

<b>C<sub>qo</sub> =</b>	0.21	(dimensionless)
<b>h =</b>	0.6096	(m)
<b>d =</b>	0.0113	(m)
<b>t<sub>s</sub> =</b>	0.3048	(m)
<b>k<sub>s</sub> =</b>	1.0E-8	(m/s)
<b>Q =</b>	7.68E-08	PLR (m <sup>3</sup> /s/ defect)

The calculations yielded a PLR of Q = 7.68E-8 m<sup>3</sup>/s/defect. This can be converted to gpd per defect as follows:

$$\frac{7.68E-8 \text{ m}^3 / \text{s}}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{1.75 \text{ gpd}}{\text{defect}}$$

To establish the TPL, the PLR is multiplied by the defect rate and the LSA of the leach pad in acres. A defect rate of one (1) hole per acre that is 11.3 mm in diameter was selected. This defect rate is based on empirical investigations published by J.P. Giroud and Bonaparte (1989). The Heap Leach Pad has an LSA of 9,438,077 sf or 217 acres.

$$TPL = \frac{1.75 \text{ gpd}}{\text{defect}} \times \frac{1 \text{ defect}}{\text{acre}} \times 217 \text{ acres} = 379.75 \text{ gpd}$$

Therefore, the TPL through the liner system of the Heap Leach Pad using LPS as the low permeability component is approximately 380 gpd.

#### 4.2 Potential Leakage through a Geomembrane/GCL lined Heap Leach Pad

Table 4.2 presents the leakage through a heap leach pad liner system consisting of a GCL and a geomembrane liner.

**Table 4.2 PLR for the Heap Leach Pad (GCL and Geomembrane)**

<b>C<sub>qo</sub> =</b>	0.21	(dimensionless)
<b>h =</b>	0.6096	(m)
<b>d =</b>	0.0113	(m)
<b>t<sub>s</sub> =</b>	0.006	(m)
<b>k<sub>s</sub> =</b>	5.0E-11	(m/s)
<b>Q =</b>	1.16E-08	PLR (m <sup>3</sup> /s/ defect)

The calculations yielded a PLR of Q = 1.16E-8 m<sup>3</sup>/s/defect. This can be converted to gpd per defect as follows:

$$\frac{1.16E-8 \text{ m}^3 / \text{s}}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{0.26 \text{ gpd}}{\text{defect}}$$



To establish the TPL, the PLR is multiplied by the defect rate and the LSA of the leach pad 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 Heap Leach Pad has an LSA of 9,438,077 sf or 217 acres.

$$TPL = \frac{0.26 \text{ gpd}}{\text{defect}} \times \frac{1 \text{ defect}}{\text{acre}} \times 217 \text{ acres} = 56.42 \text{ gpd}$$

Therefore, the TPL through the liner system of the Heap Leach Pad using GCL as the low permeability component is approximately 56 gpd.

### 4.3 Conclusions

As indicated in Sections 4.1 through 4.2, the TPL through the Heap Leach Pad Liner system would be:

- 380 gpd for a geomembrane/LPS liner system; and
- 56 gpd for a geomembrane/GCL composite liner system.

These calculations were performed for the purpose of evaluating BADCT for different liner designs and to establish the degree of engineering control for each design. The proposed liner system for the Rosemont Heap Leach Pad is a composite liner consisting of a GCL and a geomembrane liner. Without having a GCL or LPS liner underneath the geomembrane, the TPL would be approximately 1,030,197 gpd.

## 5.0 Liner Leakage Analysis for the Raffinate and PLS Ponds

The following calculations were used to determine the TPL through the bottom liner of the Raffinate and PLS Ponds. The PLR was estimated using Giroud's Equation (Giroud, 1997) as presented in Section 2.0. The PLR is based on the assumption that the fluid on the bottom liner will be contained within the LCRS sump, and that the sump will contain one (1) defect that is two (2) mm in diameter. The Raffinate Pond and PLS Ponds have the same sump dimensions and a depth of 1.5 feet (0.4572 meters).

### 5.1 Potential Leakage through the Bottom Liner of the Raffinate and PLS Ponds

Table 5.1 presents the PLR through the bottom liner of the Raffinate or PLS Pond. The calculations used the same method to quantify the PLR through a geomembrane/GCL composite liner system as presented in Section 3.2 for a single-lined pond.

**Table 5.1 PLR for the Bottom Liner of the Raffinate/PLS Pond**

<b>C<sub>qo</sub> =</b>	0.21	(dimensionless)
<b>h =</b>	0.4572	(m)
<b>d =</b>	0.002	(m)
<b>t<sub>s</sub> =</b>	0.0060	(m)
<b>k<sub>s</sub> =</b>	5.0E-11	(m/sec)
<b>Q =</b>	4.97E-09	PLR (m <sup>3</sup> /s/defect)

The calculations yielded a PLR of Q = 4.97E-9 m<sup>3</sup>/s/defect. This can be converted to gpd per defect as follows:

$$\frac{4.97E-9 \text{ m}^3 / \text{s}}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{0.113 \text{ gpd}}{\text{defect}} \times 1 \text{ defect} = 0.113 \text{ gpd}$$

Therefore, the estimated TPL through the bottom liner of either the Raffinate or PLS Pond is approximately 0.113 gpd or 14.5 fluid ounces per day.

As indicated in Appendix P of the APP application (Tetra Tech, 2009), if the Raffinate Pond design utilized six (6) inches of LPS, the TPL would be approximately one (1) gallon per day. In order to quantify the total degree of engineering control achieved by the prescriptive BADCT design of the Raffinate and PLS Ponds, a TPL of 129 gpd was calculated for a liner system that did not include a GCL or LPS layer.

## 5.2 Leak Collection and Removal System

The Arizona Mining BADCT Guidance Manual (ADEQ, 2004) Section 2.3.2.5 recommends the following for a Process Solution Pond Leak Collection and Removal System(LCRS):

*“The LCRS shall be designed to result in minimal hydraulic head on the lower liner and provide for the collection and removal of liquids from between the upper and lower liner. The LCRS shall consist of a layer of sand, gravel, geonet or other permeable material located between the two (2) geomembranes. Materials used as drainage media must achieve a flow capacity equivalent to a one (1) foot thick layer with a saturated hydraulic conductivity of 10<sup>-2</sup> cm/sec or greater and three (3) percent slope, and must be chemically compatible with the solution stored in the pond. The LCRS must drain to a sump design to facilitate liquid extraction and leak monitoring. A three (3) percent minimum slope is required to promote drainage to a collection sump. ...”*

In order to show that the minimum slope of the pond bottom meets prescriptive BADCT guidance, Tetra Tech calculated the flow capacity of an inner liner system consisting of the prescriptive BADCT criteria of a one (1) foot thick layer of 10<sup>-2</sup> cm/sec material at a 3% slope and the selected geonet with a transmissivity of 9.66 gal/minute/foot at a 1% minimum slope.

The following calculations use Darcy’s velocity estimate for a confined aquifer with one (1) dimensional flow in a homogenous media (Schwartz / Zhang, 2003):

$$q = \frac{k * h_o - h_L}{\Delta L}$$

$$Q = H * B * q$$



Where:

- q = Darcy flow velocity (cm/s);
- Q = Darcy Flow (cm<sup>3</sup>/s);
- k = hydraulic conductivity (cm/s);
- h<sub>o</sub> = hydraulic head at the origin (cm);
- h<sub>L</sub> = hydraulic head at the length L (cm);
- L = Length of the segment (cm);
- H = Thickness of the material; and
- B = Unit Width of one (1) cm.

### 5.2.1 Prescriptive BADCT LCRS

The prescriptive BADCT guidance for an LCRS recommends a one (1) foot thick layer of material with a saturated hydraulic conductivity of 10<sup>-2</sup> cm/sec or greater and three (3) percent slope. The calculations below represent a hypothetical pond bottom that is 100 feet long.

- k = 1x10<sup>-2</sup> cm/s;
- h<sub>o</sub> = Three (3) feet = 91.44 cm;
- h<sub>L</sub> = Zero (0);
- L = 100 feet = 3,048 cm; and
- H = One (1) foot = 30.48 cm; and
- B = One (1) cm.

Therefore:

$$q = \frac{10^{-2} \times (91.44 - 0)}{3,048} = 3 \times 10^{-4} \text{ cm/s}$$

$$Q = 3 \times 10^{-4} \times 30.48 \times 1 = 9.1 \times 10^{-3} \text{ cm}^3 / \text{s}$$

The flow capacity of the prescriptive BADCT LCRS is 9.1x10<sup>-3</sup> cm<sup>3</sup>/sec.

### 5.2.2 Proposed LCRS

The Technical Specifications associated with the final design of the Rosemont Heap Leach Facilities specify a geonet that is 60 mil thick with a transmissivity of 9.66 gallons per minute per foot. The proposed minimum slope for the pond bottom is 0.5%. The calculations below represent a hypothetical pond bottom that is 100 feet long.

- k = T/H where T = Transmissivity = 9.66 gallons per minute per foot;
- h<sub>o</sub> = Six (6) inches = 15.24 cm;
- h<sub>L</sub> = Zero (0);



L = 100 feet = 3,048 cm; and

H = 60 mil = 0.06 inches = 0.1524 cm.

In order to use Darcy's law, the Transmissivity of the geonet must be converted to a hydraulic conductivity as follows:

$$T = \frac{9.66 \text{ gallon}}{\text{min} \times \text{foot}} \times \frac{3,785 \text{ cm}^3}{\text{gallon}} \times \frac{1 \text{ min}}{60 \text{ s}} = \frac{609 \text{ cm}^3}{\text{ft} \cdot \text{s}}$$

$$k = \frac{T}{H} = \frac{609 \text{ cm}^3}{\text{ft} \cdot \text{s}} \times \frac{1 \text{ ft}}{30.48 \text{ cm}} = \frac{19.98 \text{ cm}^2}{\text{s}} / 0.1524 \text{ cm} = \frac{131.1 \text{ cm}}{\text{s}}$$

Therefore:

$$q = \frac{131.1 \times (15.24 - 0)}{3,048} = \frac{3,995.9}{3,048} = 0.6555 \text{ cm} / \text{s}$$

$$Q = \frac{0.6555 \text{ cm}}{\text{s}} \times 0.1524 \text{ cm} (\text{height}) \times 1 \text{ cm} (\text{width}) = 0.1 \text{ cm}^3 / \text{s}$$

The flow capacity of the proposed LCRS is 0.1 cm<sup>3</sup>/second at a 0.5% slope.

The flow capacity of the proposed LCRS is greater than that indicated in the prescriptive BADCT guidance. Therefore, the proposed LCRS for the Rosemont PLS Pond and Raffinate Pond provides a greater degree of engineering control than the prescriptive BADCT LCRS system.

## 6.0 Raffinate Pond – Alert Level Leakage Rate Calculations

The purpose of the following analysis was to determine the PLR through the upper liner of the double-lined Raffinate Pond in order to propose Alert Level 1 (AL1) and Alert Level 2 (AL2).

The AL1 leakage rate is used to evaluate the liner performance in a process solution pond under typical operating conditions. The AL1, as measured by the amount of fluid pumped by the pond's LCRS, is a low-level trigger that may indicate the presence of a small hole or defect in the top geomembrane of a double-lined, process solution pond.

The AL2 leakage rate, as measured by the amount of fluid pumped by the pond's LCRS, is a high-level trigger that indicates a serious malfunction of the liner system.

The leakage rates were calculated using Bernoulli's equation for free flow through an opening as previously described in Section 2.0. The calculations are dependent on the area of the hole (a), the maximum hydraulic head on the liner (hw), and the LSA of the pond.

For the Raffinate Pond, the maximum hydraulic head on the liner was determined using the total depth of the pond (26 feet) and subtracting the required three (3) feet of freeboard for a maximum hydraulic head of 23 feet (7.0 meters). The LSA of the pond was estimated to be 41,733 sf or 0.96 acres.

### 6.1 Calculation of the AL1 for the Raffinate Pond

Table 6.1 presents the parameters and calculation results for the PLR through the top liner of the Raffinate Pond.

**Table 6.1 PLR Calculation for the Raffinate Pond (AL1)**

<b>C<sub>B</sub> =</b>	0.6	(dimensionless)
<b>a =</b>	3.14	(mm <sup>2</sup> )
<b>g =</b>	9.81	(m/s <sup>2</sup> )
<b>h<sub>w</sub> =</b>	7.0	(m)
<b>Q =</b>	2.21E-05	PLR (m <sup>3</sup> /s/defect)

The calculations yielded a PLR of Q = 2.21E-5 m<sup>3</sup>/s/defect. This can be converted to gpd per defect as follows:

$$\frac{2.21E-5 \text{ m}^3 / \text{s}}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{504.31 \text{ gpd}}{\text{defect}}$$

To establish AL1, 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 Raffinate Pond has an LSA of 41,733 sf or 0.96 acres.

$$AL1 = \frac{504.31 \text{ gpd}}{\text{defect}} \times \frac{1 \text{ defect}}{\text{acre}} \times 0.96 \text{ acre} = 484.1 \text{ gpd}$$

Based on the assumptions presented herein, AL1 for the Raffinate Pond was calculated to be 484 gpd.

### 6.2 Calculation of AL2 for the Raffinate Pond

According to Giroud and Bonaparte (1989), a failure of the geomembrane due to poor design, or accidental punctures, may be represented by a single 11.3 mm diameter (a = 100 mm<sup>2</sup>) hole per acre. Table 6.2 presents the parameters and calculation results for the PLR through the top liner of the Raffinate Pond.

**Table 6.2 PLR Calculation for the Raffinate Pond (AL2)**

<b>C<sub>B</sub> =</b>	0.6	(dimensionless)
<b>a =</b>	100	(mm <sup>2</sup> )
<b>g =</b>	9.81	(m/s <sup>2</sup> )
<b>h<sub>w</sub> =</b>	7.0	(m)
<b>Q =</b>	7.04E-04	PLR (m <sup>3</sup> /s/defect)



The calculations yielded a PLR of  $Q = 7.04E-4 \text{ m}^3/\text{s}/\text{defect}$ . This can be converted to gpd per defect as follows:

$$\frac{7.04E-4 \text{ m}^3/\text{s}}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{16,060.9 \text{ gpd}}{\text{defect}}$$

To establish AL2, 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 Raffinate Pond has an LSA of 41,733 sf or 0.96 acres.

$$AL2 = \frac{16,060.9 \text{ gpd}}{\text{defect}} \times \frac{1 \text{ defect}}{\text{acre}} \times 0.96 \text{ acre} = 15,418.5 \text{ gpd}$$

Based on the assumptions presented herein, AL2 for the Raffinate Pond was calculated to be 15,418.5 gpd.

The system will be design with the pumping capacity to accommodate the AL2 leakage rate of 15,418.5 gpd or 10.7 gpm. However, the Alert Level will be lowered to provide a factor of safety of 1.5 as follows:

$$15,418.5 \div 1.5 = 10,279 \text{ gpd}$$

Additionally, because the AL2 level for the Raffinate Pond is very large, it is necessary to verify that the geonet drainage layer has sufficient capacity to transmit the flow to the sump.

As presented in Section 5.2.2, the specified geonet drainage layer for the Raffinate Pond has a Transmissivity of 9.66 gallons per minute per foot. This can be converted to gallons per day per foot as follows:

$$\frac{9.66 \text{ gallons}}{\text{min}/\text{foot}} \times \frac{60 \text{ min}}{\text{hour}} \times \frac{24 \text{ hour}}{\text{day}} = 13,910.4 \text{ gpd}/\text{ft}$$

The minimum bottom width of the Raffinate Pond is about 30 feet. Therefore, the geonet drainage layer will be able to transmit approximately 417,312 gpd and will accommodate the design flow of 15,418.5 gpd.

### 6.3 Conclusions

The ALs for the Raffinate Pond, as measured by the amount of fluid potentially pumped by the LCRS, were calculated to be:

- AL1 = 484 gpd;
- AL2 = 10,279 gpd or 7.1 gpm; and
- Pumping Capacity = 15,418.5 gpd or 10.7 gpm.

If it is determined during normal operations that the amount of fluid pumped by the LCRS exceeds AL1, Rosemont will take action to determine the cause. This action may include



physical inspection, mechanical leak detection, electric leak location, or other methods as appropriate.

If it is determined during normal operations that the amount of fluid pumped by the LCRS exceeds AL2, the contingency plan should be followed as described in Section 8.0 of the Rosemont Copper Project APP application (Tetra Tech, 2009a).

## 7.0 PLS Pond – Alert Level Leakage Rate Calculations

The purpose of the following analysis was to determine the PLR through the upper liner of the double-lined PLS Pond in order to propose AL1 and AL2 values.

PLRs are calculated using Bernoulli's equation for free flow through an opening (as previously described in Section 2.0). As indicated in Section 5.0, the calculations are dependent on the area of the hole (a), the maximum hydraulic head on the liner (h<sub>w</sub>), and the pond's LSA.

For the PLS Pond, the maximum hydraulic head on the liner is defined as the vertical distance from the invert of the spillway to the bottom of the pond which is 17 feet (5.18 meters), and the pond's LSA is 147,607 sf or 3.39 acres.

### 7.1 Calculation of the AL1 for the PLS Pond

Table 7.1 presents the parameters and calculation results for the PLR through the top liner of the PLS Pond.

**Table 7.1 PLR Calculation for the PLS Pond (AL1)**

<b>C<sub>B</sub> =</b>	0.6	(dimensionless)
<b>a =</b>	3.14	(mm <sup>2</sup> )
<b>g =</b>	9.81	(m/s <sup>2</sup> )
<b>h<sub>w</sub> =</b>	5.18	(m)
<b>Q =</b>	1.90E-05	PLR (m <sup>3</sup> /s/defect)

The calculations yielded a PLR of Q = 2.06E-5 m<sup>3</sup>/s/defect. This can be converted to gpd per defect as follows:

$$\frac{1.90E-5 \text{ m}^3 / \text{s}}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{433.7 \text{ gpd}}{\text{defect}}$$

To establish AL1, 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 PLS Pond has an LSA of 147,607 sf or 3.39 acres.

$$AL1 = \frac{433.7 \text{ gpd}}{\text{defect}} \times \frac{1 \text{ defect}}{\text{acre}} \times 3.39 \text{ acres} = 1,470.2 \text{ gpd}$$

Based on the assumptions presented herein, AL1 for the PLS Pond was calculated to be 1,470 gpd.

## 7.2 Calculation of AL2 for the PLS Pond

According to Giroud and Bonaparte (1989), a failure of the geomembrane due to poor design, or accidental punctures, may be represented by a single 11.3 mm diameter ( $a = 100 \text{ mm}^2$ ) hole per acre. Table 7.2 presents the parameters and calculation results for the PLR through the top liner of the PLS Pond.

**Table 7.2 PLR Calculation for the PLS Pond (AL2)**

<b>C<sub>B</sub> =</b>	0.6	(dimensionless)
<b>a =</b>	100	(mm <sup>2</sup> )
<b>g =</b>	9.81	(m/s <sup>2</sup> )
<b>h<sub>w</sub> =</b>	5.18	(m)
<b>Q =</b>	6.05E-04	PLR (m <sup>3</sup> /s/defect)

The calculations yielded a PLR of  $Q = 6.05E-4 \text{ m}^3/\text{s}/\text{defect}$ . This can be converted to gpd per defect as follows:

$$\frac{6.05E-4 \text{ m}^3/\text{s}}{\text{defect}} \times \frac{264.17 \text{ gallons}}{\text{m}^3} \times \frac{60 \text{ s}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = \frac{13,808.7 \text{ gpd}}{\text{defect}}$$

To establish AL2, the PLR would be 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 PLS Pond has a LSA of 147,607 sf or 3.39 acres.

$$AL2 = \frac{13,808.7 \text{ gpd}}{\text{defect}} \times \frac{1 \text{ defect}}{\text{acre}} \times 3.39 \text{ acres} = 46,811.5 \text{ gpd}$$

Based on the assumptions presented herein, AL2 for the Raffinate Pond was calculated to be 46,812 gpd.

The system will be design with the pumping capacity to accommodate the AL2 leakage rate of 46,812 gpd or 32.5 gpm. However, the Alert Level will be lowered to provide a factor of safety of 1.5 as follows:

$$46,812.5 \div 1.5 = 31,208.3 \text{ gpd}$$

Additionally, because the AL2 level for the Raffinate Pond is very large, it is necessary to verify that the geonet drainage layer has sufficient capacity to transmit the flow to the sump.

As presented in Section 5.2.2, the specified geonet drainage layer for the Raffinate Pond has a Transmissivity of 9.66 gallons per minute per foot. This can be converted to gallons per day per foot as follows:



$$\frac{9.66 \text{ gallons}}{\text{min/foot}} \times \frac{60 \text{ min}}{\text{hour}} \times \frac{24 \text{ hour}}{\text{day}} = 13,910.4 \text{ gpd/ft}$$

The bottom width of the Raffinate Pond is about 198 feet. Therefore, the geonet drainage layer will be able to transmit approximately 2,754,259.2 gpd and will accommodate the AL2 flow of 46,812 gpd.

### 7.3 Conclusions

The ALs for the PLS Pond, as measured by the amount of fluid potentially pumped by the LCRS, were calculated to be:

- AL1 = 1,470 gpd;
- AL2 = 31,208 gpd or 21.7 gpm; and
- Pumping Capacity = 31,208 gpd or 32.5 gpm.

If it is determined during normal operations that the amount of fluid pumped by the LCRS exceeds AL1, Rosemont will take action to determine the cause. This action may include physical inspection, mechanical leak detection, electric leak location, or other methods as appropriate.

If it is determined during normal operations that the amount of fluid pumped by the LCRS exceeds AL2, the contingency plan should be followed as described in Section 8.0 of the Rosemont Copper Project APP application (Tetra Tech, 2009a).

## 8.0 Summary and Conclusions

Table 8.1 summarizes the calculated TPLs through the lined facilities associated with the Heap Leach Facility at the proposed Rosemont Copper Project.

**Table 8.1 Calculated TPLs through Heap Leach Facilities**

Facility	Total Potential Leakage (gallons per day)		
	No LPS or GCL	LPS	GCL
<b>Raffinate Pond</b>	129	1.0	0.113
<b>Heap Leach Pad</b>	1,030,197	380	56
<b>PLS Pond</b>	129	1.0	0.113
<b>Stormwater Pond</b>	2,450	155	51

As shown in Table 8.1, GCL achieves a better degree of engineering control when compared to LPS. Also, LPS achieves a superior degree of engineering control when compared to liner systems without a low permeability layer. These calculations were performed for the purpose of



evaluating BADCT for different liner designs and to establish the degree of engineering control for each design.

To allow for added safety the pumping capacity will be sized to handle the calculated AL2 level flow but the alert level will be adjusted with a factor of safety of 1.5. This will result in the alert levels for the Raffinate and PLS Ponds as shown below:

The Alert Levels for the Raffinate Pond were calculated to be:

- AL1 = 480 gpd;
- AL2 = 10,182 gpd or 7.1 gpm; and
- Pumping Capacity = 15,272 gpd or 10.6 gpm.

The Alert Levels for the PLS Pond were calculated to be:

- AL1 = 1,470 gpd;
- AL2 = 31,208 gpd or 21.7 gpm; and
- Pumping Capacity = 31,208 gpd or 32.5 gpm.

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- ADEQ, 2004. Arizona Mining BADCT Guidance Manual, Aquifer Protection Program, Publication TB-04-01.
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- Tetra Tech Carrera, J., and Kohlman, A. (2009c). *Rosemont Raffinate Pond Stability Analysis*. Technical Memorandum to File. Technical Memorandum Dated September 24, 2009.

**ATTACHMENT 1**  
**TECHNICAL MEMORANDA**  
ROSEMONT RAFFINATE POND STABILITY ANALYSIS

## Technical Memorandum

---

**To:** File  
**Cc:** Joel Carrasco and Troy Meyer (Tetra Tech)  
**From:** Jiny Carrera and Alyssa Kohlman  
**Project #:** 114-320807-5.3  
**Subject:** **Rosemont Raffinate Pond Stability Analysis**  
**Date:** September 24, 2009

---

### 1.0 Introduction

This technical memorandum summarizes the results of a slope stability analysis performed on the embankment of the Raffinate Pond for the proposed Rosemont Copper Project (Project) in Pima County, Arizona. Information provided in this technical memorandum supersedes any previous stability or facility descriptions for the Raffinate Pond presented in the Leaching Facilities Design (Tetra Tech, 2007b), the Aquifer Protection Permit (APP) Application (Tetra Tech, 2009a), and the Rosemont Heap Leach Facility Permit Design Report (Tetra Tech, 2009c). The Raffinate Pond is located near the northeast corner of the Plant Site Area. The Raffinate Pond is proposed to be double-lined with a leak collection and removal system (LCRS) over a Geosynthetic Clay Liner (GCL). The Raffinate Pond will store raffinate from the SX-EW Plant before it is pumped to the Heap Leach Pad.

Only the most critical section (steepest, maximum height) of the Raffinate Pond embankment was analyzed. This section is shown on Figure 01 (Section A). Both block and global (rotational) failures were evaluated for a shallow, full height failure condition, and a loss of containment failure condition for the outside embankment slope ratio of 2H:1V. Attachment 1 contains the model outputs from the stability analysis.

The stability analysis was performed assuming that the channel (natural drainage) near the toe of the pond embankment (Figure 01) will be filled with compacted Willow Canyon material (Site Grading Fill). The stability figures in Attachment 1 show the channel-fill and pond embankment.

### 2.0 Construction of Model Cross Section

As shown on Figure 01, the Raffinate Pond is underlain by Arkose material from the Willow Canyon Formation on the northern and eastern edges and is underlain by older alluvium on the southern and western edges. The embankment is proposed to consist of locally excavated weathered bedrock from the Willow Canyon Formation. The critical section of the Raffinate Pond Embankment occurs at the southeast corner where the older alluvium is present (Figure 01). Due to the variable thickness of the older alluvium, the quantity to be removed for cut to fill construction is unknown. Based on testing results of the Willow Canyon in the Plant Site Area, the Willow Canyon is anticipated to have a lower strength value than the older alluvium. Therefore, the older alluvium was neglected in the stability analysis.

### 3.0 Design Criteria

Design of the Raffinate Pond embankment is governed by requirements of the Arizona Department of Environmental Quality (ADEQ) as detailed in the Arizona Mining BADCT Guidance Manual (ADEQ, 2004). Based on these requirements, the minimum stability criteria adopted for the Raffinate Pond embankment is presented in Table 3.01. Per BADCT requirements (ADEQ, 2004), site specific testing of material shear strength was performed. Additionally, a quality control testing program will be conducted during construction to determine grain size, plasticity index, moisture, density, etc., of the materials used to construct the Raffinate Pond embankment.

**Table 3.01 Minimum Stability Requirements (with testing)**

Analysis Condition	Required Minimum Factor of Safety
Static	1.30
Pseudostatic	1.00

As documented in the Geologic Hazards Assessment (Tetra Tech, 2007a), the site seismicity was analyzed for two (2) levels of ground motion: the Maximum Probable Earthquake (MPE) and the Maximum Credible Earthquake (MCE). These values are 0.045g for the MPE and 0.326g for the MCE. In order to determine the appropriate design earthquake, the applicable rules pertaining to the Raffinate Pond embankment were reviewed.

In the unlikely event of a failure of the Raffinate Pond embankment, solutions would flow into the Plant Water/Temporary Storage (PWTS) Ponds. Additionally, the operational life of the facility is relatively short (less than 10 years). Any damage caused by the failure of the Raffinate Pond embankment would be limited to the Project site (i.e., property owned or controlled by the dam owner) and is unlikely to result in loss of human life. Therefore, the MPE was utilized for pseudostatic analyses. To allow for damping and attenuation of the bedrock acceleration within a slope or embankment, and to account for the rigid body pseudostatic model, the pseudo-static coefficient used in the model was a conservative estimate of horizontal ground motion equivalent to 2/3 of the MPE, or 0.03g.

### 4.0 Modeling Methods

The slope stability analysis was conducted using the Slope/W component of the GeoStudio 2007 software package produced by Geo-Slope International, Ltd. Slope/W was used to perform limiting equilibrium analyses using the general limit equilibrium (GLE) method, which satisfies both force and moment equilibrium. The Slope/W program incorporates a search routine to locate those failure surfaces with the least factor of safety within user defined search limits. Trial failure surfaces were defined with “entry and exit” and “block specified” slip surfaces, resulting in a range of possible locations to search for the most critical (lowest factor of safety) potential failure surface. Full height failure surfaces intersecting the crest of the embankment were considered.

Since the facility will be lined, the analysis was conducted assuming that steady-state seepage will not occur through the embankment. The phreatic surface used in the model was applied to

the foundation materials of the pond and was set just below the ground surface to account for the occasional seepage that is observed in the area. Pseudostatic analyses were conducted to evaluate the performance of the embankment under seismic conditions, using 2/3 of the design peak ground acceleration of the MPE, or 0.03g. The pseudostatic analyses subjects the two-dimensional sliding mass to a horizontal acceleration equal to an earthquake coefficient multiplied by the acceleration of gravity.

## 5.0 Material Properties

The material properties presented in Table 5.01 for the embankment and foundation materials were determined from field and laboratory testing (Tetra Tech, 2009b), experience with similar materials, and professional judgment. Direct shear testing was completed on young alluvium (which is expected to have equal or greater strength properties than the older alluvium) and the Willow Canyon Formation collected during drilling and test pit sampling. As explained in Section 2.0, the older alluvium was conservatively neglected in the stability analysis. Material properties for the in-situ Willow Canyon material were based on the direct shear testing results of the remolded Willow Canyon material. This is appropriate since the in-situ material is expected to have similar strength properties to the remolded material.

**Table 5.01 Material Properties**

Material	Strength Model	Phi (degrees)	Cohesion (psf)	Unit Weight (pcf)
Willow Canyon Formation (Arkose) (in situ and remolded)	Mohr-Coulomb	34	0	118

## 6.0 Results

Both static and pseudostatic factors of safety against a full-height failure of the Raffinate Pond embankment were found to be adequate. Shallow failures were analyzed as were deep seated failures with block and circular failure modes. The shallow failures represent the minimum factors of safety; however, failures of this type can be easily repaired and are unlikely to cause significant damage or loss of fluid from the Raffinate Pond. Deep seated failures have higher factors of safety and represent a failure that is likely to release fluid from the Raffinate Pond. The results of the analyses are provided in Attachment 1 to this memo and summarized in Table 6.01.

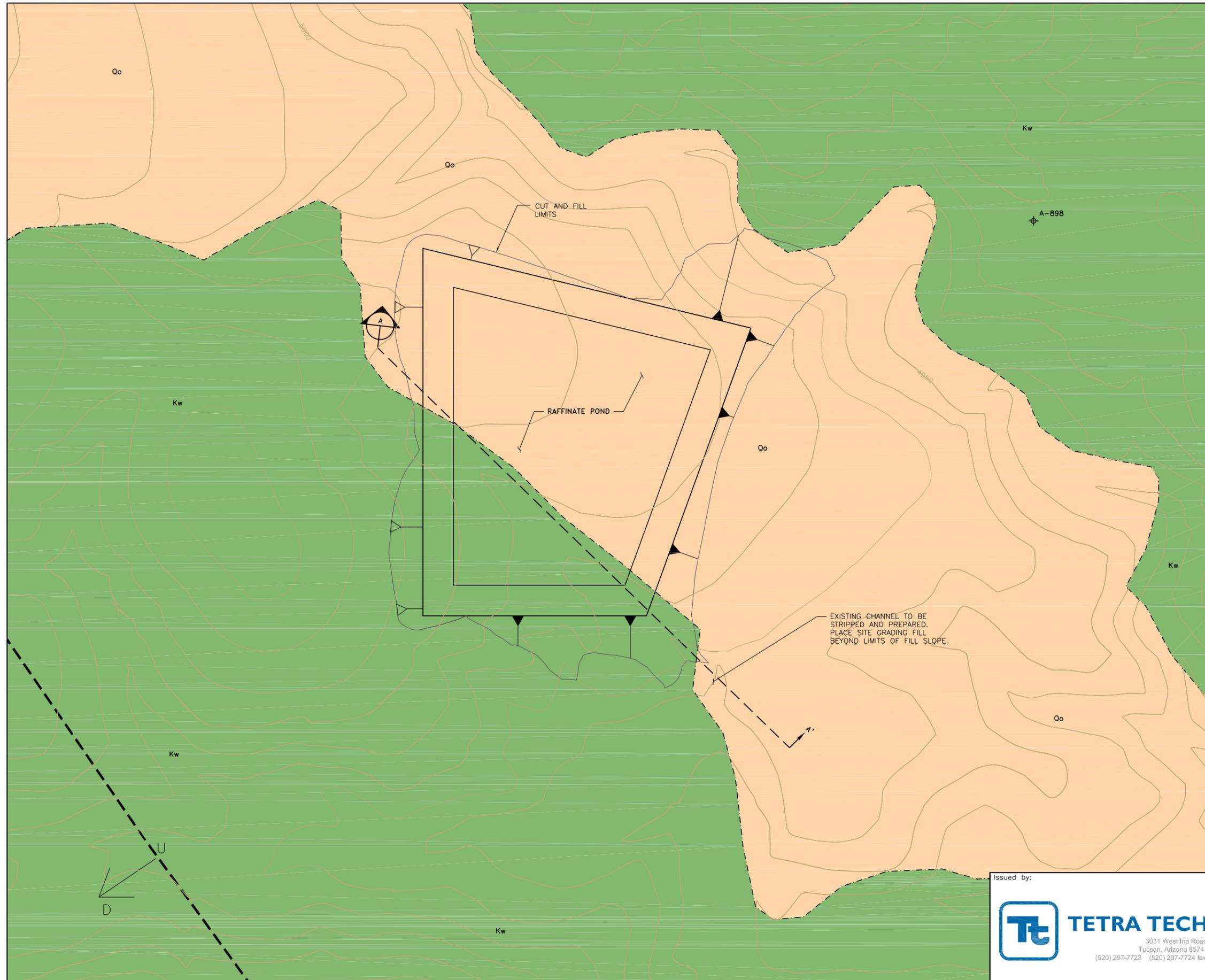
**Table 6.01 Slope Stability Results**

Case	Safety Factor	
	Static	Pseudostatic
Shallow, Full-Height Failure – Circular	1.42	1.32
Shallow, Full-Height Failure – Block	1.69	1.61
Loss of Containment – Circular	1.67	1.54
Loss of Containment – Block	2.39	2.17

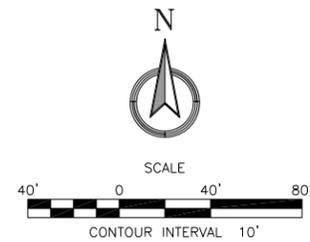
## 7.0 References

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- Tetra Tech (2009c). *Rosemont Heap Leach Facility Permit Design Report*. Prepared for Rosemont Copper Company. Report Dated May 2009.

**FIGURE**



- LEGEND:**
- A-898 BOREHOLE COMPLETED BY AUGUSTA RESOURCE, ANACONDA COMPANY, AND ANAMAX MINING COMPANY FROM 1963 TO 2008
  - Kw WILLOW CANYON FORMATION, BISBEE GROUP (EARLY CRETACEOUS)
  - Qo OLDER ALLUVIUM (LATE PLEISTOCENE)
  - EXISTING CONTOURS
  - GEOLOGIC CONTACT PER TETRA TECH - DASHED WHERE INFERRED
  - FAULT - ARROW INDICATES DIP DIRECTION OF FAULT PLANES
  - CUT SLOPE
  - FILL SLOPE
  - LOCATION OF STABILITY CROSS SECTION



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<b>RAFFINATE POND SECTION FOR STABILITY ANALYSIS</b>			 REVISION
Project:	Project no.:	Figure no.:	
ROSEMONT COPPER	320807	01	
Location:	Date:		
PIMA COUNTY, ARIZONA	11/09		

# **ATTACHMENT 1**

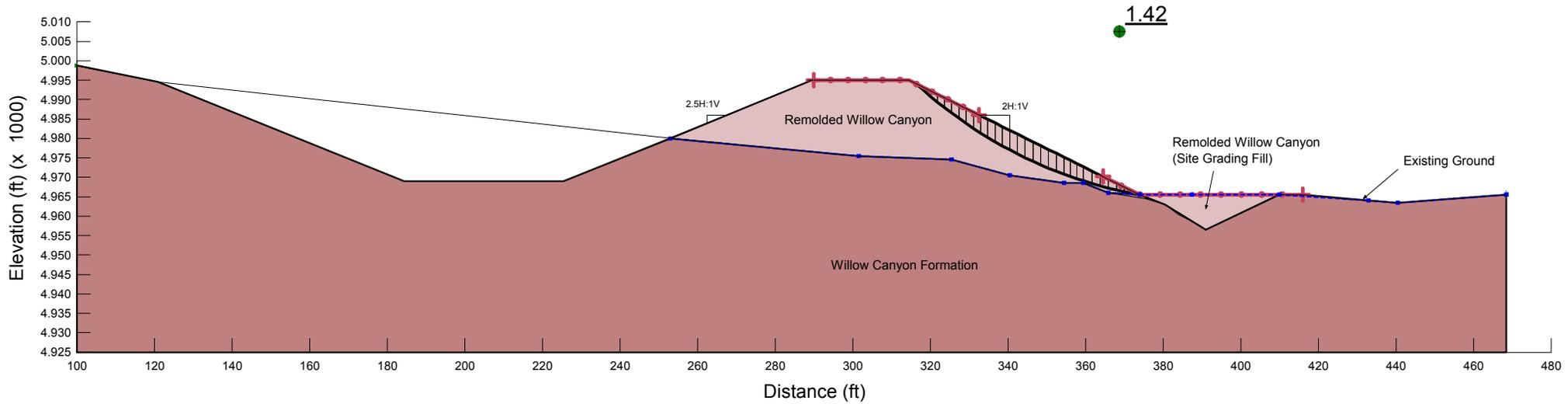


**ROSEMONT FINAL DESIGN  
RAFFINATE POND**

Static - Circular  
Horz Seismic Value: 0

Name: Willow Canyon Fm in-situ  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °

Name: Remolded Willow Canyon Fm  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °  
Phi-B: 0 °  
Piezometric Line: 1



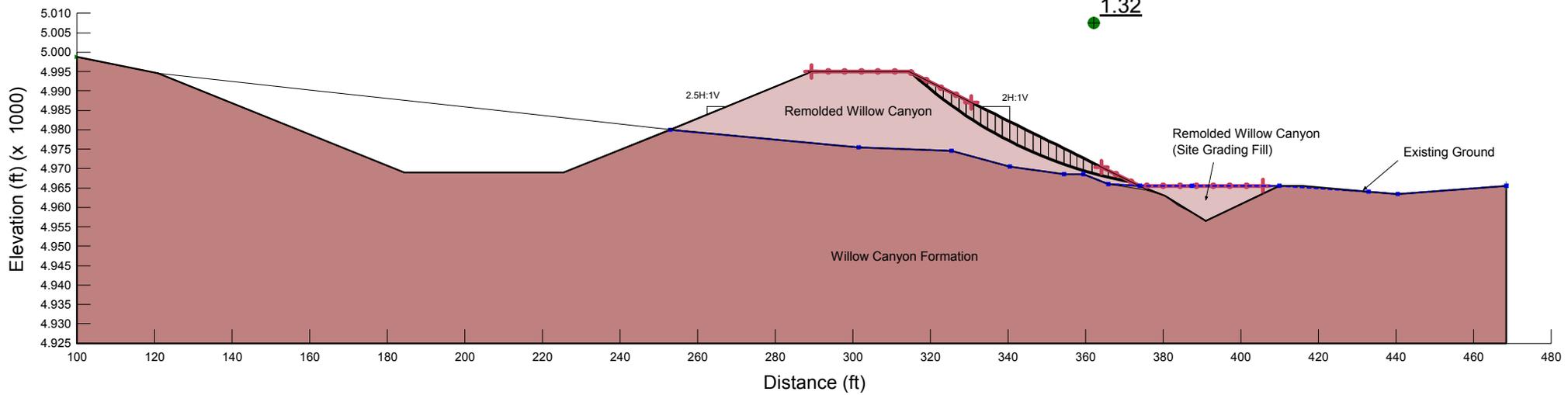


**ROSEMONT FINAL DESIGN  
RAFFINATE POND**

Pseudostatic - Circular  
Horz Seismic Value: 0.03

Name: Willow Canyon Fm in-situ  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °

Name: Remolded Willow Canyon Fm  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °  
Phi-B: 0 °  
Piezometric Line: 1



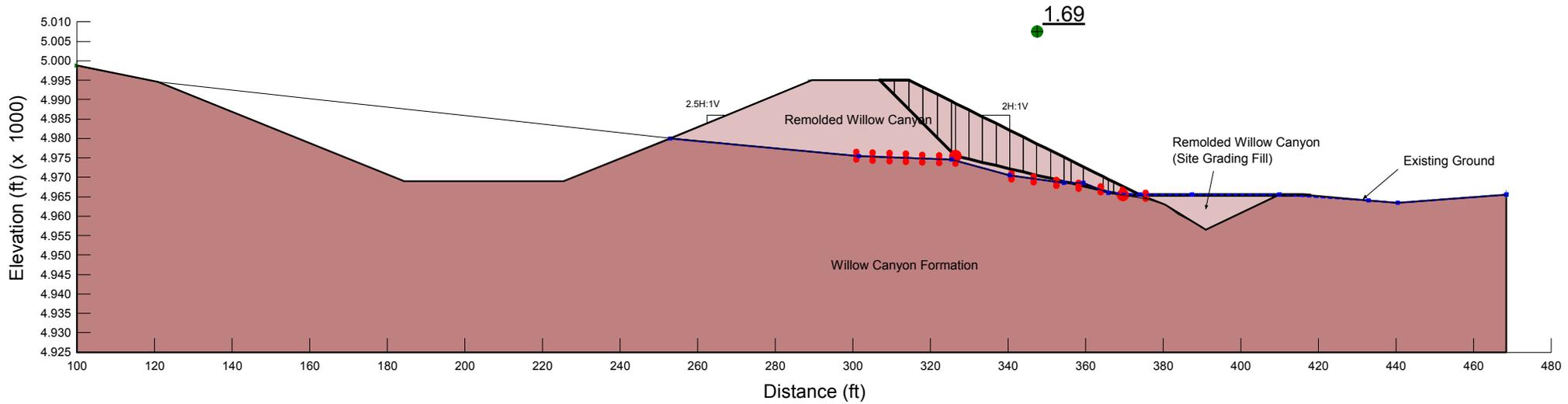


**ROSEMONT FINAL DESIGN  
RAFFINATE POND**

Static - Block  
Horz Seismic Value: 0

Name: Willow Canyon Fm in-situ  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °

Name: Remolded Willow Canyon Fm  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °  
Phi-B: 0 °  
Piezometric Line: 1



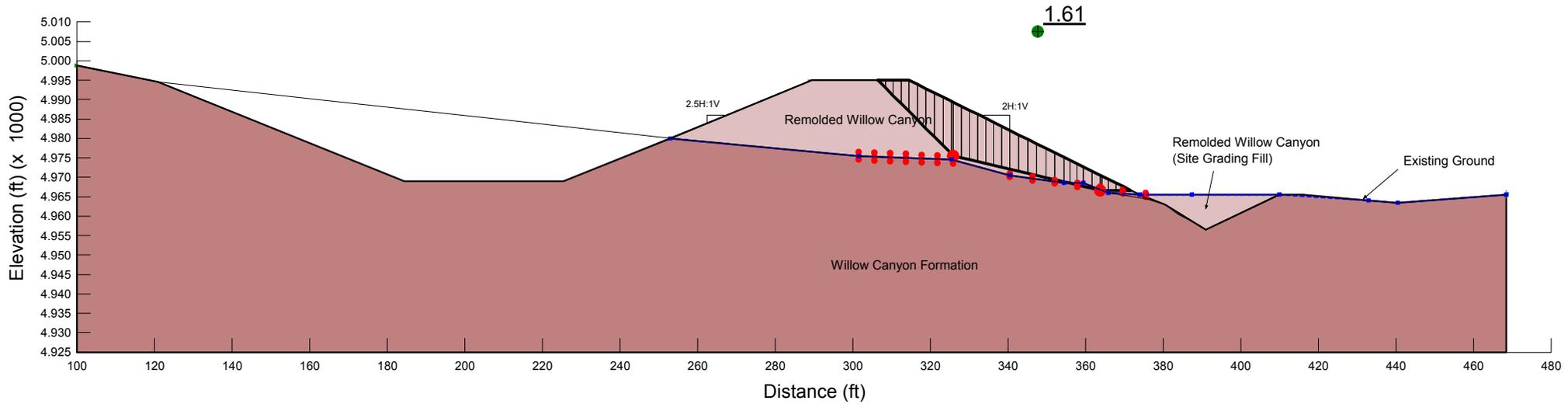


**ROSEMONT FINAL DESIGN  
RAFFINATE POND**

Pseudostatic - Block  
Horz Seismic Value: 0.03

Name: Willow Canyon Fm in-situ  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °

Name: Remolded Willow Canyon Fm  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °  
Phi-B: 0 °  
Piezometric Line: 1



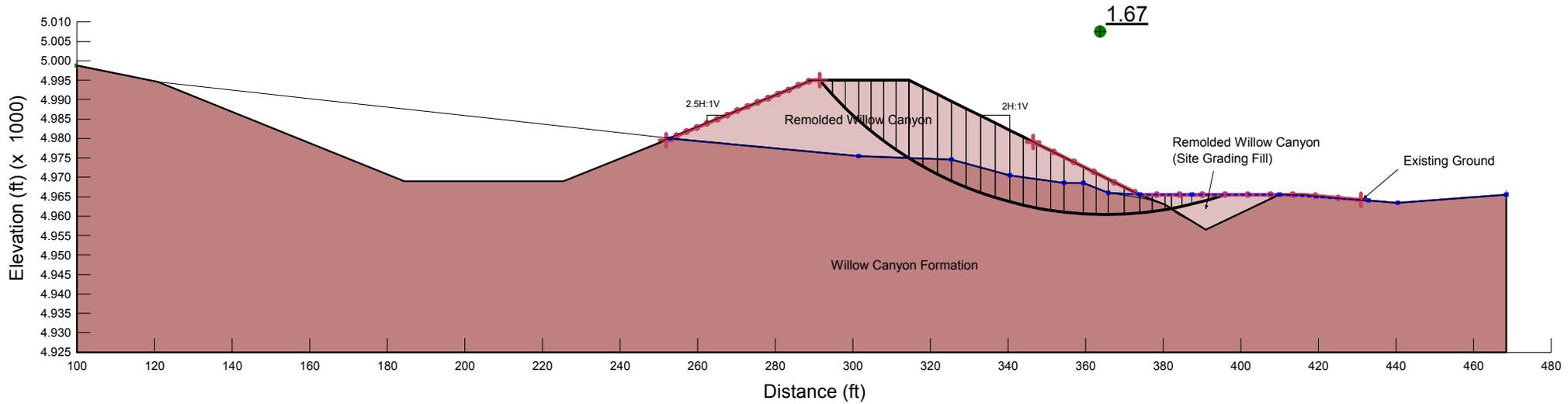


**ROSEMONT FINAL DESIGN  
RAFFINATE POND**

Static - Circular, Loss of containment  
Horz Seismic Value: 0

Name: Willow Canyon Fm in-situ  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °

Name: Remolded Willow Canyon Fm  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °  
Phi-B: 0 °  
Piezometric Line: 1



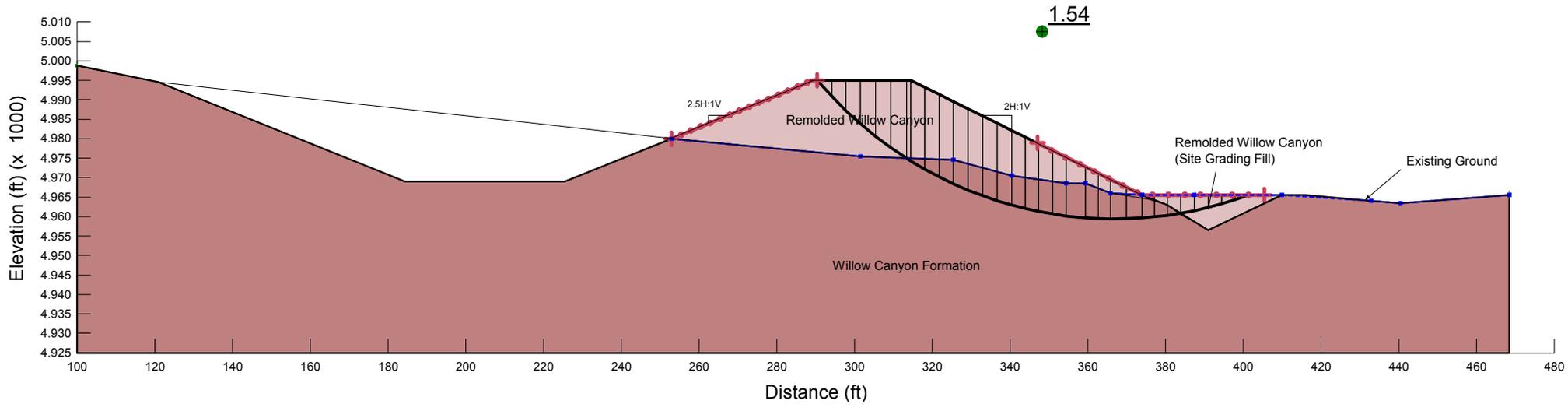


**ROSEMONT FINAL DESIGN  
RAFFINATE POND**

Pseudostatic - Circular, Loss of containment  
Horz Seismic Value: 0.03

Name: Willow Canyon Fm in-situ  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °

Name: Remolded Willow Canyon Fm  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °  
Phi-B: 0 °  
Piezometric Line: 1



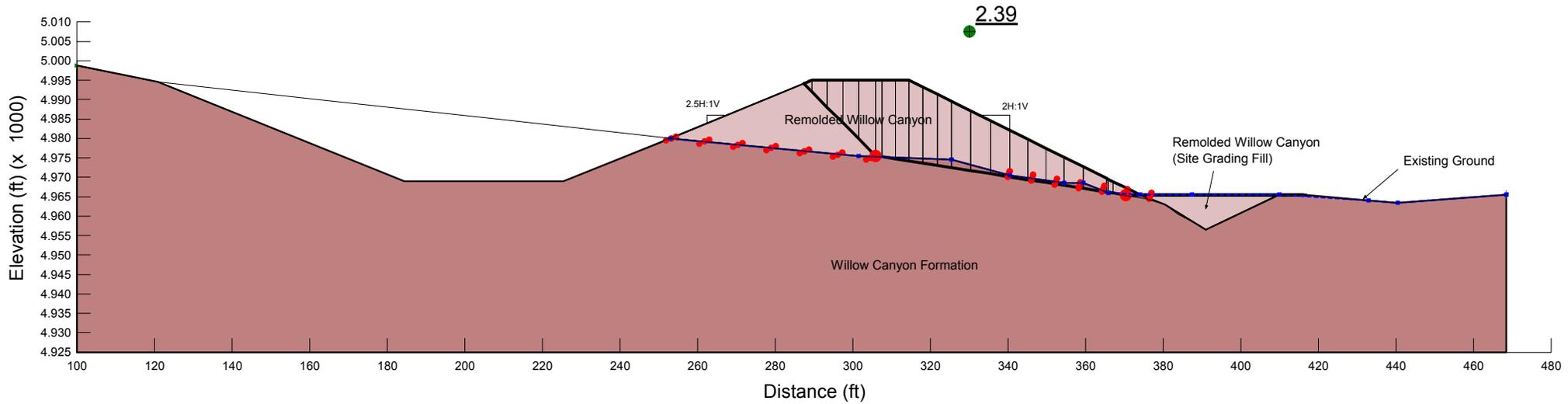


**ROSEMONT FINAL DESIGN  
RAFFINATE POND**

Static, Loss of Containment  
Horz Seismic Value: 0

Name: Willow Canyon Fm in-situ  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °

Name: Remolded Willow Canyon Fm  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °  
Phi-B: 0 °  
Piezometric Line: 1





**ROSEMONT FINAL DESIGN  
RAFFINATE POND**

Pseudostatic - Block  
Horz Seismic Value: 0.03

Name: Willow Canyon Fm in-situ  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °

Name: Remolded Willow Canyon Fm  
Model: Mohr-Coulomb  
Unit Weight: 118 pcf  
Cohesion: 0 psf  
Phi: 34 °  
Phi-B: 0 °  
Piezometric Line: 1

