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Technical Memorandum

To:	File
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Subject:	**Rosemont Aquifer Protection Permit Application Liner Leakage Calculations**
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The purpose of this 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 Aquifer Protection Permit (APP) regulated facilities at the Rosemont Copper Project (Project). The calculations were used to estimate the potential leakage rates (PLRs) through geomembrane liner systems proposed for facilities at the Project site. Additionally, calculations were performed to propose Alert Level liner leakage rates for potential flow to the Leak Collection and Removal System (LCRS) in the process solution ponds. This memorandum is organized as follows:

- Section 1.0 presents the equations that will be used in the following sections;
- Section 2.0 presents the BADCT analysis of alternative liner systems for a typical single-lined pond;
- Section 3.0 presents the BADCT analysis of alternative liner systems for the PWTS Pond;
- Section 4.0 presents the BADCT analysis of alternative liner systems for the Stormwater Pond;
- Section 5.0 presents the BADCT analysis of alternative liner systems for the Heap Leach Pad;
- Section 6.0 presents the BADCT analysis of alternative liner systems for the double-lined Raffinate and PLS Ponds;
- Section 7.0 presents the calculations used to determine the proposed Alert Level 1 (AL1) and Alert Level 2 (AL2) for the double-lined Raffinate Pond;
- Section 8.0 presents the calculations used to determine the proposed AL1 and AL2 for the double-lined PLS Pond;
- Section 9.0 presents a summary of the previous sections; and
- Section 10.0 lists cited references.

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1.0 Equations

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

1.1 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^3/s) or gallons per day (gpd)];

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). Empirical investigation published by Giroud and Bonaparte (1989) show 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 effects the amount of time necessary for a fluid to flow through the material.

d = Diameter of circular defect (m^2); 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^2] 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 $1x10^{-6}$ cm/s was used for the low permeable soil (LPS) calculations. A standard geosynthetic clay liner (GCL) permeability of $5x10^{-9}$ cm/s was selected for the GCL calculations (Cetco, 2009).

1.2 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 process solution ponds. This equation was also used to calculate the rate of liquid migration or PLR through liner systems that do not utilize LPS or GCL.

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

Where:

Q = rate of liquid migration or PLR through a geomembrane hole (m^3/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_w = Liquid depth on top of the geomembrane (m).

2.0 BADCT Analysis for a Single-Lined Pond

This section presents calculations for the PLR through a single-lined pond liner system. In order to evaluate the level of engineering control achieved as part of the BADCT analysis, PLRs were calculated for three (3) liner systems.

- A system consisting of six (6) inches of LPS (10^{-6} cm/sec material) and a geomembrane liner (Section 2.1);
- A system consisting of a GCL and a geomembrane liner (Section 2.2); and
- A prescriptive BADCT liner system for a non-stormwater pond consisting of a geomembrane liner lying on a prepared non-LPS (permeable) subgrade (Section 2.3).

PLRs were calculated using a hydraulic head of three (3) meters (m) and a single circular defect that is two (2) mm in diameter. For these scenarios, subgrade and subsurface geology were not considered in the calculations.

2.1 Single-Lined Pond with a Low Permeability Soil Layer

The rate of liquid migration was calculated using Giroud's Equation as presented in Section 1.0. The following values were established to represent the variables of the equation.

- Height of liquid on top of geomembrane: The maximum head allowed by Giroud's Equation [three (3) meters] was selected;
- Diameter of circular defect: A defect rate of one (1) hole per acre that is two (2) mm in diameter was selected. This defect rate is based on empirical investigations published by J.P. Giroud and Bonaparte, (1989);
- Thickness of LPS: A prescriptive BADCT liner system for a process solution pond has six (6) inches of LPS underneath the geomembrane liner. Although this analysis is intended to represent a non-stormwater pond, this option was selected as an alternative BADCT design; and
- Hydraulic conductivity of low permeability component: The prescriptive BADCT permeability standard of $1x10^{-6}$ cm/s was used for the LPS calculations (ADEQ, 2004).

Table 2.01 presents the PLR through a composite liner system comprised of a six (6) inch thick layer of LPS and a geomembrane liner.

Table 2.01 PLR for a single-lined Pond with LPS

C_{qo} =	0.21	(dimensionless)
h =	3.0	(m)
d =	0.002	(m)
t_s =	0.1524	(m)
k_s =	1.0E-8	(m/s)
Q =	5.15E-07	PLR (m^3/s/defect)
Q =	11.76	PLR (gpd/defect)
	1	Number of defects per acre
Q =	**11.76**	PLR (gpd/acre)

2.2 Single-Lined Pond with a Geosynthetic Clay Liner

The rate of liquid migration was calculated using Giroud's Equation as presented in Section 1.0. The following values were established to represent the variables of the equation.

- Height of liquid on top of geomembrane: The maximum head allowed by Giroud's Equation [three (3) 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: This calculation uses a GCL having a thickness of six (6) mm underneath the geomembrane liner. Although this analysis is intended to represent a non-stormwater pond, this option was selected as an alternative BADCT design; and
- Hydraulic conductivity of low permeability component: A standard GCL permeability of $5x10^{-9}$ cm/s was selected for the GCL calculations (Cetco, 2009).

Table 2.02 presents the PLR through a composite liner system comprised of a GCL as the low permeability component and a geomembrane liner.

Table 2.02 PLR for a single-lined Pond with GCL

C_{qo} =	0.21	(dimensionless)
h =	3.0	(m)
d =	0.002	(m)
t_s =	0.0060	(m)
k_s =	5.0E-11	(m/s)
Q =	1.43E-07	PLR (m^3/s/defect)
Q =	3.25	PLR (gpd/defect)
	1	Number of defects per acre
Q =	**3.26**	PLR (gpd/acre)

2.3 Prescriptive BADCT liner system for a Non-Stormwater Pond

For a non-stormwater pond, prescriptive BADCT requires a minimum six (6) inches of minus 3/8 inch native or natural materials compacted to a minimum of 95% of the maximum dry density as determined by the standard proctor (ASTM D-698) overlain by a 60-mil HDPE geomembrane (ADEQ, 2004).

Because a low permeability component (GCL or LPS) is not required for the prescriptive BADCT liner system for a non-stormwater pond, the rate of liquid migration or PLR can be estimated using Bernoulli's equation for free flow through an opening as presented in Section 1.0.

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

- Dimensionless coefficient (C_B): related to the shape of the edges of the hole (for sharp edges $C_B = 0.6$);
- The hole area (a): A single, two (2) mm diameter [area (a) = 3.14 mm^2] 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); and
- Liquid depth on top of the geomembrane (h_w): Even though there is no limit on the hydraulic head associated with Bernoulli's equation for free flow through an opening, the same hydraulic head of three (3) meters was used to estimate the rate of liquid migration or PLR.

Table 2.03 presents the PLR calculation for a prescriptive BADCT lined non-stormwater pond.

Table 2.03 PLR for a Prescriptive BADCT Lined Non-Stormwater Pond

C_B =	0.6	(dimensionless)
a =	3.14	(mm^2)
g =	9.81	(m/s^2)
h_w =	3.0	(m)
Q =	1.44E-05	PLR (m^3/s/defect)
Q =	329.9	PLR (gpd/defect)
	1	Number of defects per acre
Q =	**329.9**	PLR (gpd/acre)

2.4 Conclusions

In summary, the PLRs for a single-lined, non-stormwater pond with three (3) meters of hydraulic head on the geomembrane liner and one (1) hole per acre that is two (2) mm in diameter are as follows:

- 11.76 gpd/acre for a geomembrane/LPS composite liner system;
- 3.26 gpd/acre for a geomembrane/GCL composite liner system; and
- 329.9 gpd/acre for a prescriptive BADCT 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 non-stormwater ponds at Rosemont is a geomembrane/GCL composite liner system. This comparison has shown 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.

3.0 BADCT Analysis for the PWTS Pond

As stated in Section 1.0, Giroud's Equation assumes the hydraulic head on the liner to be less than or equal to three (3) meters and does not account for permeation of liquids through the liner. The PWTS 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 potential leakage rates do not account for permeation of liquids through the liner.

Based on the feasibility level design of the PWTS Pond presented in the Site Water Management Plan (Tetra Tech, 2007), the maximum hydraulic head on the liner is 27.4 meters (90 feet) and the pond's lined surface area (LSA) is approximately 12.05 acres.

3.1 PWTS Pond with a Low Permeability Soil Layer

The rate of liquid migration or PLR for the PWTS Pond was calculated using Giroud's Equation as presented in Section 1.0. 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 (27.4 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: This calculation uses a LPS layer having a thickness of six (6) inches underneath the geomembrane liner; and
- Hydraulic conductivity of low permeability component: The prescriptive BADCT permeability standard of 1×10^{-6} cm/s was used for the LPS calculations (ADEQ, 2004).

Table 3.01 presents the PLR through a composite liner system comprised of a six (6) inch thick layer of LPS and a geomembrane liner.

Table 3.01 PLR for the PWTS Pond lined with LPS

C_{qo} =	0.21	(dimensionless)
h =	27.4	(m)
d =	0.002	(m)
t_s =	0.1524	(m)
k_s =	1.0E-8	(m/s)
Q =	2.08E-05	PLR (m^3/s/defect)
Q =	474.8	PLR (gpd/defect)
	1	Number of defects per acre
Q =	474.8	PLR (gpd/acre)
LSA =	12.05	acres
Q =	**5,721.4**	**PLR (gpd)**

3.2 PWTS Pond with a Geosynthetic Clay Liner

The rate of liquid migration was calculated using Giroud's Equation as presented in Section 1.0. 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 (27.4 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: This calculation uses 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 (Cetco, 2009).

Table 3.02 presents the PLR through composite a liner system comprised of a GCL as the low permeability component and a geomembrane liner.

Table 3.02 PLR for the PWTS Pond with GCL

C_{qo} =	0.21	(dimensionless)
h =	27.4	(m)
d =	0.002	(m)
t_s =	0.0060	(m)
k_s =	5.0E-11	(m/s)
Q =	8.43E-06	PLR (m^3/s/defect)
Q =	190.4	PLR (gpd/defect)
	1	Number of defects per acre
Q =	190.4	PLR (gpd/acre)
LSA =	12.05	acres
Q =	**2,293.7**	**PLR (gpd)**

3.3 Prescriptive BADCT Lined PWTS Pond

Because a low permeability component (GCL or LPS) is not required for a prescriptive BADCT liner system, the rate of liquid migration or PLR can be estimated using Bernoulli's equation for free flow through an opening as presented in Section 1.0.

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

- Dimensionless coefficient (C_B): related to the shape of the edges of the hole (for sharp edges C_B = 0.6);
- The hole area (a): A single, two (2) mm diameter [area (a) = 3.14 mm^2] 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); and

- Liquid depth on top of the geomembrane (h_w): The same hydraulic head of 27.4 meters was used to estimate the rate of liquid migration or PLR.

Table 3.03 presents the PLR calculation for a prescriptive BADCT lined PWTS Pond.

Table 3.03 PLR for a Prescriptive BADCT Lined PWTS Pond

C_B =	0.6	(dimensionless)
a =	3.14	(mm^2)
g =	9.81	(m/s^2)
h_w =	27.4	(m)
Q =	4.37E-05	PLR (m^3/s/defect)
Q =	997.0	PLR (gpd/defect)
	1	Number of defects per acre
Q =	997.0	PLR (gpd/acre)
LSA =	12.05	acres
Q =	**12,014**	**PLR (gpd)**

3.4 Conclusions

As indicated in Tables 3.01 through 3.03, the minimum PLRs through the PWTS Pond would be:

- 5,721 gpd for a geomembrane/LPS Liner system;
- 2,294 gpd for a geomembrane/GCL composite liner system; and
- 12,014 gpd for a prescriptive BADCT liner system.

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 are excluded from these calculations by Giroud because the rates have not yet been quantified through research. The calculations used in this section to estimate the leakage rates are the minimum anticipated leakage rates through the PWTS Pond, but are greater than those that would be calculated with a limited hydraulic head.

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 non-stormwater ponds at Rosemont is a geomembrane/GCL composite liner system. This comparison has shown 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 Stormwater Pond

As stated in Section 1.0, Giroud's Equation assumes the hydraulic head on the liner to be less than or equal to three (3) meters and 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.

Based on the feasibility level design of the Stormwater Pond presented in the Leaching Facilities Design (Tetra Tech, 2007), the maximum hydraulic head on the liner is 6.4 meters, (21 feet) and the pond's lined surface area (LSA) is approximately 4.36 acres.

4.1 Stormwater Pond with a Low Permeability Soil Layer

The rate of liquid migration or PLR for the Stormwater Pond was calculated using Giroud's Equation as presented in Section 1.0. 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 (6.4 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: This calculation uses a LPS layer having a thickness of six (6) inches underneath the geomembrane liner; and
- Hydraulic conductivity of low permeability component: The prescriptive BADCT permeability standard of 1×10^{-6} cm/s was used for the LPS calculations (ADEQ, 2004).

Table 4.01 presents the PLR through a composite liner system comprised of a six (6) inch thick layer of LPS and a geomembrane liner.

Table 4.01 PLR for the Stormwater Pond lined with LPS

C_{qo} =	0.21	(dimensionless)
h =	6.4	(m)
d =	0.002	(m)
t_s =	0.1524	(m)
k_s =	1.0E-8	(m/s)
Q =	1.69E-06	PLR (m^3/s/defect)
Q =	38.7	PLR (gpd/defect)
	1	Number of defects per acre
Q =	38.7	PLR (gpd/acre)
LSA =	4.36	acres
Q =	**168.6**	**PLR (gpd)**

4.2 Stormwater Pond with a Geosynthetic Clay Liner

The rate of liquid migration was calculated using Giroud's Equation as presented in Section 1.0. 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 (6.4 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: This calculation uses 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 (Cetco, 2009).

Table 4.02 presents the PLR through a composite liner system comprised of a GCL as the low permeability component and a geomembrane liner.

Table 4.02 PLR for the Stormwater Pond with GCL

C_{qo} =	0.21	(dimensionless)
h =	6.4	(m)
d =	0.002	(m)
t_s =	0.0060	(m)
k_s =	5.0E-11	(m/s)
Q =	5.72E-07	PLR (m^3/s/defect)
Q =	13.0	PLR (gpd/defect)
	1	Number of defects per acre
Q =	13.0	PLR (gpd/acre)
LSA =	4.36	acres
Q =	**56.9**	**PLR (gpd)**

4.3 Prescriptive BADCT liner system for the Stormwater Pond

Because a low permeability component (GCL or LPS) is not required for a prescriptive BADCT liner system, the rate of liquid migration or PLR can be estimated using Bernoulli's equation for free flow through an opening as presented in Section 1.0.

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

- Dimensionless coefficient (C_B): related to the shape of the edges of the hole (for sharp edges C_B = 0.6);
- The hole area (a) A single, two (2) mm diameter [area (a) = 3.14 mm^2] 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); and

- Liquid depth on top of the geomembrane (h_w): The maximum hydraulic head allowed by the design (6.4 meters) was used to estimate the rate of liquid migration or PLR.

Table 4.03 presents the PLR calculation for a prescriptive BADCT lined Stormwater Pond.

Table 4.03 PLR for a Prescriptive BADCT Stormwater Pond

C_B =	0.6	(dimensionless)
a =	3.14	(mm^2)
g =	9.81	(m/s^2)
h_w =	6.4	(m)
Q =	2.11E-05	PLR (m^3/s/defect)
Q =	481.9	PLR (gpd/defect)
	1	Number of defects per acre
Q =	481.9	PLR (gpd/acre)
LSA =	4.36	acres
Q =	**2,101**	**PLR (gpd)**

4.4 Conclusions

As indicated in Tables 4.01 through 4.03, the minimum PLRs through the Stormwater Pond would be:

- 169 gpd for a geomembrane/LPS Liner system;
- 57 gpd for a geomembrane/GCL composite liner system; and
- 2,101 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 are excluded from these calculations by Giroud because the rates have not yet been quantified through research. The calculations used in this Section to estimate the leakage rates are the minimum anticipated leakage rates through the Stormwater Pond, but are greater than those that would be calculated with a limited hydraulic head.

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 non-stormwater ponds at Rosemont is a geomembrane/GCL composite liner system. This comparison has shown 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.

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5.0 BADCT Analysis for the Heap Leach Pad

This section presents calculations for the PLR through heap leach pad liner systems. PLRs were calculated for two (2) liner systems.

- A liner system consisting of one (1) foot of LPS (10^{-6} cm/sec material) and a geomembrane liner; and
- A 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 ($a = 100\ mm^2$) 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 1.0. The following values have been established to represent the variables of the equation for the heap leach pad liner leakage calculation.

- CQF (C_{qo}): 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 0.6096 meters [two (2.0) feet] 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_s): The prescriptive BADCT standard of one (1) foot of LPS was selected for the scenario presented in Table 5.01 (ADEQ, 2004). A standard GCL thickness of six (6) mm was selected for the GCL scenario presented in Table 5.02 (Cetco, 2009);
- Hydraulic conductivity of low permeability component (k_s): The prescriptive BADCT permeability standard of $1\text{x}10^{-6}$ cm/s was selected for the LPS scenario presented in Table 5.01 (ADEQ, 2004). A standard GCL permeability of $5\text{x}10^{-9}$ cm/s was selected for the GCL scenario presented in Table 5.02 (Cetco, 2009); and
- LSA: Based on the feasibility level design of the Heap Leach Pad, the LSA for phases 1 and 2 is 200 acres (Tetra Tech, 2007).

5.1 PLR Through a Geomembrane/LPS lined Heap Leach Pad

Table 5.01 presents the PLR through a heap leach pad liner system consisting of a one (1) foot thick LPS layer overlain by a geomembrane.

Table 5.01 PLR for a Heap Leach Pad with LPS

C_{qo} =	0.21	(dimensionless)
h =	0.6096	(m)
d =	0.0113	(m)
t_s =	0.3048	(m)
k_s =	1.0E-8	(m/s)
Q =	7.68E-08	PLR (m^3/s/ defect)
Q =	1.75	PLR (gpd/defect)
	1	Number of defects per acre
Q =	1.75	PLR (gpd/acre)
LSA	200	acres
Q	**350.0**	**gpd**

5.2 PLR Through a Geomembrane/GCL lined Heap Leach Pad

Table 5.02 presents the leakage through a heap leach pad liner system consisting of a GCL overlain by a geomembrane.

Table 5.02 Liner Leakage for a Heap Leach Pad with GCL

C_{qo} =	0.21	(dimensionless)
h =	0.6096	(m)
d =	0.0113	(m)
t_s =	0.006	(m)
k_s =	5.0E-11	(m/s)
Q =	1.16E-08	PLR (m^3/s/ defect)
Q =	0.264	PLR (gpd/defect)
	1	Number of defects per acre
Q =	0.264	PLR (gpd/acre)
LSA	200	acres
Q	**52.8**	**(gpd)**

5.3 Conclusions

In summary, the calculated PLRs from a single-lined heap leach pad, having an average of two (2) feet of hydraulic head on the geomembrane liner and one (1) hole per acre that is 11.3 mm in diameter, are as follows:

- 1.75 gpd/acre for a geomembrane/LPS liner system; and
- 0.264 gpd/acre for a geomembrane/GCL composite liner system.

When these rates is applied to the anticipated LSA of 200 acres (phases 1 & 2 of the Heap Leach Pad), the PLRs would be:

- 350.0 gallons per day for the geomembrane/LPS liner system; and
- 52.8 gallons per day 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. In order to quantify the total degree of engineering control achieved by the prescriptive BADCT design of the Heap Leach Pad, a PLR of 947,200 gpd was calculated using Bernoulli's equation for free flow through an opening for a liner system that did not include a GCL or an LPS layer.

6.0 BADCT Analysis for the Raffinate and PLS Ponds

The following calculations were used to determine the PLR through the bottom liner of the Raffinate and PLS Ponds. The PLR was estimated using Giroud's Equation (Giroud, 1997) as presented in Section 1.0. The PLR is based on the assumptions 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. From the feasibility level design of the Raffinate Pond (Tetra Tech, 2007), the LCRS sump has a depth of 0.4572 meters (1.5 feet).

6.1 PLR Through the Bottom Liner of the Raffinate Pond

Table 6.01 presents the calculations used to determine the PLR through the bottom liner of the Raffinate Pond. The calculations use the same methods used to quantify the PLR through a geomembrane/GCL composite liner system for a single-lined pond as presented in Section 2.2.

Table 6.01 PLR for the Bottom Liner of the Raffinate Pond

C_{qo} =	0.21	(dimensionless)
h =	.4572	(m)
d =	0.002	(m)
t_s =	0.0060	(m)
k_s =	5.0E-11	(m/sec)
Q =	4.97E-09	PLR (m^3/s/defect)
Q =	0.114	PLR (gpd/defect)
	1	Number of installation defects
Q =	**0.114**	PLR (gpd)

The PLR through the bottom liner of the Raffinate Pond is approximately 0.114 gpd or approximately 14.6 fluid ounces per day. If the Raffinate Pond design utilized six (6) inches of LPS, the leakage rate 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 Pond, a PLR of 129 gpd was calculated for a liner system that did not include a GCL or LPS layer, as determined using Bernoulli's equation for free flow through an opening.

6.2 Calculation of the PLR through the PLS Pond Liner System

As indicated in the Heap Leach Facilities Design (Tetra Tech, 2007), the LCRS sumps for the PLS Pond and Raffinate Pond have the same dimensions. Therefore, as indicated in Section 6.1, the PLR through the bottom liner of the PLS Pond is approximately 0.114 gpd or approximately 14.6 fluid ounces per day. If the PLS Pond design utilized six (6) inches of LPS, the leakage rate 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 PLS Pond, a PLR of 129 gpd was calculated for a liner system that did not include a GCL or LPS layer, as determined using Bernoulli's equation for free flow through an opening.

7.0 Raffinate Pond – Alert Level Calculations

The purpose of the following analysis was to evaluate the PLR through the upper liner of the proposed double-lined Raffinate Pond to propose AL1 and AL2 for the APP application.

The AL1 leakage rate is designed to evaluate the performance of a process solution pond's liner under typical operating conditions. The AL1, as measured by the amount of fluid pumped out of a process solution pond's LCRS, is a low-level trigger that would 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 out of a process solution pond's LCRS, is a high-level trigger that indicates a serious malfunction of the liner system in a double-lined, process solution pond.

The leakage rates were calculated using Bernoulli's equation for free flow through an opening (previously described in Section 1.0). The calculations are dependent on the area of the hole (a), the maximum hydraulic head on the liner (h_w), and the pond's LSA.

Based on the feasibility level design of the Raffinate Pond, the maximum hydraulic head on the liner is 6.1 meters and the pond's lined surface area (LSA) is 0.55 acres (Tetra Tech, 2007).

7.1 Calculation of the AL1 for the Raffinate Pond

According to Giroud and Bonaparte (1989), a single, two (2) mm diameter [area (a) = 3.14 mm^2] hole per acre allows for seam defects that may still exist after intensive quality assurance resulting from fabrication or installation factors; excessive moisture or humidity; improper ambient or sealing temperature; and contamination by dust or dirt. However, because the Raffinate Pond's LSA is about ½ acre, it is unreasonable to expect that there will be less than one (1) hole in the liner. Therefore, the acceptable defect rate was conservatively modified herein to be one (1) hole per ½ acre or two (2) holes per acre for calculation of AL1.

Table 7.01 presents the parameters and calculation results for the Raffinate Pond AL1.

Table 7.01 AL1 Calculation for the Raffinate Pond

C_B =	0.6	(dimensionless)
a =	3.14	(mm^2)
g =	9.81	(m/s^2)
h_w =	6.1	(m)
Q =	2.07E-05	PLR (m^3/s/defect)
Q =	471.5	PLR (gpd/defect)
	2	Number of defects per acre
Q =	942.9	PLR (gpd/acre)
LSA =	0.55	(acres)
AL1	**518.6**	**gpd**

Based on the assumptions presented herein, the AL1 for the Raffinate Pond was calculated to be 518.6 gpd.

7.2 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^2) hole per acre. However, as discussed in Section 7.1, due to the size of the pond the acceptable defect rate was modified herein to be two (2) holes per acre. Table 7.02 presents the parameters and calculation results for the Raffinate Pond AL2.

Table 7.02 AL2 Calculation for the Raffinate Pond

C_B =	0.6	(dimensionless)
a =	100	(mm^2)
g =	9.81	(m/s^2)
h_w =	6.1	(m)
Q =	1.32E-03	PLR (m^3/s/defect)
Q =	15,014.4	PLR (gpd/defect)
	2	Number of defects per acre
Q =	30,028.7	PLR (gpd/acre)
LSA =	0.55	(acres)
AL2	**16,515.8**	**gpd**

Based on the assumptions presented herein, the AL2 for the Raffinate Pond was calculated to be 16,515.8 gpd.

7.3 Conclusions

AL1 and AL2 for the Raffinate Pond were calculated to be 518.6 gpd and 16,515.8 gpd, respectively.

8.0 PLS Pond – Alert Level Leakage Rate Calculations

The purpose of the following analysis was to evaluate the PLR through the upper liner of the proposed double-lined PLS Pond and to propose Alert Levels for the APP application.

The PLRs were calculated using Bernoulli's equation for free flow through an opening (as previously described in Section 1.0). As indicated in Section 7.0, the calculations are dependent on the area of the hole (a), the maximum hydraulic head on the liner (h_w), and the pond's LSA.

Based on the feasibility level design of the PLS Pond, the maximum hydraulic head on the liner is 5.85 meters and the pond's LSA is 3.03 acres (Tetra Tech, 2007).

8.1 Calculation of the AL1 for the PLS Pond

In order to maintain consistency between the process solution ponds, the same defect rate used to determine AL1 for the Raffinate Pond described in Section 8.1 was used to determine AL1 for the PLS Pond. Therefore, the AL1 for the PLS Pond was determined by using two (2) defects per acre that are two (2) mm in diameter. Table 8.01 presents the parameters and calculation results for the PLS Pond's AL1.

Table 8.01 AL1 Calculation for the PLS Pond

C_B =	0.6	(dimensionless)
a =	3.14	(mm^2)
g =	9.81	(m/s^2)
h_w =	5.85	(m)
Q =	4.04E-05	PLR (m^3/s/defect)
Q =	460.8	PLR (gpd/defect)
	2	Number of defects per acre
Q =	921.6	PLR (gpd/acre)
LSA =	3.03	(acres)
AL1	**2,792.3**	**gpd**

Based on the assumptions presented herein, the AL1 for the PLS Pond was calculated to be 2,792.3 gpd.

8.2 Calculation of AL2 for the PLS Pond

In order to maintain consistency between the process solution ponds, the same defect rate used to determine AL2 for the Raffinate Pond described in Section 7.2 was used to determine AL2 for the PLS Pond. Therefore, the AL2 for the PLS Pond was determined by using two (2) defects per acre that are 11.3 mm in diameter. Table 8.02 presents the parameters and calculation results for the PLS Pond's AL2.

Table 8.02 AL2 Calculation for the PLS Pond

C_B =	0.6	(dimensionless)
a =	100	(mm^2)
g =	9.81	(m/s^2)
h_w =	5.85	(m)
Q =	1.29E-05	PLR (m^3/s/defect)
Q =	14,674.4	PLR (gpd/defect)
	2	Number of defects per acre
Q =	29,348.8	PLR (gpd/acre)
LSA =	3.03	(acres)
AL2	**88,926.7**	**gpd**

Based on the assumptions presented herein, the AL2 for the PLS Pond was calculated to be 88,926.7 gpd.

8.3 Conclusions

AL1 and AL2 for the PLS Pond were calculated to be 2,792.3 gpd and 88,926.7 gpd, respectively.

9.0 Summary and Conclusions

Table 9.01 summarizes the calculated PLRs through the lined facilities.

Table 9.01 Calculated PLRs through Lined Facilities

Facility	Potential Leakage Rates (gallons per day)		
	No LPS or GCL	LPS	GCL
PWTS Pond	12,014	5,721	2,294
Raffinate Pond	129	1.0	0.114
Heap Leach Pad	947,200	350	52.8
PLS Pond	129	1.0	0.114
Stormwater Pond	2,101	169	57

As shown in Table 9.01, 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.

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

- AL1 = 518.6 gallons per day; and
- AL2 = 16,515.8 gallons per day.

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

- AL1 = 2,792.3 gallons per day; and
- AL2 = 88,926.7 gallons per day.

10.0 References

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