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TECHNICAL MEMORANDUM

DATE: February 06, 2019 **PROJECT #**: 605.1604

TO: Vicky Peacey and Greg Ghidotti, Resolution Copper

FROM: Chris Gregory and Tim Bayley

PROJECT: Tailing Storage Facility Alternatives, Resolution Copper

SUBJECT: Results of Updated Seepage Transport Models Incorporating Additional Seepage Controls for TSF Alternative Sites

Introduction

At the direction of the US Forest Service (USFS), Montgomery and Associates (M&A) has prepared this technical memorandum to document preliminary results of fate and transport modeling using additional seepage controls to reduce seepage rates developed for Resolution Copper (RC) tailings storage facility (TSF) alternatives. This document provides quantitative results of the GoldSim fate and transport models for the TSF alternatives, using reduced TSF seepage rates obtained from the addition of seepage control measures. The five TSF alternatives considered in this analysis are listed below:

- Alternative 2: Near West Modified Proposed Action (Modified Centerline Embankment – "Wet")
- Alternative 3: Near West Modified Proposed Action (High-density Thickened NPAG Scavenger Tailings and Segregated PAG Pyrite Tailings Cell – "Dry")
- Alternative 4: Silver King Filtered
- Alternative 5: Peg Leg
- Alternative 6: Skunk Camp

The analysis was conducted using seepage transport models previously developed with GoldSim's Contaminant Transport module (M&A, 2018a-d). Modeling was conducted for life of mine (LOM) and post-closure to a reasonable predictive duration of 245 years after the start of mining.

The objective of this analysis was to develop preliminary estimates of groundwater and surface water concentrations downgradient of the TSF alternatives based on the rates of tailings seepage after the application of additional seepage collection measures. The seepage rates were determined based on implementation of Best Available Demonstrated

Control Technology (BADCT) and other seepage collection and engineering controls (M&A 2019, KCB 2019a-b and Golder 2019).

For Alternatives 3, 5 and 6, implementation of additional BADCT features and seepage collection measures resulted in reduced seepage approximately equal to or below preliminary estimates of allowable seepage (M&A 2018e). For Alternatives 2 and 4, the BADCT features either could not adequately reduce seepage or they were not technically feasible and thus could not meet the preliminary allowable rates.

This analysis provides the fate and transport results of the optimized seepage rates for all of the TSF alternatives. Additionally, the results of downgradient concentrations at each model subdomain have been included in this analysis in response to a request by the USFS.

It should be noted that the term "reduced seepage rate" used in this document refers to the modeled rate of *uncollected tailings seepage* to bypass BADCT and other seepage controls, rather than the total rate of tailings seepage—collected and uncollected. The term "collected seepage" refers to water that exits through the TSF footprint, but is subsequently collected by seepage drains, seepage collection dams or pump-back wells. It is also important to note that the GoldSim models include many simplifications and assumptions; therefore, model results should not be regarded as definitive. Once a final TSF has been selected and final BADCT and other seepage control measures have been determined, modeled impacts will be refined within the final Environmental Impact Study (EIS) consistent with the Aquifer Protection Permit (APP) program.

Determination of Reduced Seepage Rates

Prior to this analysis, seepage rates were determined using models that incorporated only seepage controls required for geotechnical stability. The objective of the revised modeling was to demonstrate that the allowable seepage rates could be achieved for each TSF using practicable engineering solutions. A summary of reduced seepage rates developed with the revised models is shown in **Table 2**.

The reduced seepage rates for Alternatives 2 and 3 were determined using steady-state groundwater flow models developed in MODFLOW-USG (M&A 2019). The revised models included implementation of finger drains, blanket drains, liners, grout curtains, and a double layer of seepage collection dams with pump-back wells. The results indicated seepage rates of 20.7 acre-feet per year (af/yr) for Alternative 2 and 2.7 af/yr for Alternative 3. Estimates of seepage and transit times into each of three model drainages were provided in the steady-state model memorandum (Tables 5 through 7 of M&A 2019).

In the case of Alternative 4, reduced seepage rates were determined by an analysis conducted by KCB (KCB, 2018 and 2019a). The results of the analysis provided a range of potential uncaptured seepage rates for the two levels of engineering controls. Level 1

controls included pile underdrainage, lined collection ditches and collection ponds that cut off the alluvium. Level 2 controls included Level 1 controls, in addition to targeted grouting of fractures in the foundation and pump-back wells for seepage return. Based on the analysis, implementation of Level 2 controls would result in uncollected TSF seepage of approximately 9 to 17 af/yr during LOM. For the updated GoldSim seepage transport model, 17 af/yr was conservatively selected as the LOM reduced seepage rate. The post-closure seepage rate was based on an analysis of Alternative 4 tailings seepage water chemistry and varies from 15.2 to 31.9 af/yr (Rio Tinto, 2018).
The reduced seepage rate for Alternative 5 was determined by Golder and Associates (Golder, 2019). Implementation of BADCT technologies included covers, and seepage control measures included additional pump-back wells. Seepage rates were estimated for both conventional and thin lift depositional techniques. The results of the investigation suggested that a reduced seepage rate of 261 af/yr, equal to the preliminary allowable rate, could be attained through a combination of engineering controls, depositional techniques, and additional pump-back wells.

In the case of Alternative 6, a range of reduced seepage rates was developed based on two-dimensional infiltration modeling in SEEP/W (KCB, 2019b) with additional seepage control measures. The two-dimensional model included underdrains, seepage collection ponds with a cutoff wall, a grout curtain and pump-back wells. The results indicated that reduced seepage rates were approximately 40 to 110 gallons per minute (gpm) during LOM and 125 to 160 gpm during post-closure. For the seepage transport model, 110 gpm (178 af/yr) and 160 gpm (258 af/yr) were conservatively selected as the optimized rates for LOM and post-closure, respectively.

Methods

The present analysis was conducted using seepage transport models previously developed with GoldSim's Contaminant Transport module (M&A, 2018a-d). The reduced seepage rates provided by the models previously mentioned (M&A 2019, KCB 2019a-b and Golder 2019) were assigned as tailings seepage values within the GoldSim models. Additional monitoring of groundwater and surface water concentrations downstream of the TSF locations was implemented at each model subdomain, per request of the United States Forest Service. For each alternative, modeling was conducted for life of mine (LOM) and post-closure to a reasonable predictive duration of 245 years after the start of mining.

Model results are presented without background water quality concentrations—referred to as "model results"—and with background water quality concentrations—referred to as "total predicted concentrations". Tables of total predicted concentrations are included for select aquifer and surface water model subdomains located downgradient of TSF footprints and near locations of previously collected water quality samples.

A list of model subdomains used for analysis of total predicted concentrations is provided below. Locations of model subdomains and sampling sites are shown on **Figures 1 through 4.**

- Alternatives 2, 3 and 4:
  - Queen Creek 3 subdomain, based on well DS17-17 (aquifer)
  - Whitlow Ranch Dam subdomain (surface water)

- Alternative 5:
  - Donnelly Wash 2 subdomain, based on Tea Cup Well (aquifer)
  - Gila River below Donnelly Wash (surface water)

- Alternative 6:
  - Dripping Springs 1 subdomain, based on Skunk Camp Well (aquifer)
  - Gila River below Dripping Springs Wash (surface water)

In the case of Alternatives 2, 3 and 4, background water quality concentrations were based on median concentrations of samples collected at well DS17-17 and Whitlow Ranch Dam. In the case of Alternative 5 and 6, background concentrations were based on sampling events collected from wells near the TSF footprints and from surface water locations along the Gila River.

Results

Model results of seepage rates for all TSF alternative sites are provided in **Appendices A through E**. The following observations are made regarding the results and applicable water quality standards:

Alternative 2

- At Whitlow Ranch Dam subdomain, **selenium model results** are above the surface water quality standard for years 64 through 98, and 116 through 245

- At Whitlow Ranch Dam subdomain, **selenium total predicted concentrations** are above the surface water quality standard for years 47 and 51 through 245

Alternative 3

- No concentrations observed above standards

Alternative 4

- At Happy Camp West subdomain, **selenium model results** are above the aquifer water quality standard for years 42 through 245; **antimony model results** are above the aquifer water quality standard for years 82 through 87 and years 91 through 245; and, **cadmium model results** are above the aquifer water quality standard for years 234 through 245

- At Happy Camp East subdomain, **selenium model results** are above the aquifer water quality standard for years 58 through 245

- At Whitlow Ranch Dam subdomain, **selenium model results** are above the surface water quality standard for years 59 through 245

- At Whitlow Ranch Dam subdomain, **selenium total predicted concentrations** are above the surface water quality standard for years 44 through 245

Alternative 5

- Donnelly Wash subdomain 1 is immediately beneath the TSF, thus the comparison to water quality standards is made at Donnelly Wash 2 subdomain, which is immediately downstream of the TSF. No concentrations are observed above the standards with the exception of nitrate-nitrogen.

    - **Nitrate-nitrogen total predicted concentrations** are above the aquifer water quality standard for years 1 through 245. However, this is a result of the background nitrate-nitrogen concentration of 15.2 mg/L being above the aquifer standard of 10 mg/L, and is not due to elevated nitrate-nitrogen concentrations in Alternative 5 tailings seepage chemistry. The background nitrate-nitrogen concentration may be erroneous or due to localized contamination from nearby ranch activity (Tea Cup Well); therefore, additional aquifer water quality characterization is warranted.

Alternative 6

- No concentrations observed above standards

Discussion

The GoldSim models are most suitable for qualitative comparisons between TSF alternatives and should not be mistaken for a precise prediction of future concentrations. Many assumptions have been made in order to align the models and facilitate comparison

between alternatives. Most of these assumptions have been intentionally conservative in nature, and consequently, model results of downgradient water quality concentrations are likely overpredicted (biased higher than expected).

The results of this analysis suggest that meeting applicable water quality standards with BADCT and other engineering seepage controls may be more practical and technically feasible at TSF Alternatives 3, 5 and 6 than at Alternatives 2 and 4. For Alternatives 3, 5 and 6, seepage rates were reduced to levels approximately equal to or below preliminary allowable seepage estimates with additional modeled seepage controls, while for Alternatives 2 and 4, allowable rates were not attained. Overall at this stage of the analysis, the seepage controls at Alternative 6 appear to be the most straightforward/least complex, followed by Alternative 5 and then Alternative 3.

In nearly all cases where model results were observed above water quality standards, selenium was the constituent of concern. This is partly due to the very low surface water standard for selenium that applies to chronic exposure for aquatic and wildlife warmwater, equal to 0.002 mg/L (Arizona Administrative Code - Title 18, Ch. 11, Art. 4, Sup. 16-4, 2016). In the case of Alternative 5, total predicted nitrate-nitrogen concentrations of TSF seepage in the Donnelly Wash 2 subdomain meet water quality standards, however they are observed above the aquifer water quality standard of 10 mg/L, due to measured background concentration of nitrate-nitrogen in Tea Cup Well of 15.2 mg/L (**Table 9 of Appendix D**). Were the comparison made with groundwater from a well not impacted by ranch activity, the seepage from ALT 5 would comply with the nitrate-nitrogen standard.

References

ADEQ, 2016, Arizona Department of Environmental Quality – Water Quality Standards Supplement 16-4, Arizona Administrative Code: Title 18, Chapter 11, December 31, 2016.

Klohn Crippen Berger Ltd. (KCB), 2018, Resolution Copper Project - DEIS Design for Alternative 4 - Silver King Filtered - Doc. # CCC.03-26000-EX-REP-00006-Rev.0, June 2018.

_____, 2019a, Resolution Copper Project - DEIS Alternative 4 Silver King Filtered – Uncaptured Seepage, January, 2019.

_____, 2019b, Resolution Copper Project - DEIS Design for Alternative 6 - Skunk Camp, Appendix IV - Doc. # CCC.03-81600-EX-MMO-00024 – Rev.2. January, 2019.

Golder Associates Inc., 2019, Alternative 5 – Peg Leg Water Balance – Additional BADCT Technologies to Reduce Seepage: Technical Memorandum prepared for Resolution Copper Mining, January, 2019.

Montgomery & Associates, 2018a, TSF Alternatives 2 and 3 - Near West: Life of Mine and Post-Closure Seepage Transport Modeling: Technical Memorandum prepared for Resolution Copper Mining LLC, September 14, 2018.

_____, 2018b, TSF Alternative 4 - Silver King: Life of Mine and Post-Closure Seepage Transport Modeling: Technical Memorandum prepared for Resolution Copper Mining LLC, September 14, 2018.

_____, 2018c, TSF Alternative 5 - Peg Leg: Life of Mine and Post-Closure Seepage Transport Modeling: Technical Memorandum prepared for Resolution Copper Mining LLC, September 14, 2018.

_____, 2018d, TSF Alternative 6 - Skunk Camp: Life of Mine and Post-Closure Seepage Transport Modeling: Technical Memorandum prepared for Resolution Copper Mining LLC, September 14, 2018.

_____, 2018e, Estimated Preliminary Allowable Seepage from TSF Alternative Sites for Comparative Analysis: Technical Memorandum prepared for Resolution Copper Mining LLC, December 21, 2018.

_____, 2019, Alternatives 2 and 3 Steady-State Modeling: Technical Memorandum prepared for Resolution Copper Mining LLC, January, 2019.

Rio Tinto, 2018, Prediction of Tailings Seepage Water Chemistry Influenced by Tailings Weathering Processes: Technical Memorandum Draft prepared for Resolution Copper Mining LLC, July 29, 2018.

Table 1. Comparison of Model Results and Natural Site Attributes of Tailings Storage Facility Alternatives

Tailings Storage Facility (TSF) Alternative	Preliminary Allowable Seepage Rate [1] (af/yr) [2]	Revised Model Reduced TSF Seepage Rate [3] (af/yr)		Groundwater System				Surface Water System		
				TSF Footprint Foundation Hydraulic Conductivity [4]	Groundwater Transport Pathway		Number of Constituents above AWQS [5]	Surface Water Transport Pathway		Number of Constituents above SWQS [6]
		Life of Mine	Post-Closure		Hydraulic Conductivity	Aquifer Volume		Distance to Surface Water	Flow Rate (af/yr)	
Alternative 2 Near West ("wet")	3	20.7	20.7	Low	Fast	Small	0	Short	794	1 (Se)
Alternative 3 Near West ("dry")	3	2.7	2.7	Low	Fast	Small	0	Short	794	0
Alternative 4 Silver King	6	9 - 17 [7]	15.2 - 31.9 [8]	Low	Fast	Small	3 (Cd, Sb, Se)	Long	794	1 (Se)
Alternative 5 Peg Leg	261	261	261	Medium	Medium	Large	1 (NO3-N) [10]	Medium	30,900	0
Alternative 6 Skunk Camp	329	65 - 178 [9]	202 - 258 [9]	Medium	Fast	Medium	0	Long	28,200	0

Notes:

[1] Based on a preliminary analysis of allowable seepage without any modeled constituent observed above applicable water quality standards during the 245-year model period (M&A, 2018e)

[2] af/yr = acre-feet per year

[3] For model details, see technical memorandum references for: Alternatives 2 and 3 (M&A, 2019), Alternative 4 (KCB 2019a), Alternative 5 (Golder, 2019), and Alternative 6 (KCB, 2019b)

[4] Used to estimate transit times from TSF footprints to alluvial aquifers represented in Goldsim model domains; for Alternatives 4, 5 and 6, footprints are adjacent to aquifers and require no transit delays in model

[5] Number of unique constituents that occur above Aquifer Water Quality Standards (AWQS) (ADEQ, 2016) for at least one year during 245-year model period

[6] Number of unique constituents that occur above Surface Water Quality Standards (SWQS) (ADEQ, 2016) for at least one year during 245-year model period

[7] Range of optimized seepage rates based on second level engineering controls (KCB, 2019a); conservative estimate of 17 af/yr used for Goldsim modeling

[8] Seepage rates based on tailings seepage water chemistry analysis (Rio Tinto, 2018) and vary by year

[9] Conservative upper range of seepage rates used for Goldsim modeling, equal to 178 af/yr during life of mine, and 258 af/yr during post closure

[10] NO3-N exceedance is a result of background water quality, not TSF seepage

Table 2. Comparisons of Preliminary Allowable and Modeled Tailings Storage Facility Seepage Rates

Tailings Storage Facility (TSF) Alternative	Phase	Preliminary Allowable Seepage (af/yr)	Original Goldsim F&T Seepage (af/yr) [1]	Revised Model Seepage (af/yr)	Revised Model Reference	Seepage Controls added in Revised Models
Alternative 2 Near West ("wet")	Life of Mine	3	152	20.7	M&A, 2019 [2]	liners, grout curtains, and pump-back wells
	Post Closure		15			
Alternative 3 Near West ("dry")	Life of Mine	3	73	2.7	M&A, 2019 [2]	liners, grout curtains, and pump-back wells
	Post Closure		19			
Alternative 4 Silver King	Life of Mine	6	0.6	9 - 17 [3]	KCB, 2019a [5]	targeted grouting of fractures in the foundation, and pump-back wells for seepage return
	Post Closure		15.2 - 31.9 [4]	15.2 - 31.9 [4]		pump back wells turned off during post closure
Alternative 5 Peg Leg	Life of Mine	261	1293	261	Golder, 2019 [6]	additional liners, additional pump-back wells, "thin lift deposition" scenario, and analytical estimates of drain down
	Post Closure		258			
Alternative 6 Skunk Camp	Life of Mine	329	661	65 - 178 [7]	KCB, 2019b [8]	grout curtain extended from 70 to 100 feet bgs, and pump-back well extended from 20 to 70 feet bgs and relocated from Alluvium to Gila Conglomerate. Pump-back well turned off during post closure
	Post Closure		258	202 - 258 [7]		

Notes:

[1] af/yr = acre-feet per year

[2] Montgomery & Associates, 2019, Alternatives 2 and 3 Steady-State Modeling: Technical Memorandum prepared for Resolution Copper Mining LLC, January, 2019

[3] Range of optimized seepage rates based on second level engineering controls; conservative estimate of 17 af/yr used for Goldsim modeling

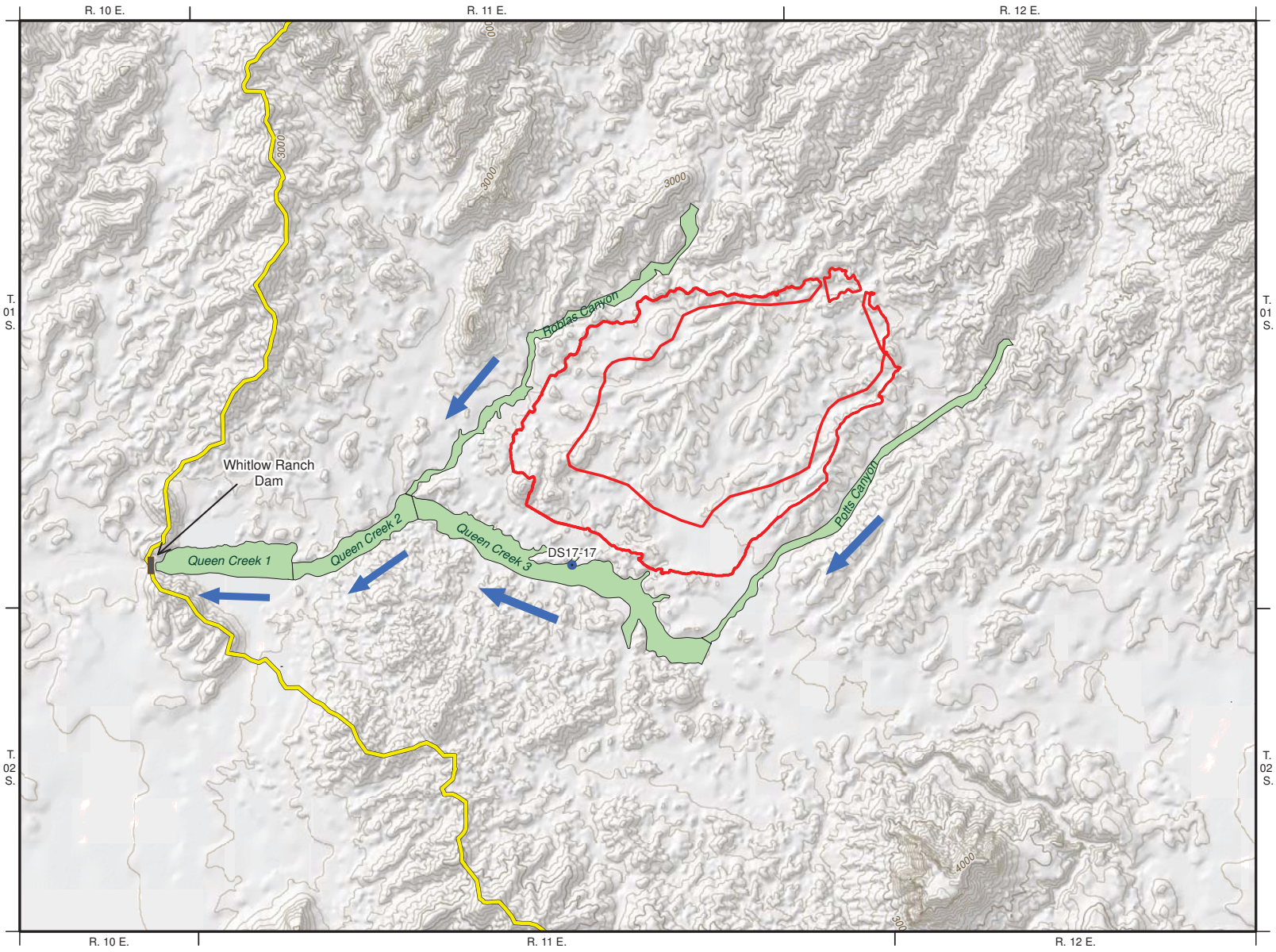
[4] Seepage rates vary by year and are based on Alternative 4 tailings seepage water chemistry analysis (Rio Tinto, 2018)

[5] Klohn Crippen Berger Ltd. (KCB), 2019a, Resolution Copper Project - DEIS Alternative 4 Silver King Filtered – Uncaptured Seepage: Draft, January, 2019

[6] Golder Associates Inc., 2019, Alternative 5 – Peg Leg Water Balance – Additional BADCT Technologies to Reduce Seepage: Technical Memorandum prepared for Resolution Copper Mining, January, 2019

[7] Conservative upper range of seepage rates used for Goldsim modeling, equal to 178 af/yr during life of mine, and 258 af/yr during post closure

[8] Klohn Crippen Berger Ltd. (KCB), 2019b, Resolution Copper Project - DEIS Design for Alternative 6 - Skunk Camp, Appendix IV - Doc. # CCC.03-81600-EX-MMO-00024 – Rev.2. January, 2019



EXPLANATION

- Aquifer Subdomain
- Proposed TSF Footprint
- Superior Basin Boundary
- Flow Direction
- Well DS17-17

Aquifer Subdomain	Length (ft)	Area (ft^2)	Average Width (ft)
Potts Canyon	20,200	7,524,243	370
Roblas Canyon	20,700	7,590,766	370
Queen Creek 3	15,700	17,899,651	1,140
Queen Creek 2	6,400	5,656,661	880
Queen Creek 1	6,300	8,327,969	1,320

Notes:

1. Average widths of aquifer elements calculated by dividing aquifer polygon areas by lengths

0 1,000 2,000 3,000 4,000
Meters

0 0.5 1 1.5 2
Miles

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TSF ALTERNATIVES 2 AND 3 GOLDSIM MODELS LOCATION MAP

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2019

FIGURE 1

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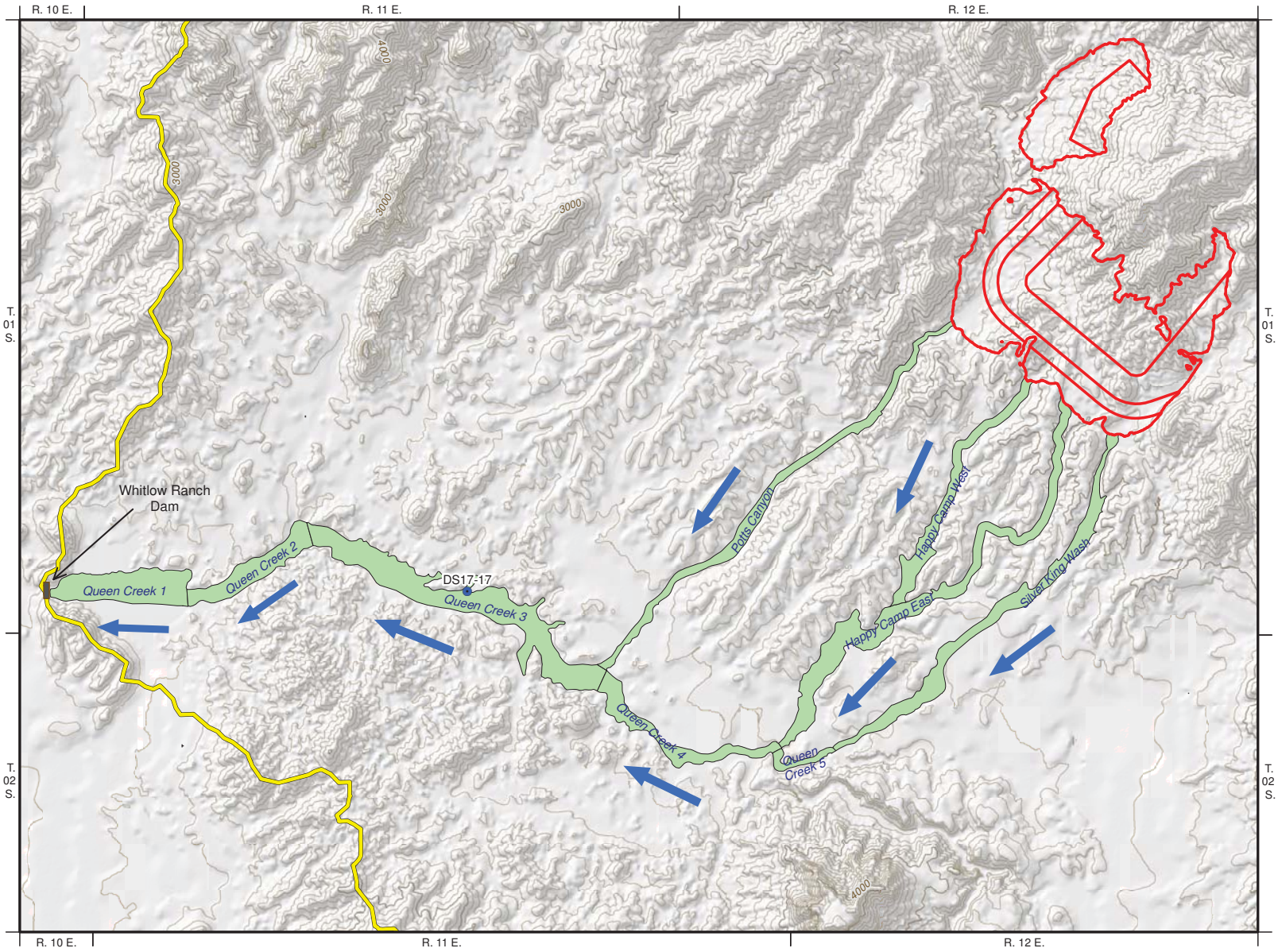

EXPLANATION

- Aquifer Subdomain
- Proposed TSF Footprint
- Superior Basin Boundary
- Flow Direction
- Well DS17-17

Aquifer Subdomain	Length (ft)	Area (ft^2)	Average Width (ft)
Silver King	20,100	10,219,800	510
Happy Camp E	23,700	14,186,100	600
Happy Camp W	12,300	6,052,900	490
Potts Canyon	23,400	8,340,600	360
Queen Creek 5	3,500	1,082,900	310
Queen Creek 4	9,900	5,398,500	550
Queen Creek 3	15,700	17,899,700	1,140
Queen Creek 2	6,400	5,656,700	880
Queen Creek 1	6,300	8,328,000	1,320

Notes:

1. Average widths of aquifer elements calculated by dividing aquifer polygon areas by lengths

0 1,000 2,000 3,000 4,000
Meters

0 0.5 1 1.5 2
Miles

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TSF ALTERNATIVE 4 GOLDSIM MODEL LOCATION MAP

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FIGURE 2

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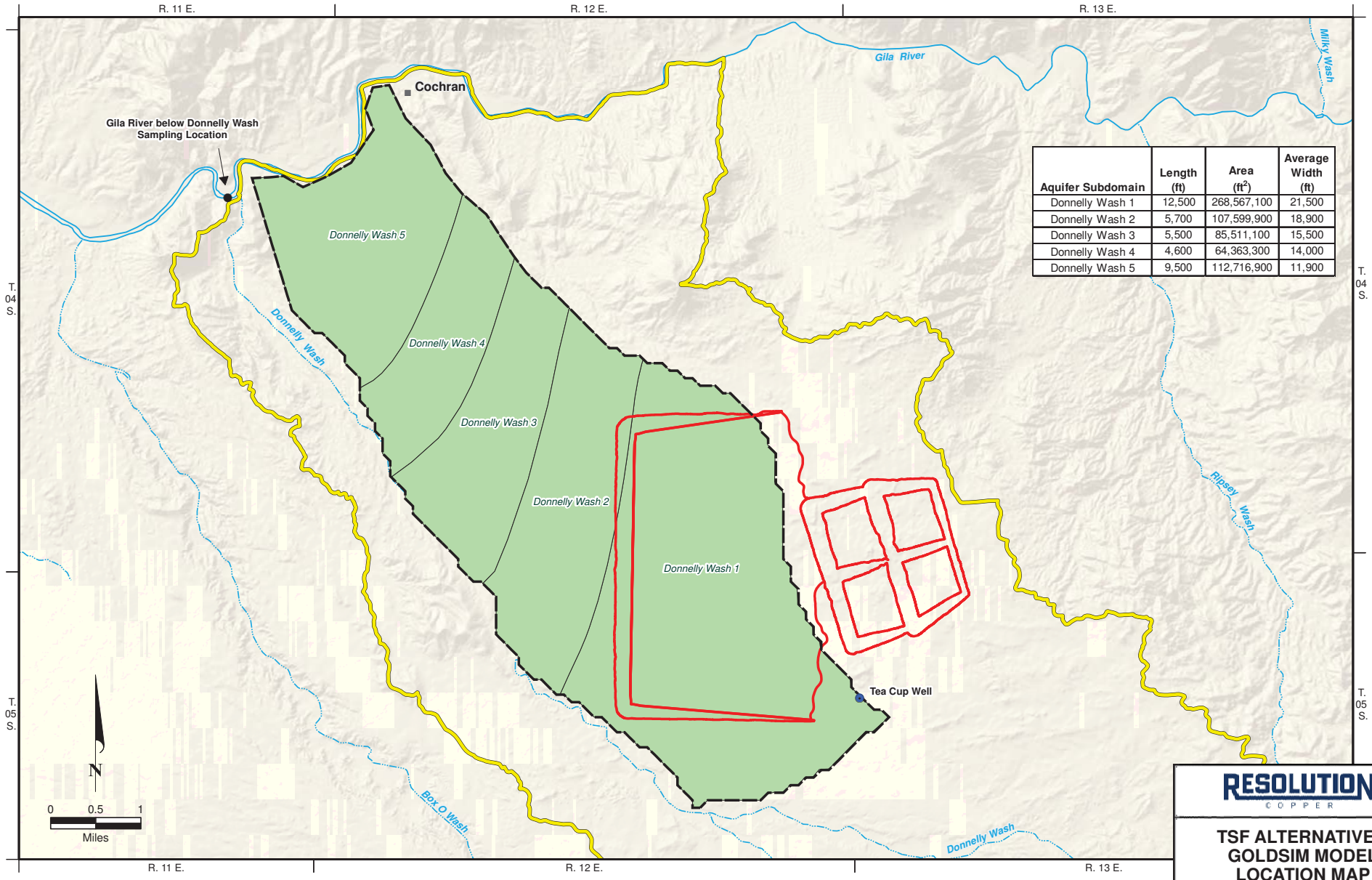

Aquifer Subdomain	Length (ft)	Area (ft^2)	Average Width (ft)
Donnelly Wash 1	12,500	268,567,100	21,500
Donnelly Wash 2	5,700	107,599,900	18,900
Donnelly Wash 3	5,500	85,511,100	15,500
Donnelly Wash 4	4,600	64,363,300	14,000
Donnelly Wash 5	9,500	112,716,900	11,900

EXPLANATION

- Aquifer Subdomain
- Proposed TSF Footprint
- Alluvium and Basin Fill Aquifer Boundary
- Donnelly Wash Drainage
- Tea Cup Well
- Gila River Sampling Location

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TSF ALTERNATIVE 5 GOLDSIM MODEL LOCATION MAP

2018

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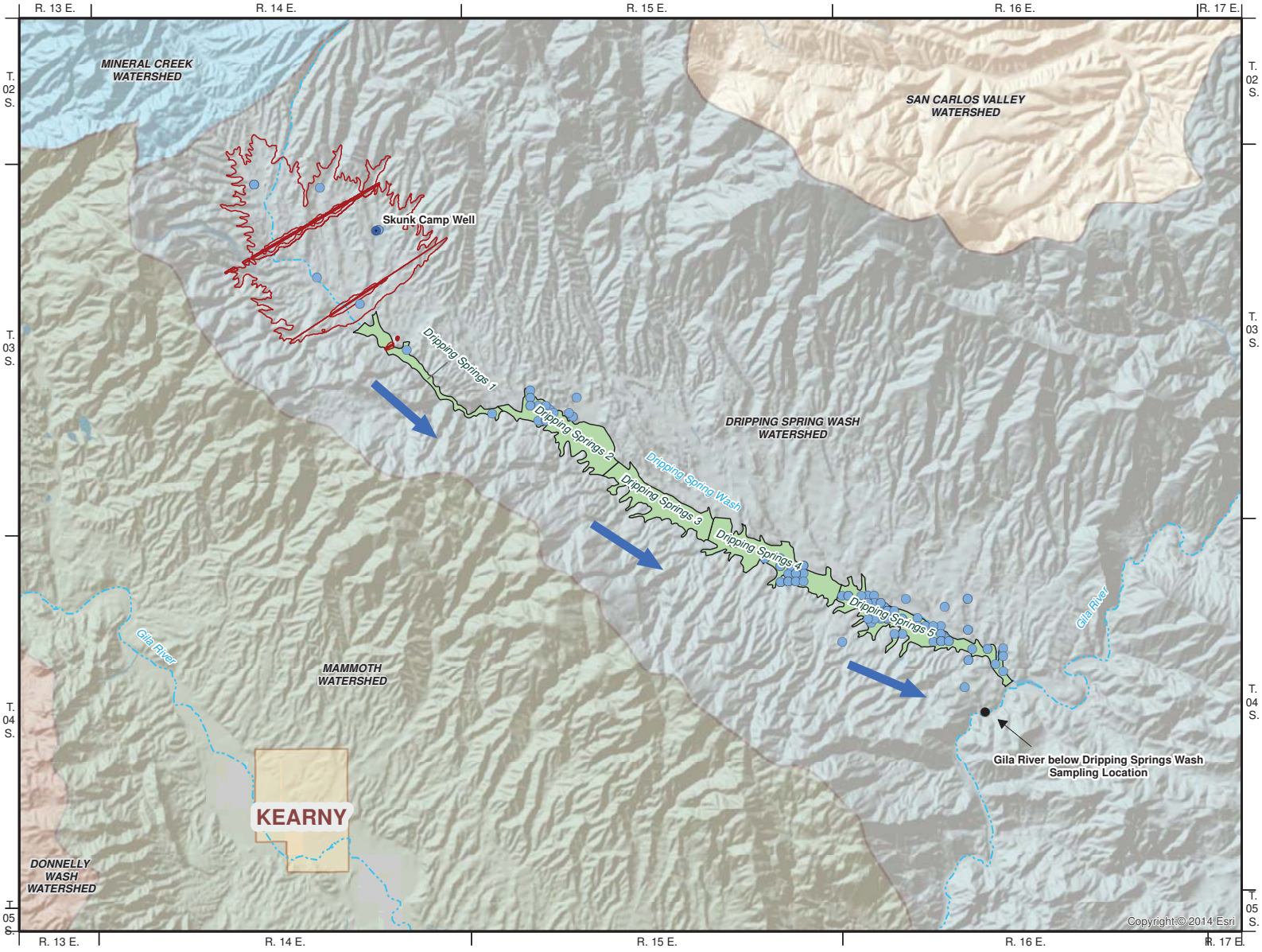
FIGURE 3



EXPLANATION

- Aquifer Subdomain
- Proposed TSF Footprint
- ADWR Watershed Boundary
- Flow Direction
- ADWR Well
- Skunk Camp Well
- Gila River Sampling Location

Aquifer Subdomain	Length (ft)	Area (ft^2)	Average Width (ft)
Dripping Springs 1	15,400	15,977,900	1,040
Dripping Springs 2	11,200	23,192,700	2,070
Dripping Springs 3	10,000	20,060,700	2,010
Dripping Springs 4	12,200	26,001,800	2,130
Dripping Springs 5	17,200	27,462,500	1,600

Notes:

1. Average widths of aquifer elements calculated by dividing aquifer polygon areas by lengths

0 2,500 5,000
Meters
0 1 2 3 4
Miles

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TSF ALTERNATIVE 6 GOLDSIM MODEL LOCATION MAP

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FIGURE 4

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Victoria Boyne

From: ResolutionProjectRecord
Subject: FW: EXTERNAL:Action Items from Geochem Workgroup Meetings 11/13, 12/11 - Final GoldSim Model Report
Attachments: Updated Seepage Transport Models_M&A_06Feb19.pdf; Appendix E_Alt 6 Results_Tbls 1-10.xlsx; Appendix A_Alt 2 Results_Tbls 1-10.xlsx; Appendix B_Alt 3 Results_Tbls 1-10.xlsx; Appendix C_Alt 4 Results_Tbls 1-14.xlsx; Appendix D_Alt 5 Results_Tbls 1-10.xlsx; Updated Seepage Transport Models_MA_Tables-Figures-6Feb19.pdf

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Cc: Chris Garrett <cgarrett@swca.com>; Donna Morey <dmorey@swca.com>; Ghidotti, Greg (G&I) <Gregory.Ghidotti@riotinto.com>; RCPermitting <RCPermitting@riotinto.com>; Morissette, Mary (RC) <Mary.Morissette@riotinto.com>
Subject: EXTERNAL:Action Items from Geochem Workgroup Meetings 11/13, 12/11 - Final GoldSim Model Report

Mary,

For your review and consideration, please see the attached updated GoldSim modeling report incorporating additional seepage controls for all the TSF alternatives for comparative analysis. The attachments include the following:

- Model Report
- Tables and Figures
- Appendices A-E providing results in Excel

Thanks,

Vicky Peacey
Senior Manager – Environment, Permitting and Approvals

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