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TECHNICAL MEMORANDUM

DATE: December 17, 2018 **PROJECT #**: 605.8206

TO: Victoria Peacey and Greg Ghidotti, Resolution Copper

FROM: Derek Groenendyk and Tim Bayley

PROJECT: Near West Tailings Facility

SUBJECT: Alternatives 2 and 3 Steady-State Modeling

Introduction

At the request of the United States Forest Service and the groundwater working group for the Resolution Copper EIS, Montgomery & Associates (M&A) has prepared this technical memorandum to support the draft environmental impact statement (DEIS) being prepared by the United States Forest Service as part of the ongoing National Environmental Policy Act review process for the Resolution Project near Superior, Arizona. The DEIS for the proposed Resolution Copper mine includes the following tailings storage facility alternatives:

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

This memorandum was written to document model construction and results of steady-state groundwater flow modeling (Model) of the proposed Near West Tailings Storage Facility (TSF). The Model was prepared to provide estimates of TSF seepage rates and travel times for Alternatives 2 and 3 in support of GoldSim contaminant transport modeling. The site of the proposed TSF is in the Superior Basin, which is in the upper Queen Creek watershed, from its headwaters to Whitlow Ranch Dam (**Figure 1**).

The Model was developed in MODFLOW-USG (Panday and others, 2013) to provide estimates of seepage rates into the three drainages adjacent to the TSF footprint (Potts Canyon, Roblas Canyon and Queen Creek) and travel times from the TSF to these drainages during maximum build-out conditions. The engineering and design of the TSF are documented in design reports by Klohn Crippen Berger Ltd. (KCB) (KCB, 2018 a,b). The Model is intended to be a simplified representation of both natural hydrogeologic conditions and engineered tailings conditions. While the seepage rates and travel times derived from this Model are considered to be useful tools for TSF alternatives comparison, it is important to recognize that several conservative assumptions are built into the Model that may over predict seepage:

Conservative Assumptions

The Model represents steady-state conditions assuming operational conditions at full TSF build-out. The hydraulic gradients developed under the modeled conditions are expected to be steeper than would occur during the actual transient build-out of the mine, likely resulting in an overestimate of seepage rates. In addition, these steeper gradients would result in shorter travel times than would be likely to occur during transient mine build-out.

Model Layering & Geometry

The Model was developed with fourteen layers representing the constructed TSF and natural subsurface (**Figure 2**). Layers one through seven represent tailings and are only active where the TSF is present. Layer seven includes a blanket drain under the proposed extent of the TSF embankment. Model cells in layers one through seven are active based on the vertical and horizontal extent of the TSF at the end of mining operations. Layer eight is the uppermost layer below the natural ground surface, and represents land surface. Layer eight also contains finger drains where they are present under the TSF. Layers nine through fourteen represent the remainder of the subsurface to a depth of 650 feet below land surface.

Alluvium in the Model was separated into two units, one representing Queen Creek and the other representing the tributaries of Queen Creek in the basin. Alluvial tributaries within the TSF footprint are assumed to be filled with tailings material where finger drains are not present. The Queen Creek alluvium varies in thickness from 10 to 49 feet and is present in model layers eight and nine. Tributary alluvium is considered to be 10 feet thick and is present only in layer eight. **Figure 2** provides detailed information on model layering and thickness. Values shown in **Figure 2** represent model cell thickness in feet.

Model grid cells in the area of the TSF are 100 x 100 feet; outside the area of the TSF, model cells are 500 x 500 feet (**Figure 3**). Model layering was based on the original, pre-TSF land surface. The land surface elevation for each model cell is calculated as the spatially-weighted average of a 22.5 x 22.5 feet Digital Elevation Model of the area.

Model Domain and Boundary Conditions

The model domain is shown on **Figure 3** and extends to the Superior Basin boundary in the northwest and northeast, the Queen Creek alluvium in the south and southwest, and the Happy Camp drainage in the southeast. Model boundaries to the north, west, and northeast are represented as no-flow boundaries. The southeastern model boundary is approximately perpendicular to observed groundwater flow contours (M&A, 2017a) along the Happy Camp drainage and was simulated as a no-flow boundary. The south/southwestern boundary of the Model is the southern extent of the Queen Creek alluvial deposits. A specified-flux boundary was used to simulate 319 acre-feet per year (AF/yr) of groundwater underflow entering the model domain from the south side of Queen Creek as determined in the Superior Basin Conceptual Model (M&A, 2017a). This specified-flux boundary was implemented using the MODFLOW WEL package.

Hydrogeology

The geologic setting of the proposed TSF site is complex including many rock types and a series faulted and tilted structural features. The principal Hydrogeologic Units (HGUs) identified in the study area include (in order of increasing age): Quaternary alluvial deposits, Tertiary Gila Conglomerate, Tertiary sandstone, younger Tertiary volcanic rocks, Tertiary Apache Leap Tuff, older Tertiary volcanic rocks, Tertiary Whitetail Conglomerate, Tertiary-Cretaceous intrusive igneous rocks, Paleozoic sedimentary rocks, younger Precambrian intrusive igneous rocks, younger Precambrian sedimentary, older Precambrian intrusive igneous rocks, and older Precambrian metamorphic rocks. Additional description of the geologic setting of the TSF foundation is provided in the following reports:

Hydrogeologic studies of the Near West tailings site include:

- Near West Tailings Storage Facility: Geotechnical Site Characterization Report, KCB, 2017
- Construction, Development, & Testing of Hydrologic Test Wells at the Near West Tailings Site: Resolution Copper, M&A, 2017b
- Near West TSF Geotechnical Field Investigation Summary Report, Golder Associates, 2017
- Conceptual Hydrogeologic Model for Proposed Near West Tailings Storage Facility, M&A, 2017a

Hydraulic Properties

Numerous hydraulic tests were conducted to determine the hydraulic properties of the geologic units.

Testing conducted at the TSF site and documented by M&A (2017a) includes:

- Packer tests and falling head tests in 38 open boreholes
- Constant-rate pumping tests in eight (8) hydrologic test wells
- Short-duration pumping tests in four (4) geotechnical piezometers and one (1) hydrologic test well
- Slug tests in eight (8) hydrologic test wells and four (4) piezometers
- Downhole nuclear magnetic resonance (NMR) geophysical logging.

Measured hydraulic conductivity values near the TSF range from 4.0×10^{-5} feet per day (ft/d) in the Diabase to over 1,000 ft/d in the Queen Creek alluvium. However, for the purpose of this simplified modeling study, a single homogenous isotropic material was used to represent the bedrock units. Homogenous isotropic materials with differing hydraulic conductivities were also used to represent the tributary and Queen Creek alluvium, drain, and tailing units (**Table 1**).

The representative hydraulic conductivity of the bedrock was determined to be 1.32×10^{-2} ft/d, by calculating the volume-weighted geometric mean of the HGUs present in the subsurface (M&A, 2017c). Aquifer testing indicated that the hydraulic conductivity of the Queen Creek alluvium was much higher than the surrounding bedrock; the Model uses a value of 1,000 ft/d (M&A, 2017a). The tributary alluvium has a hydraulic conductivity of 500 ft/d in the Model.

Tailings material is represented as a homogeneous, isotropic material with a hydraulic conductivity of 2.83×10^{-2} ft/d which is the expected composite hydraulic conductivity of the scavenger beach. The blanket drain is represented with a homogeneous isotropic highly conductive gravel material, with a hydraulic conductivity of 142 ft/d. Finger drains are also represented by a homogeneous isotropic highly conductive gravel material, with a hydraulic conductivity of 283 ft/d (KCB, 2018a,b).

TSF Engineering Features

This Model includes TSF engineering features that are considered necessary for geotechnical stability of the TSF, which includes a blanket drain, a network of finger drains, and seepage collection dams with pump back wells in drainage channels that drain the footprint of the TSF (**Figure 4**). Full design details of these structures is presented by KCB (2018a,b).

The blanket drain is designed to be a 3-foot thick, highly conductive layer consisting of coarse gravel that drains the embankment of the TSF. The blanket drain is located in model layer seven (a 3-foot thick layer) beneath the complete extent of embankment and is represented by a high hydraulic conductivity (142 ft/d). Discharge from the blanket drain to the perimeter of the embankment reports to a MODFLOW Drain Cell (DRN), and exits the simulated flow system. In reality, discharge from the blanket drain would emerge at land surface and flow through lined channels along the embankment toe to the finger drains before reaching the seepage collection dams; however, this surface flow is not being simulated. The stage of the DRNs at the perimeter of the embankment are equal to the elevation of the bottom of layer seven, with a drain conductance of $1x10^6$ square feet per day (ft^2/d).

Finger drains are designed as 10 feet thick by 30 feet wide channels filled with highly conductive coarse gravel excavated into existing alluvial channels under the TSF. Finger drains are located in model layer eight beneath the blanket drain and extend to the perimeter of the embankment in the model. Flow in the finger drains reports to simulated DRNs at the downstream end, and exits the simulated flow system. As is the case with the blanket drains, in reality, discharge from the finger drains would result in surface flow that reports to the seepage collection dams through lined channels but is not explicitly simulated. The stage of the DRNs at the end of the finger drains is equal to the elevation of the bottom of the layer eight, with a drain conductance of $1x10^6$ ft^2/d.

The primary seepage collection dams are designed as general fill dams covered on the upstream side with a geomembrane placed in excavated alluvium downstream of the TSF to capture seepage from the finger drains. They will include a grouted cut-off wall that extends into the subsurface below and a well on the upstream side to pump seepage back onto the TSF. The cut-off walls beneath each seepage collection dam are simulated using MODFLOW's Horizontal Flow Barrier (HFB) package. The cut-off walls are only in alluvium cells in model layer eight where seepage collection dams are present. The cut-off walls have a thickness of 3 feet, a depth of 10 feet, a width of 100 feet (covering the entire downstream cross-sectional area of the cell), and a hydraulic conductivity of $2.83x10^{-3}$ ft/d. Pump back wells are represented with DRN cells located upgradient from the cut-off walls in layer eight. The DRNs have a stage equal to the bottom elevation of the cell, with a drain conductance of $1x10^6$ ft^2/d. Water that enters these drain cells exits the simulated system.

Model Inputs and Outputs

A complete water balance of the model domain is provided in M&A (2017a). This memorandum summarizes the model domain water balance and describes its translation into the steady-state numerical model.

Inflows

Estimated recharge for the model domain was calculated using the approach outlined by Anderson and others (1992) to be 676 AF/yr (M&A, 2017a). When converted to percent of precipitation, the estimated recharge was 1.5% of precipitation. This is consistent with other regional aquifer recharge studies (Osterkamp, 1973; Freethey and Anderson, 1986; Woodhouse, 1997).

Recharge to groundwater was partitioned between diffuse recharge occurring through bedrock infiltration and focused recharge along streambeds. Based on Meixner and others (2016), 25% of the recharge was assigned to bedrock areas of the model and 75% was assigned to alluvial drainages.

Subflow in the Queen Creek alluvial channel at the southeastern model boundary was estimated to be 42 AF/yr using Darcy's Law (M&A, 2017a). This inflow was represented in the model using MODFLOW's well (WEL) package. The flux is applied to model layer eight.

Groundwater underflow enters the model domain from the southwest at the boundary between the Queen Creek Alluvium and the bedrock immediately to the south. Groundwater inflow from the south is estimated to be 319 AF/yr based on a water balance of the Superior Basin (M&A, 2017a).

TSF Recharge

Recharge during active deposition on the tailings was estimated by KCB using a 1D unsaturated numerical water flow model (**Table 4**) (KCB, 2018a,b). The rate of recharge applied to the TSF at maximum build-out is 2.29×10^{-3} ft/d for Alternative 2 and 6.17×10^{-4} ft/d for Alternative 3. These rates represent the net rate of water applied to the TSF during build-out taking into account precipitation, evaporation, and runoff. Recharge in the TSF is added through MODFLOW's well (WEL) package. The wells have an injection rate equal to the rate of applied water (ft/d) x cell area (ft^2).

Model cells representing cleaner tailings covered by ponds have an injection rate based on the unit gradient conditions for consolidated cleaner tailings material, which has a vertical hydraulic conductivity of 7.08x10^{-4} ft/d. The location and extent of the ponded cleaner tailings changes throughout the duration of TSF construction. The cleaner tailings cells in the Model used to represent the area of ponded recharge for both Alternatives 2 and 3 are based on the tailings build-out from the KCB design for Alternative 2 (2018a). The representative cells cover an area near the maximum extent of the ponded area and are located near the center of the TSF footprint, which occurs approximately 25 years after the start of mining operations in Alternative 2 (**Figure 4**).

Outflows

Very little groundwater development has occurred within the model domain. Approximately 1.3 miles southeast of the proposed TSF, there is an irrigation well, Arizona Department of Water Resources (ADWR) 55-627523, that is estimated to pump 5 AF/yr of groundwater per year (M&A, 2017a) and is included in the Model. Several small windmill and solar ranch wells exist within the model domain; however, their groundwater abstraction is considered to be negligible. There are no other known significant point withdrawals within the study area.

Groundwater also leaves the system through groundwater evapotranspiration (GET) which primarily occurs in alluvial drainage channels. A total annual GET rate of 305 AF/yr was estimated for the study area (M&A, 2017a). The conceptual model water balance had an error of -65 AF/yr that can be balanced by reducing GET from 305 AF/yr to 240 AF/yr. GET is represented in the Model using MODFLOW's ETS package. The GET was evenly distributed across alluvium shown in **Figure 3** based on grid cell size. Groundwater evaporation is assumed to only occur outside the footprint of the TSF.

Surface water flow in Queen Creek at Whitlow Ranch Dam comprises the most significant outflow in the system. Bedrock (Apache Leap Tuff) forces groundwater to the surface in this location and is conceptualized as the exit point for all groundwater and surface water in the Superior Basin. Groundwater reporting to the surface upstream from the dam exits the basin through a culvert in the dam as surface water. Baseflow rates for Queen Creek at Whitlow Ranch Dam were estimated using a Delta Filter analysis. An assessment of 16 years of daily baseflow in Queen Creek at Whitlow Ranch Dam suggests a median baseflow rate (groundwater outflow) of approximately 794 AF/yr (M&A, 2017a).

Water Balance

A complete water balance of the Superior Basin can be found in the Conceptual Hydrogeologic Model for Proposed Near West Tailings Storage Facility report (M&A, 2017a). The areal recharge over the footprint of the TSF made up 63 AF/yr of the total natural recharge. When removed, the areal recharge outside the TSF is equal to

613 AF/year. The models for Alternatives 2 and 3 have natural recharge outside the TSF of 613 AF/yr, recharge along the southern boundary of Queen Creek of 319 AF/yr, and subflow entering Queen Creek of 42 AF/yr.

TSF recharge for the scavenger beach tailings have recharge rates that vary based on the model alternative. For Alternative 2 the scavenger beach tailings recharge rate is 1,912 AF/yr and cleaner tailings recharge rate of 220 AF/yr and for Alternative 3 the recharge rates are 508 AF/yr for the scavenger beach tailings and 220 AF/yr for the cleaner tailings.

In the Model representing Alternative 2 GET totaled 216 AF/yr, a reduction of 24 AF/yr from the balanced conceptual model of 240 AF/yr (M&A, 2017a) and for Alternative 3 GET equals 215 AF/yr, a reduction of 25 AF/yr. In both Models ADWR well 55-627523 goes dry, a loss of 5 AF/yr in withdrawals. This results in a natural flow at Whitlow Ranch Dam of 760 AF/yr and 759 AF/yr when accounting for 63 AF/yr of reduced inflow and the 29 AF/yr and 30 AF/yr of reduced withdrawals, for Alternative 2 and 3 respectively.

Drains in and surrounding the TSF capture 1,938 AF/yr or 91% of the TSF recharge in Alternative 2 and 612 AF/yr or 84% of the TSF recharge in Alternative 3. Seepage out of the TSF that is not captured by the drains for Alternative 2 is 194 AF/yr and 116 AF/yr for Alternative 3. The baseflow at Whitlow Ranch Dam increases to 955 AF/yr for Alternative 2 and to 875 AF/yr for Alternative 3. The complete water balance for Alternative 2 and Alternative 3 can be found in **Table 3**.

Solute Transport Parameters

The MODFLOW-USG transport package was used as a tool to determine the portion of water that originates from the TSF (seepage) and enters Potts Canyon, Roblas Canyon, and Queen Creek. The seepage that enters the three alluvial domains is provided as the seepage inflow for GoldSim (GoldSim, 2017) simulations used to estimate total seepage.

The Model used solute transport to determine how much TSF seepage water enters each of the three alluvial channels surrounding the TSF (Potts Canyon, Roblas Canyon, and Queen Creek) by adding water to the TSF with a unit (1) concentration. The ETS package was used to remove flow but not solute mass. Transport is simulated using the steady-state flow field until concentrations were constant through transport model time.

Porosity values were estimated from specific yield results from pumping tests and NMR logs (M&A, 2017a), or were taken from the literature. Porosities assigned to HGUs are listed in **Table 4**.

Longitudinal dispersivity of 30 feet was used based on Ayra (1986) having a field scale on the order of 2,300 feet (the shortest distance between the toe of the TSF and Queen Creek). This is consistent with the value provided by the Xu and Eckstein (1995) equation and is also in the lower half of the range of dispersivities in Gelhar and others, (1992). The transverse dispersivity was 3 feet; one order-of-magnitude smaller than the longitudinal dispersivity.

Results

Flow Rates

The results from this Model are used to provide estimates of TSF seepage rates for the GoldSim (GoldSim, 2017) contaminant transport modeling being done for Alternatives 2 and 3. The major pathways for seepage to leave the TSF and travel downstream to Whitlow Ranch Dam via Queen Creek are through Roblas Canyon, Potts Canyon, and a portion of Queen Creek adjacent to the TSF. Potts and Roblas Canyons are southeast and northwest of the TSF, respectively, and flow into Queen Creek.

The spatial extents of the aquifer subdomains used to determine flow and concentration are shown on **Figure 5**. The amount of seepage from the TSF that enters Potts Canyon, Roblas Canyon, and Queen Creek immediately adjacent to the TSF for Alternatives 2 and 3 is presented in **Table 5**. Total seepage represents the total contribution of flow to Queen Creek sourced from the TSF and is equal to total TSF recharge less the seepage captured by finger drains, embankment drains, and seepage collection dams.

Travel Times

The GoldSim (GoldSim, 2017) contaminant transport models being developed for Alternatives 2 and 3 only model flow through the alluvium. However, seepage must travel from the TSF foundation through the bedrock units before entering the alluvium. Because of the irregular geometry and the fact that the driving hydraulic gradient is based on hydraulic head differences between the TSF and the surrounding rock, this calculation requires outputs from this model.

Transit time for seepage to enter the drainages was calculated based on the modeled groundwater gradient and hydraulic properties of the subsurface between the crest of the embankment on the TSF and respective drainage. Because this steady-state calculation represents full TSF build-out conditions, this calculation is considered conservative and may underestimate travel times during transient TSF build-out. The drainages are represented by the domains on **Figures 5 and 6**, for Alternatives 2 and 3 respectively.

The equation used to calculate transit time, t, is as follows:

$$t = \frac{D}{v}$$

Where D is the distance from the crest of the water table in the TSF to the drainage and v the flow velocity which is calculated as:

$$v = \frac{K}{n}\frac{dh}{dl}$$

Where K is the hydraulic conductivity, n the porosity, dh difference in head between the embankment of the TSF and drainage, dl the distance between the locations of head values used (here, equal to D) (Freeze & Cherry, 1979).

Contours of groundwater elevations for Alternative 2 used to calculate transit time are shown on **Figure 5** and the contours for Alternative 3 are shown on **Figure 6**.
The hydraulic conductivity and porosity values used for each drainage were estimated to be the spatially weighted average of the geologic units in the uppermost 100 feet of the area between the TSF and the drainage. The average gradient along each drainage was used to calculate the transit time for seepage leaving the TSF and entering the drainage. The specific values used for all quantities including the calculated transit times are listed in **Tables 6 and 7** for Alternatives 2 and 3, respectively.

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RESOLUTION
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December 21, 2018

Ms. Mary Rasmussen
US Forest Service
Supervisor's Office
2324 East McDowell Road
Phoenix, AZ 85006-2496

Subject: Response to Actions from November 13, 2018 Geochemistry Meeting

Dear Ms. Rasmussen,

In response to the action items from the Geochemistry meeting held on November 13, 2018 please find attached the following for your review and consideration:

- USFS Request: Sensitivity for seepage / back of envelope calculation
    - *RC Response: See Attachment 1 – Seepage Analysis by KCB*

- USFS Request: Calculate for each site the capacity of allowable seepage and assess the ability to meet that seepage rate at each site.
    - *RC Response: See Attachment 2 – M&A, December 2018 Technical Memorandum "Estimated Preliminary Allowable Seepage from TSF Alternative Sites for Comparative Analysis."*
        - *Additional modeling is underway to assess additional design features and seepage controls needed to meet those rates*

- USFS Request: RCM to complete the SWCA draft graphics on full build out and post closure for each alternative
    - *RC Response: See Attachment 3 – RC comments on SWCA graphics are in yellow highlighted red text*
    - *Attachment 4 – Response Table addressing Mark Williamson review comments and updated reports for Alternatives 2 and 3:*
        - *M&A, December 2018 "Alternatives 2 and 3 Steady-State Modeling"*
        - *M&A, December 2018 "TSF Alternatives 2 and 3 – Near West: Life of Mine and Post-Closure Seepage Transport Modeling"*

- USFS Request: Annotate Kate's graphic with information on all alternatives
    - *RC Response: See Attachment 3*

- <u>USFS Request</u>: RCM to provide additional analog examples of PAG within NPAG sub-aqueously in desert environment if current memo is not enough after review
    - *RC Response: See Attachment 5 – Case Studies for Resolution TSF Technologies*

Sincerely,

Vicky Peacey

Vicky Peacey,

Senior Manager, Environment, Permitting and Approvals; Resolution Copper Company, as Manager of Resolution Copper Mining, LLC

Cc: Ms. Mary Morissette; Senior Environmental Specialist; Resolution Copper Company

Enclosure(s):

Attachment 1 – Seepage Analysis by KCB
Attachment 2 – M&A, December 2018 Technical Memorandum "*Estimated Preliminary Allowable Seepage from TSF Alternative Sites for Comparative Analysis*."
Attachment 3 – RC comments on SWCA graphics (yellow highlighted red text)
Attachment 4 – M&A, December 2018 "*Alternatives 2 and 3 Steady-State Modeling*" and M&A, December 2018 "*TSF Alternatives 2 and 3 – Near West: Life of Mine and Post-Closure Seepage Transport Modeling.*"
Attachment 5 - Case Studies for Resolution TSF Technologies