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Project Memorandum

To:	**SWCA**		
Attention:	**Chris Garrett, Donna Morey**		
From:	**Gabriele Walser**	**Date:**	**October 26, 2020**
Subject:	**Skunk Camp Model Review**		
Project No.:	**1704007-06**		

On behalf of the Secretary of Agriculture, the Tonto National Forest is preparing an Environmental Impact Statement (EIS) for the mining operations proposed by Resolution Copper Mining, LLC. (Resolution Copper). The Resolution Copper Project (EIS) Water Working Group, with support from BGC Engineering USA Inc. (BGC), was tasked with summarizing and evaluating Montgomery & Associates' (M&A 2020a) 3-D groundwater flow and transport model of the proposed Skunk Camp Tailings Storage Facility (TSF) and KCB Consultants Ltd. (KCB 2020) 1-D seepage model.

1.0 INTRODUCTION

The proposed Skunk Camp TSF was described in the Draft EIS (DEIS) under Alternative 6 and identified as the Lead Agency's preferred alternative for the TSF site (Tonto National Forest, 2019). In response to public and agency comments on the DEIS, the Tonto National Forest requested additional analysis of the proposed Skunk Camp TSF. M&A developed a numerical 3-D groundwater flow and transport model of the proposed Skunk Camp TSF (M&A 2020a). The modeling effort by M&A expands on a previous GoldSIM model, described in the DEIS. KCB performed a 1-D assessment of vertical seepage through different TSF components for input into the groundwater model (KCB 2020).

The scope of this memo includes a critical evaluation of the setup, calibration, application and predictions of the M&A (2020a) Skunk Camp TSF groundwater flow and transport model, including the related inputs from the KCB (2020) seepage model.

2.0 SEEPAGE MODELING

KCB (2020) performed four separate modeling tasks to estimate seepage from the TSF. The one-dimensional model evaluations included the following conditions:

- Scavenger Beach Seepage Model
- Pyrite Cell Leakage Model
- Cycloned Sand Embankment Leakage Estimate
- Scavenger and Pyrite Tailings Closure Cover Model.

Seepage for scavenger beach tailings was estimated to be 43 inches per year during early operations, decreasing to 19 inches per year at the end of operations and remaining about 1 inch per year throughout post-closure. Seepage for near dam scavenger beach tailings was estimated to be higher initially (i.e., 77 inches per year during early operations), but decreasing similarly to the scavenger beach tailings over time. Seepage through the cycloned sand embankment was estimated to vary between 0 and 43 inches per year during tailings operations but decreasing to 0.6 inches per year (3% of precipitation) long term post-closure.

The seepage modeling does not include a description of the fate of the initial bleed water, and it is unclear if this bleed water is considered in the operational plans.

The one-dimensional modeling approach is judged to be appropriate for the physical systems considered and the estimated seepage volumes for input into the groundwater model appear to be reasonable. However, to appropriately account for variability and uncertainty in the physical systems a range of parameters and boundary conditions should have been considered in a sensitivity analysis. Such an approach would have yielded a range of seepage values for input into the groundwater model.

Seepage through the water-covered pyrite tailings was estimated directly in the groundwater model (see Section 3.3.1).

3.0 GROUNDWATER FLOW AND TRANSPORT MODEL

3.1. Conceptual Model

3.1.1. Data Collection Effort

After the Forest Service identified the Skunk Camp TSF as part of the preferred alternative, Resolution Copper began additional data collection efforts. A substantial amount of data was collected and presented in multiple reports: KCB 2019, M&A 2020b, 2020c, and 2020d. M&A (2020b) developed a conceptual model and described the conceptual model in detail.

3.1.2. Groundwater Elevation

M&A (2020b) developed a groundwater elevation map for the proposed Skunk Camp TSF location and surrounding area. M&A (2020b) hypothesized a groundwater divide within the model domain, between the proposed TSF location and ASARCO’s Ray Mine, approximately 3 miles east of the Ray Mine pit model boundary.

This hydrogeological interpretation is supported by the existence of a surface water divide and by the groundwater elevation in well DH19-14. However, continued and/or changed operation of the Ray Mine may cause the groundwater divide to shift until possibly, for example, groundwater underlying the proposed TSF may drain towards the Ray Mine. The potential for such future scenarios should be considered during design and development of the TSF and associated monitoring plans.

3.1.3. Water Balance

M&A (2020b) developed a conceptual water balance, considering recharge from precipitation, and groundwater outflows through evapotranspiration and groundwater discharge to surface water. Any water discharged to the Ray Mine is included as discharge to surface water.

A steady-state water balance was assumed; this assumption should be tested over time and variability in inputs, outputs and changes in water storage considered.

3.1.4. Overall Appropriateness

The conceptual model is based on a substantial data collection effort in the field and is reasonable for the current understanding of the system. However, without information on future plans of the Ray Mine, it cannot be concluded that general flow directions and water balances in the study area will remain unchanged. The conceptual model should be re-evaluated regularly as designs for this mine and others in the area are advanced and implemented, and during operation of the proposed TSF.

3.2. Numerical Model

3.2.1. Code Selection

3.2.1.1. Groundwater Flow Model

M&A (2020a) selected Modflow-USG (Panday et al. 2013) to model the study area. Modflow-USG was developed by the USGS and is in the public domain. This choice of code allowed detailed simulation of the proposed TSF using a nested grid with smaller grid size embedded within the larger model domain.

3.2.1.2. Transport Model

USG-Transport (Panday 2019) was used for transport modeling. A transport module was first added to USG in 2017 and has not yet been widely used.

3.2.2. Model Domain, Grid and Layers

The model domain includes the Dripping Spring watershed where the proposed TSF is located, plus partial watershed areas to the north- and southwest, with boundaries set along Mineral Creek and the Gila River. The boundaries are located sufficiently distant from the proposed TSF, to minimize lateral boundary effects on flow near the proposed TSF. That is, head distributions and flow in the vicinity of the proposed TSF will be dominated by hydraulic conductivity distributions, natural recharge and applied seepage rates from the TSF, plus any applied pumping.

A nested grid approach is used, with grid cell sizes of 500 by 500 feet distant from the proposed TSF and 100 by 100 feet surrounding the proposed TSF. Thirteen layers were used, with thin layers at the top to allow for simulating finger drains.

The model domain and discretization were judged to be appropriate for the current stage of evaluation.

3.2.3. Domain Boundary Conditions

Boundary conditions for the model domain include specified head boundaries along the Gila River and Mineral Creek. The Gila River is a perennial stream with flow controlled by discharge from Coolidge Dam below the San Carlos Lake, although flows may drop below 1 cfs. Along the study area, the Gila River is characterized by an alluvial channel. Mineral Creek is a perennial stream upstream of the Ray Mine, located in Apache Leap Tuff.

Due to the perennial nature of these two streams, they are likely in contact with groundwater and the constant head boundaries are reasonable representations of the boundary conditions for steady-state, average conditions. The rates and locations of recharge and discharge along the constant head boundaries should have been shown in the report and compared to any losing and gaining reaches observed in the field.

The bottom of the Ray Mine pit is represented as a constant-head boundary. The historical route of Mineral Creek, which bisects Ray Mine, is simulated as a general-head boundary to represent the sink caused by the Ray Mine pit dewatering.

The remaining domain boundaries coincide with topographic divides (i.e., surface water divides) and are modeled as no-flow boundaries. Although there is little well information or evidence to confirm that the topographic divides also function as groundwater divides, the simulated general flow direction towards the Gila River to the south and towards the perennial stretch of Mineral Creek in the north seem reasonable and suggest the no-flow boundaries are appropriate.

3.2.4. Natural Recharge and Evapotranspiration

Total recharge was estimated in the conceptual model from precipitation values based on PRISM (Parameter-elevation Regressions on Independent Slopes Model) distribution (Prism Climate Group, 2020) and applied in the numerical model (M&A 2020b). Precipitation in the model area ranges from 11 to 30 inches per year, with estimated recharge percentages varying from 1.1% to 2.8% from lower elevation to the higher elevation (M&A 2020b). When applying this recharge in the numerical model, M&A applied half the estimated recharge values over the wider area and increased the recharge along Dripping Spring drainage. This approach resulted in the same total recharge volume as a uniform distribution. During calibration, the total recharge value was increased by 26%. This resulted in recharge rates from 0.08 to 0.53 inches per year (0.7 to 1.7% of precipitation) over the wider model area, and a rate of 5.14 inches per year for Dripping Spring Wash. No additional recharge was applied in the alluvium along the Gila River.

For comparison, the recharge rate used by WSP (2019) for the mine groundwater model ranged from 0.02 to 0.57 inches per year (0.1 to 2.5% of precipitation) over most of the model area, with increased recharge from 0.67 to 1.92 inches per year for some drainages.

Evapotranspiration was modeled based on vegetation estimates. Average modeled evapotranspiration rate was approximately 29 inches per year in locations where both groundwater dependent vegetation was identified, and the modeled water table was close to the surface. Groundwater dependent vegetation was predominantly found in drainages, including the Dripping Spring Wash, and the simulated evapotranspiration likely offsets the increased recharge in drainages to some degree.

While the overall recharge volume seems reasonable, gross recharge rates were adjusted during calibration, and the recharge distribution was adjusted to increase recharge in Drippings Springs alluvial corridor, without a similar adjustment in the alluvium along the Gila River. Thus, the distribution and rate of recharge seems somewhat arbitrary. This important input to the numerical model should have been examined with a sensitivity and uncertainty analysis for the predictive simulations.

3.2.5. Groundwater - Surface Water Interaction

Interactions between groundwater and surface water were inadequately considered in the numerical model, but the absence of simulated groundwater - surface water interactions is sufficient for a screening model.

Boundary conditions simulated the ground- surface water interaction for the Gila River and Mineral Creek through specified head boundary conditions. Such an approach assumes no impacts on surface water elevations for changed conditions, although rates of exchange between surface water and groundwater may change magnitude and/or direction. The appropriateness of this representation should be carefully evaluated for simulating future scenarios.

Springs or ephemeral drainages were not considered, although they could possibly have been used as soft targets to aid with calibration. That is, calibration targets could have included the prediction of discharge, or at least the presence of the water table close to ground surface, in areas of known discharge (see Section 3.2.8 Calibration).

3.2.6. Existing Wells

Although groundwater pumping occurs in the Dripping Spring Watershed for irrigation, stock or domestic uses, pumping volumes were considered to be small, and no agricultural or domestic wells were modeled.

3.2.7. Hydraulic Parameters

Hydraulic conductivities were estimated based on the field program described in M&A (2020c and 2020d) and adjusted during calibration.

Hydraulic conductivity of the Dripping Spring fault was set at approximately one order of magnitude lower that conductivity of the alluvium along Dripping Spring Wash, but higher than conductivity of the Gila Formation underlying the proposed TSF location. The ratio of horizontal to vertical hydraulic conductivity for the Dripping Spring alluvium and the Gila Formation was set to be between 1 and 100. The ratio of horizontal to vertical hydraulic conductivity for the Dripping Spring Fault was allowed to vary from 0.01 to 100 because the orientation of the fault implies vertical hydraulic conductivity could be larger than horizontal. No information is provided about which areas of the fault were assigned a vertical hydraulic conductivity that is larger than the horizontal hydraulic conductivity, however, this would provide useful information to understand where the fault functions as a conduit. This information should have been provided.

3.2.8. Calibration

The calibration was partially assessed by visual comparison of a simulated water level contour map compared to the conceptual groundwater contours.

Some additional “soft” targets for calibration (i.e. targets where a qualitative but not a quantitative comparison of observed to modeled conditions is conducted) should also have been investigated in the report:

- The model should predict a sufficiently shallow water table in areas where groundwater dependent vegetation occurs.
- The model should predict a sufficiently shallow water table in areas where springs or perennial reaches occur inside the model.
- The rates and locations of recharge and discharge along the constant head boundaries should be compared to any losing and gaining reaches observed in the field.

A quantitative calibration was conducted for water levels observed in 26 existing wells. Steady state calibration resulted in head residuals from 0 to 110 feet. Of 26 calibration targets, the majority have residuals of less than 40 feet, only four targets have residuals greater than 40 feet. The largest residuals occur upstream of the proposed TSF to the north and west, near the groundwater divide. This is indicative of the difficulty of modeling the groundwater divide between northern Mineral Creek and Dripping Spring Wash. Modeled groundwater flow is more towards the west than to the northwest as is the case in the conceptual model groundwater contours. However, this does not seem to change flow towards the proposed TSF, and therefore may be of minor importance in the calibration.

Heads underneath and downstream of the proposed TSF more closely match the observed heads. The scaled Root Mean Squared Error is 3.2 % and indicates a reasonable calibration.

The model is lacking any flux calibration. It seems that no quantitative flux targets exist, however, evaluation of flows from constant or general head boundaries should have been done.

Recharge was adjusted during calibration. The numerical model’s simulated water inflow from recharge is 26% higher than initially estimated in the conceptual model (M&A 2020b), but within a reasonable range for the estimates. No transient calibration was performed.

Five pumping tests with durations from 1 day to 2 weeks were performed and should have been used for a transient calibration in the vicinity of the TSF. However, no substantial, long-term transient hydrologic data sets are available for the wider study area.

3.3. Predictive Model Setup

An additional 7 layers were added above the 13 layers in the steady state model, to allow simulating the proposed TSF which would extend a total of 600 feet above land surface. Hydraulic properties for the additional TSF layers were based on lab tests of tailings materials. The tailings materials were provided by Resolution Copper from samples taken from exploration holes for metallurgical test processing. The predictive numerical model simulated the operations stage for a duration of 41 years, and the post-closure stage for a duration of 400 years. The operations stage was represented by 36 stress periods and post-closure was represented by 8 stress periods. The number and length of the stress periods were determined using information from the TSF design by KCBCL (2020) and appear adequate to simulate operations and drain down of the TSF.

3.3.1. Tailings Seepage

Seepage through the various TSF components and for different time periods was based on leakage calculation by KCB (2020) and implemented with the well package in Modflow-USG. The well package allows for the injection of water into the model domain. An exception was the pyrite cells, where constant head boundary conditions were used to model the water cover of the tailings. Seepage from the pyrite cells including pyrite cell embankment that leaves the TSF (i.e., was not captured by the seepage control measures) was modeled to be a total of 17,000 acre-feet (of 165,000 acre-feet total seepage) over the model duration.

KCB (2020) developed steady-state models to evaluate vertical flux through the pyrite cells. KCB (2020) estimated a vertical flux of approximately 18,000 acre-feet for the same time period for the pyrite cells and embankment. This vertical flux is not equivalent to seepage, since some part of the vertical flux will be captured by seepage control measures before leaving the TSF. The agreement between KCB (2020) modeled vertical flux and modeled seepage is good.

Because true tailings materials do not yet exist, the hydraulic properties of the tailings, including how they may change over time, should have been the subject of sensitivity analyses, for both the KCB (2020) and M&A (2020a) evaluations.

3.3.2. Transport Parameters

Longitudinal dispersivity was set to a value such that the Peclet number would be less than 2. With a horizontal model grid cell dimension of 100 feet, this results in a longitudinal dispersivity of 75 feet. The transverse dispersivity was 7.5 feet; one order of magnitude smaller than the longitudinal dispersivity.

It is difficult to estimate dispersivity, and these values seem reasonable; however, a sensitivity and uncertainty analysis would be necessary to evaluate a range of possible outcomes for different assumed values.

3.3.3. Model Implementation of Seepage Control Measures

The grout curtain was simulated in the model using USG-Transport Horizontal Flow Barrier (HFB) package to represent a 3-foot thick; 100-foot deep grout curtain with a hydraulic conductivity of $1x10^{-6}$ cm/sec downstream of the proposed TSF and cutting across the width of the Dripping Spring alluvium.

Seven collection wells are modeled as located downstream of the proposed TSF. Four of the collection wells are located in the main alluvial channel of Dripping Spring Wash between the toe of the proposed TSF and the grout curtain. The other three wells are in a drainage that drains from the TSF to the east of Dripping Spring Wash.

The low-permeability layers placed on the bottom and sides of the pyrite cells are modeled with HFB package (for the sides of the pyrite cells), and with the Quasi-3D Confining Bed (Q3D) package, which are used to restrict flow in the vertical direction. The Q3D confining beds cover the entire extent of the pyrite cells and terminate in the cells containing HFBs representing the vertical low-permeability layers, to create a fully lined enclosure. The low-permeability layer of the pyrite cells in the model has an equivalent hydraulic conductivity of 1×10^{-10} cm/s and thickness of 3 feet for both the HFB package and Q3D package.

Lined collection channels are represented in the model using the drain (DRN) package.

The finger drains under the main embankment are represented by high-conductivity cells 10 feet thick and 100 feet wide. The hydraulic conductivity in the finger drain cells was set at 250 ft/day. Each set of finger-drain cells ends in a cell that uses the Modflow DRN package to remove water from the model.

The model implementations of the seepage control measures are reasonable for a preliminary analysis of seepage and transport of constituents of concern from the proposed TSF.

3.4. Predictive Model Results

3.4.1. Groundwater Flow

Model results indicate that the water table downstream of the proposed TSF would drop after buildout of the proposed TSF. This drop in water table elevation is especially pronounced in the Dripping Spring Wash alluvium, where the predicted water table drops up to 50 feet after building the TSF. This is due in part to the shallow depth of the alluvium and the grout curtain and pumpback wells cutting off the alluvium from upstream recharge and flow. According to modeling results, the upper Dripping Spring Wash alluvium is above the water table after buildout of the proposed TSF.

The model report lacks a figure that shows potential changes in water table at the locations of springs downstream of the proposed TSF. Thus, it cannot be estimated whether springs downstream of the proposed TSF could be impacted by a lower water table. Such a map should have been produced, and the results discussed.

3.4.2. Transport

Modeling with Modflow-USG Transport module predicted that seepage from the proposed TSF travels with groundwater to the Gila River. Maximum simulated concentrations at the Point of Compliance occur approximately 100 years after the end of operations. This indicates that the modeled time period is sufficient.

A preferential flow path is along the Dripping Spring fault which bisects the TSF location and runs to the Gila River. Assuming a range of hydraulic conductivities for the fault would be necessary to evaluate a possible range of flow and transport outcomes along the fault. Such an analysis should have been performed.

Dripping Spring Wash alluvium is not shown as a major flow path, since it is predicted to become dewatered. A sensitivity analysis without pumpback wells and/or without a grout curtain would be necessary to show whether water flowing through the alluvium could be a conduit for preferential transport.

Model results indicate capture of 24% of seepage, which seems reasonable to meet the stated water quality objectives.

3.5. Model Sensitivity and Uncertainty

No sensitivity or uncertainty modeling was performed. Outputs from a model should generally encompass a range of possibilities, or at least an evaluation of sensitivities (Anderson et al., 2015). A sensitivity analysis should encompass hydraulic conductivity and specific storage/storativity values, and boundary conditions, including recharge and seepage modelling estimates, plus transport descriptors such as porosities, dispersivities and input concentrations over time and space.

3.6. Application of Model Seepage Controls in Reality

3.6.1. Pumpback Wells

The model simulates pumpback wells located in the Dripping Spring Fault below the proposed TSF. While the fault location is easy to discern in the model, it is more difficult in reality; actual siting of the wells so water is pumped from the fault can be difficult to achieve. An analysis without pumpback wells but with other seepage controls in place would be useful to understand the importance of the pumpback wells, and to understand possible consequences if the well screens do not intersect the most conductive portions of the fault or the pumpback wells fail.

3.6.2. Grout Curtain

A 100-ft deep grout curtain is modeled as a barrier to flow through the Dripping Spring Alluvium. Modeling a perfect grout curtain with a low hydraulic conductivity of $1\text{x}10^{-6}$ cm/sec is an easy exercise but does not consider that an imperfectly built grout curtain may have regions of higher conductivities. This concern might be mitigated by an appropriate grout design with a robust quality assurance – quality control program. An analysis without a grout curtain, but with other seepage controls in place, is necessary to understand the importance of the grout curtain.

4.0 COMPARISON TO ALTERNATIVES AND MODELING IN THE DEIS

Water quality for all potential locations for TSF sites was modeled. A GoldSim mass balance model was improved upon through a numerical model utilizing Modflow-USG for Alternative 6 - Skunk Camp, after this alternative was selected as the preferred alternative. A similar Modflow model was previously created for Alternatives 2 and 3. Comparing of the model results indicates that ground- and surface water standards can be met for Alternative 6 with a capture rate of approximately 24% of seepage. All other alternatives require a higher percentage of seepage capture to meet water ground- and surface water standards.

Downstream concentrations modeled with the Modflow-USG model are significantly lower than previously estimated with the mass balance model, despite a lower seepage collection efficiency. Results presented in the DEIS based on the mass balance model assumed a 90% seepage collection efficiency which resulted in selenium concentrations around 0.01 mg/L in the groundwater above the Gila River after 141 years. Current results from the Modflow-USG model estimate a 24% seepage collection efficiency and show selenium values below 0.001 mg/L above the Gila River after 143 years.

5.0 CONCLUSIONS

M&A (2020a) prepared a conceptual and numerical model for the Skunk Camp Tailings Alternative. A large data collection effort preceded the preparation of the model; however, many gaps in knowledge of the existing system and the proposed development remain. Consequently, the model must be considered a screening level model only. A lack of transient and transport calibration, a lack of sensitivity and uncertainty analysis, along with modeling of a not-yet existing facility with seepage controls not yet built and tested, gives predictions that can indicate trends in water quality and water quantity impacts, but does not allow for exact quantitative predictions of water quality.

The model results show much lower concentrations of constituents of concern compared to the prior mass balance model. However, the model results should only be considered an estimate. A range of possible concentrations, ranging from the results of this modeling effort to results from the previous mass balance model might give a reasonable approximation of concentrations of the constituents of concern.

While the model results should not be considered quantitative predictions, they could allow a comparison between the different TSF and mitigation alternatives. A rigorous monitoring program should be used to evaluate the degree of agreement between actual versus predicted outcomes. The model should be updated regularly based on modifications to the mine designs and surrounding conditions, plus new findings from the ongoing monitoring program.

6.0 DIFFERING OPINIONS AMONG THE WATER WORKGROUP

L. Everett & Associates (LE&A) (2020) presented a dissenting opinion on the Skunk Camp modeling being incorporated into the Final EIS, without allowing an opportunity for public comment.

The EPA (2020) suggested inclusion of the Ray Mine as a separate item into the water balance.

7.0 CLOSURE

BGC Engineering Inc. (BGC) completed this evaluation for SWCA Environmental Consultants (SWCA) and the Tonto National Forest as part of our scope of services under Subcontractor Master Services Agreement, dated September 13, 2016, and Work Authorization 10, dated April 7, 2020. The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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Yours sincerely,

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