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Project Memorandum

To:	**SWCA Environmental Consultants**
Attention:	**Chris Garrett**
From:	**Mark Zellman, P.G., C.PG., GISP., and Diana Cook, Ph.D., PE** **Date: July 1, 2020**
Subject:	**Resolution Copper Project EIS – Evaluation of Skunk Camp Site - Specific Seismic Hazard Analyses**
Project No.:	**1704005**

1.0 INTRODUCTION

1.1. Project and Environmental Impact Statement Summary

Resolution Copper Mining LLC (RCM) is proposing to develop the Resolution Copper Project (the Project), an underground copper mine, near the town of Superior, Arizona.

The U.S. Department of Agriculture Tonto National Forest (TNF) completed a Draft Environmental Impact Statement (EIS) for the Project (USFS 2019). TNF is the lead Federal agency for the EIS, and SWCA Environmental Consultants (SWCA) is the TNF's third-party EIS contractor. BGC Engineering USA, Inc. (BGC) is providing geological and geotechnical expertise to SWCA and the TNF.

As part of this Project, RCM and its consultants have completed a site-specific seismic hazard analysis for the proposed Skunk Camp tailing storage facility (TSF). Results from this study were presented in:

> Lettis Consultants International (LCI). (2020, May 19). *Site-Specific Seismic Hazard Analysis and Development of Time Histories for Resolution Copper's Proposed Skunk Camp Tailings Storage Facility, Southern Arizona*, Rev. 2 [Report]. Prepared for Resolution Copper.

1.2. Scope and Objectives

BGC has performed a desktop review of the LCI (May 19, 2020) report to provide opinions on whether:

- The work presented in the report meets applicable industry standard of practice and regulatory guidelines.
- The analysis and conclusions are defensible and appropriate for the Project.
- Supplemental analyses are warranted.

This assessment only confirms adherence so far as is indicated by the records included within LCI (May 19, 2020) and does not include a comprehensive check of all calculations.

This memorandum provides:

1. A summary of relevant state regulations and guidelines for assessing seismic hazard and estimating design ground motions.
2. A summary of the work presented by LCI (May 19, 2020).
3. A summary of BGC's assessment and any review comments pertaining to the objectives listed above.

This memorandum does not review or provide comments to the fault reconnaissance portion of this study. The fault reconnaissance review was described in BGC (June 30, 2020).

1.3. Summary of Applicable Regulatory Guidance

Guidelines pertaining to seismic hazards are addressed in Appendix E of the Arizona Mining Guidance Manual (ADEQ, 2004). With respect to tailings storage facilities the guidance:

- States the TSF design should be based on a design earthquake that ranges between the maximum probable earthquake (MPE) and the maximum credible earthquake (MCE).
- Defines MPE as the largest earthquake possible within a 100 year recurrence interval.
- Defines MCE as the maximum earthquake that appears capable of occurring under the presently known tectonic framework.
- States that the design earthquake evaluation should consider:
  1. All known active faults within 200 km of the site.
  2. Active faults are those which have ruptured in the past 35,000 years.
- States that typical design parameters resulting from a seismic hazard analysis include:
  1. Earthquake magnitude and source to site distances.
  2. Peak horizontal acceleration and design ground motion acceleration time histories for use in deformation analysis.

The ADEQ manual (2004) does not define a standard of practice for performing a deterministic or probabilistic seismic hazard analysis, but the U.S. Bureau of Reclamation and U.S. Army Corp of Engineers Best Practices in Dam and Levee Safety Risk Analysis document (USBR and USACE, 2015) does provide a basis to evaluate the current standard of practice for such studies.

1.4. Background

The LCI (May 19, 2020) site-specific seismic hazard analysis of the proposed Skunk Camp TSF followed three similar studies directed toward other Project facilities: the proposed Near West, Far West, and Pinto Valley TSFs; and Shafts 9 and 10 at the RCM mine site. Results from those studies were presented in the following project reports:

- URS. (2013, June 3). *Site-Specific Seismic Hazard Analysis for the Resolution Mining Company Tailings Storage Facilities Options, Southern Arizona* [Report]. Prepared for Resolution Copper.

- Lettis Consultants International (LCI). (2017, November 27). *Updated Site-Specific Seismic Hazard and Development of Time Histories for Resolution Copper's Near West Site, Southern Arizona* [Report]. Prepared for Resolution Copper.
- Lettis Consultants International (LCI). (2018, January 23). *Site Specific Seismic Hazard Evaluation for the Proposed Resolution Copper Mine, Southern Arizona* [Report]. Prepared for Resolution Copper.

BGC reviewed these reports and provided summaries and review comments in the following documents:

- BGC (2017, January 25). *Summary of Geotechnical Reports for the Resolution Copper Mine* [Memorandum]. Prepared for SWCA Environmental Consultants.
- BGC (2018, October 9). *Resolution Copper Project EIS – Evaluation of Seismic Hazard Analysis* [Draft Memorandum]. Prepared for SWCA Environmental Consultants.

2.0 SUMMARY OF SKUNK CAMP TSF SITE-SPECIFIC SEISMIC HAZARD ANLAYSIS

The scope of the LCI (May 19, 2020) site-specific seismic hazard analysis of the proposed Skunk Camp TSF site included:

1. Seismic source characterization and fault reconnaissance.
2. An evaluation of seismicity.
3. Site characterization.
4. Probabilistic seismic hazard analysis (PSHA).
5. Deterministic seismic hazard analysis (DSHA).
6. Determination of design earthquake ground motion.
7. Development of nine single-component horizontal time histories.

The seismic source characterization considered crustal fault source and areal source zones as potential earthquake sources. The crustal fault sources considered by LCI included all known faults showing evidence for late Quaternary (≤130,000 years before present) or repeated Quaternary (≤ 1.6 Million years before present) activity within 200 km of the site. LCI also included longer, more active sources outside the 200 km radius, such as the Pitaycachi fault in Mexico (source of the 1887 Sonora earthquake) and faults in southern California/Baja California. LCI compiled fault sources from the U.S. Geological Survey (USGS) Quaternary Fault and Fold Database[1] and a PSHA they performed for Arizona Public Service (APS) Palo Verde Nuclear Power Plant (APS 2015a and APS 2015b).

Areal source zones in LCI's source model comprise:

[1] The USGS Quaternary fault and fold database can be accessed from: https://earthquake.usgs.gov/hazards/qfaults/

- A regional source zone for the Southern Basin and Range (SBR) within which earthquakes are assumed to occur at random locations (0.4 weighting).
- A gridded seismicity model (0.6 weighting).

LCI compiled a catalog of historical seismicity extending beyond the 200 km site radius covering the years 1830 to September 2019. The LCI catalog compiled earthquakes from Wong et al. (2008), the Northern Arizona University regional seismic catalog, and the Advanced National Seismic Service (ANSS). LCI's catalog lists the largest earthquake as the May 3, 1887 moment magnitude (M) 7.4 Sonora, Mexico earthquake, which occurred approximately 330 km southwest of the Skunk Camp TSF site. The largest earthquake within 50 km of the site was an M 5.0 event on June 17, 1922, and the closest earthquakes were two M 3.5 events in 1963 (September 11 and October 21), approximately 18 km east-northeast of the site. LCI reported an M 7 event in 1830 and depicts it on a figure, but excluded it from their catalog because the record is considered unreliable by both LCI and DuBois et al. (1982).

The geology of the Skunk Camp site consists of Quaternary alluvium overlying Tertiary conglomerate (Gila Conglomerate). P-wave seismic refraction surveys were performed at the site, measuring P-wave velocities of 8,800 to 9,200 ft/sec (2,682 to 2,804 m/sec) that were interpreted to represent the Gila Conglomerate. This range of values is equivalent to an approximate shear wave velocity (V_s) of 1,300 to 1500 m/s, which LCI interprets as an upper-end value. For this study, LCI applies estimated shear wave velocity averaged to a depth of 30 m (V_{s30}) of 700 to 1,000 m/sec, similar to V_{s30} of 700 to 1,050 m/sec used for their study of the Near West TSF site (LCI, January 25, 2017), which also overlies Gila Conglomerate.

LCI employed five equally-weighted ground motion models (GMMs) in the PSHA and DSHA for faults within the 200 km radius and background seismicity. These comprised:

- Four of the five NGA-West2 models: Abrahamson et al. (2014), Chiou and Youngs (2014), Campbell and Bozorgnia (2014) and Boore et al. (2014). The fifth NGA-West2 model by Idriss (2014) was excluded because it lacks a hanging wall model and is not applicable for $V_s30 < 450$ m/s.
- Akkar et al. (2014), a European model with 47% of its records derived from normal faulting events.

Only the four equally weighted NGA-West2 GMMs were applied to the crustal fault sources beyond 200 km radius.

LCI provided estimated probabilistic values for peak horizontal ground acceleration (PGA) and tabulated unified hazard spectra (UHS) for periods between 0.1 and 10.0 sec at mean return periods of 475, 2,500, 5,000, and 10,000 years. The ground motion results are based on a V_s30 of 700 m/sec. Results based on V_{s30} of 1000 m/sec are not presented, but LCI stated that the accelerations are similar but slightly lower. Similar to the previous studies (LCI, November 27, 2017 and LCI, January 23, 2018), the results from this PSHA indicated that seismic hazard at the Skunk Camp TSF site is low to moderate, even at long return periods. Background seismicity dominates the PGA hazard because nearby Quaternary faults are absent. At a spectral period of

1.0 sec, background seismicity dominate, but contributions from the distant Cerro Prieto and Southern San Andreas fault sources appear.

LCI (May 19, 2020) compares their PSHA results against the 2014 USGS National Seismic Hazard Map (NSHM) (Petersen et al., 2014). In general, their estimated ground motions are lower than those reported by Petersen et al. (2014), similar to LCI (November 27, 2017) and LCI (January 23, 2018). They state the discrepancy is caused by differences in the treatment of the maximum magnitude included in the PSHA and crustal fault type distribution for background seismicity zones and, to a lesser extent, minimum floor values and differences in GMM's.

The deterministic analysis evaluated a hypothetical M 6.9 earthquake on the 23 km-long Whitlock Wash fault zone, the nearest Quaternary fault to the site at a distance of 52 km. LCI estimated this magnitude using published empirical relationships from Wells and Coppersmith (1994). At spectral periods less than 0.2 sec, the estimated 84th percentile spectrum has an equivalent return period similar to the 2,500-year UHS. At spectral periods greater than about 0.49 sec the equivalent return period is similar to the 5,000-year UHS. The median deterministic response spectrum has an equivalent return period between 475 and 2,500 years.

The report also provided nine horizontal-component time histories for the UHS at a return period of 10,000 years.

3.0 BGC REVIEW OF THE SKUNK CAMP TSF SITE-SPECIFIC SEISMIC HAZARD ANALYSIS

BGC has reviewed and assessed LCI's (May 19, 2020) site-specific seismic hazard analysis for the proposed Skunk Camp TSF site. In general, this study applies state-of-the-practice probabilistic procedures, meets regulatory guidelines, utilizes appropriate data, and provides appropriate and defensible results. BGC does not recommend supplemental analysis for this study.

The LCI study does not address caving-induced fault slip and/or possible seismicity induced by RCM mining; however, these scenarios are addressed under a separate study (LCI, April 13, 2020) that was not reviewed by BGC under this scope.

BGC's comments addressing standards and guidelines, data validity, data gaps, and seismic hazard conclusions are provided in the sections below.

3.1. Review Comments

1. The SBR and gridded seismicity models weightings differ from previous studies (LCI, January 23, 2018; LCI, November 27, 2017; and URS, June 3, 2013) which weighted the models equally. LCI states the reason the gridded model was weighted more heavily is because the catalog of historical seismicity spans a relatively short timeframe and is likely not representative of long-term activity. BGC considers this rationale to be reasonable.

2. LCI compares their results to the 2014 NSHM (Petersen et al., 2014). BGC notes that the 2018 NSHM (Petersen et al. 2019) was published at the time LCI would have been finalizing their report, and the seismic source model and detailed results from Petersen et al. (2019) would not have been available for LCI to incorporate into their study. The 2018 NSHM has still not been implemented in the USGS Unified Hazard Tool (UHT) (https://earthquake.usgs.gov/hazards/interactive/), so BGC is unable to make a direct comparison between LCI (May 19, 2020) and 2018 NSHM (Petersen et al. 2019) as part of this review.
3. LCI provides a table of fault parameters (LCI, May 19, 2020; Table 2), but the footnotes associated with reference numbers in the Table headers are not included in the report. Therefore, BGC is unable to assess or provided detailed comments on sources used by LCI to assign the fault parameters.
4. As documented, the earthquake catalog was compiled from reliable sources, although it is unclear if the catalog was declustered, if duplicates were removed, or if the catalog includes or excludes non-tectonic events such as blasts.

3.2. Regulatory Guidance and Standards of Practice

The PSHA and DSHA results provided by LCI adhere to the applicable guidance document (ADEQ 2004) and were performed using state-of-practice methods (USBR and USACE 2015) (see Section 1.3). The data compiled and utilized for this study are from current up-to-date references. They included active fault inventories, historical seismicity, GMMs, and site-specific estimates of V_{s30}. Probabilistic ground motions for 475, 2,500, 5,000, and 10,000-year return periods estimated from areal source zones and all known crustal fault sources within 200 km (including larger sources beyond 200 km) address the requirement for the MPE. The DSHA analysis of a M 6.9 rupture of the Whitlock Wash fault zone addresses the MCE. Historical earthquake magnitudes and distances to the site are shown in figures and nine horizontal-component time histories for the UHS at a return period of 10,000 years are provided.

3.3. Defensible and Appropriate Analysis Conclusions

The results reported in the LCI (May 19, 2020) study were derived from analyses which meet ADEQ (2004) regulatory guidance, apply current data sources and references, conform to the current standard of practice for PSHA and DSHA analysis, and are appropriate to estimate the levels of ground motion at the proposed Skunk Camp TSF site.

LCI reports that their firm rock PGA and 1.0 sec SA site specific PSHA values for a 2,475 year return period are 0.06 and 0.025 (respectively) lower than the 2014 NSHM (Petersen et al. 2014). In Petersen et al. (2019), Figure 11 compares the total mean hazard from the 2018 and 2014 NSHM. Although the figure is small-scale, it does show that the 2018 NSHM values are 0.01 to 0.05 lower than the 2014 NSHM in the Skunk Camp TSF vicinity. This suggests the 2018 NSHM hazard values could be approaching the LCI (May 19, 2020) PSHA results.

Based on the information currently available, BGC does not recommend further supplemental analysis for this study.

4.0 AUTHOR AND REVIEWER CREDENTIALS

Mark Zellman is a Senior Geologist at BGC and is certified as a professional geologist (PG). He has approximately 20 years of experience performing geologic, geotechnical, and geohazard investigations, including seismic hazard projects. Mr. Zellman has performed seismic source characterization and supported site-specific probabilistic seismic hazard assessments for multiple international sites, including locations within the Basin and Range and Colorado Plateau regions.

Diana Cook is a Senior Geological Engineer with approximately 16 years of experience in geotechnical and geological engineering, including design of earthen and rockfill dams, heap leach pads, tailings impoundments, pit stability analyses, and facility foundation designs for mining projects. Ms. Cook has worked on site-specific seismic hazard analyses for several mines in the United States, including Arizona, and around the world, and has also performed liquefaction studies for sites in the United States, South America, and Canada.

Martin Zaleski is a Senior Engineering Geologist at BGC. He holds registration as a professional geoscientist (P.Geo.) in British Columbia, Alberta, and Saskatchewan; and as a professional geologist (PG) and certified engineering geologist (CEG) in California. He has 20 years of experience in geohazards and seismic hazards in the mining, pipeline, transportation, and residential development sectors. He has led and reviewed seismic hazard assessments for discrete sites and distributed linear infrastructure networks, including studies of shaking, liquefaction, earthquake-triggered landslide, and surface fault rupture potential.

5.0 CLOSURE

BGC Engineering USA Inc. (BGC) prepared this document for the account of SWCA Environmental Consultants. 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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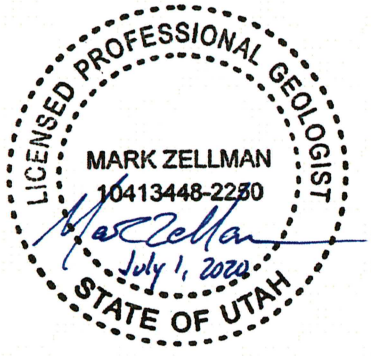
Yours sincerely,

BGC ENGINEERING USA INC.
per:



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Victoria Boyne

From: ResolutionProjectRecord
Subject: FW: Resolution Copper - Skunk Camp PSHA & Surface Faults Memos
Attachments: Resolution_BGC_SkunkCampsPSHAreview_20200701.pdf; Resolution_BGCMemo_SkunkCampSurfaceFaulting_Rev1_20200630.pdf

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From: Derek Hrubes <DHrubes@bgcengineering.ca>
Sent: Friday, July 10, 2020 1:13 PM
To: Chris Garrett <cgarrett@swca.com>; Donna Morey <dmorey@swca.com>
Cc: Nick Enos <nenos@bgcengineering.ca>; Michael Henderson <mhenderson@bgcengineering.ca>; Mark Zellman <MZellman@bgcengineering.ca>; Diana Cook <DCook@bgcengineering.ca>
Subject: Resolution Copper - Skunk Camp PSHA & Surface Faults Memos

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Hi Chris and Donna,

Attached are the finalized BGC review memos for the following:

- Skunk Camp – Specific Seismic Hazard Analyses
- Skunk Camp – Assessment of Surface Faulting Investigations

Please let us know if there is any follow-up required on these items.

Thank you,

BGC ENGINEERING INC.
per:

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