BGC ENGINEERING USA INC.
AN APPLIED EARTH SCIENCES COMPANY

710 Tenth Street - Suite 170, Golden, CO USA 80401
Telephone (720) 598-5982

Project Memorandum

To:	**SWCA Environmental Consultants**		
Attention:	**Chris Garrett**		
From:	**Mark Zellman, P.G., C.PG., GISP., and Diana Cook, Ph.D., P.E.**	**Date:**	**August 18, 2020**
Subject:	**Resolution Copper Project EIS – Evaluation of Seismic Hazard Analyses (Rev 1)**		
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 mine site, the location of Shafts 9 and 10, and the tailings storage facility (TSF) currently proposed for the Near West site near Superior, Arizona. Results of these studies are presented in three separate reports:

1. 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.
2. 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.
3. 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.

1.2. Scope and Objectives

BGC has performed a desktop review of the LCI (November 27, 2017) and LCI (January 23, 2018) reports to provide opinions on whether:

- The work presented in the reports 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 the LCI (November 27, 2017) and LCI (January 23, 2018) reports and does not include a comprehensive check of 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 in LCI (November 27, 2017) and LCI (January 23, 2018).
3) A summary of BGC's assessment and any review comments pertaining to the objectives listed above.

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 TSFs and other various types of mine facilities, the guidance:

1. 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).
    - The minimum design earthquake is the MPE.
    - The MCE should be used where human life is potentially threatened.
2. Defines MPE as the largest earthquake within a 100-year return interval.
3. Defines MCE as the maximum earthquake that appears capable of occurring under the presently known tectonic framework.
4. States that the design earthquake evaluation should consider:
    - All known active faults within 200 km of the site.
    - Active faults are those which have ruptured in the past 35,000 years.
5. States that typical design parameters resulting from a seismic hazard analysis include:
    - Earthquake magnitude and source to site distances, and
    - 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

Three probabilistic seismic hazard analysis (PSHA) studies have been completed for the Resolution Copper Project to estimate levels of earthquake ground motion that could be exceeded for various return periods (or annual frequencies). The URS (June 3, 2013) report documents the initial study which evaluated four alternative TSF sites: the Far West 1 Tailings Management Area (TMA), the Far West 2 TMA, the Near West TMA, and the Pinto Valley TMA. The LCI (LCI November 27, 2017) report provides results from their updated SHA and re-estimated ground motions for the Near West site. The LCI (January 23, 2018) report provides estimated ground motions for two additional sites: the center of the proposed mine, and a location between Shafts 9 and 10.

BGC previously reviewed the URS (June 3, 2013) report and provided assessment comments to SWCA in a memorandum (BGC, January 25, 2017). The second LCI report (November 27, 2017) provided an update to URS (June 3, 2013) based on the BGC assessment comments.

2.0 SUMMARY OF THE RCM SEISMIC HAZARD ASSESSMENTS

The LCI (November 27, 2017) and LCI (January 23, 2018) reports are each summarized below. An assessment of the reliability of the data sources, the methodologies used in these studies, and whether they adhere to industry standards is provided. This assessment only confirms adherence so far as is indicated by the records included within these reports and does not include a comprehensive check of all calculations

2.1. Summary of LCI (November 27, 2017) Updated Seismic Hazard Report for the Near West Site.

The scope of the LCI (November 27, 2017) study 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 seven horizontal-component time histories for the uniform hazard spectrum (UHS) at a return period of 1:10,000.

The LCI (November 27, 2017) study applied a seismic source model based on their previous regional studies, including seismic hazard evaluations for the Arizona Public Services (APS) Palos Verdes nuclear power plant (NPP) (APS, 2015a and APS, 2015b). The source model addressed background seismicity through a gridded seismicity model and the use of a regional seismic source zone for the southern Basin and Range (SBR). Crustal fault sources included all known Quaternary active faults within 200 kilometers (km) of the site (the previous URS (June 3, 2013) study used a radius of 100 km) and incorporated longer, more active, fault sources in southern California/Baja California. The fault sources were based on the U.S. Geological Survey's Quaternary Fault and Fold Database (https://earthquake.usgs.gov/hazards/qfaults/), and LCI's previous PSHA performed for the APS Palos Verde NPP. In addition, Hartleb and Wong (2017) performed a reconnaissance-level fault study to evaluate the possibility of surface-faulting at the Near West site and concluded that Quaternary-active faults are highly unlikely at the site. BGC did not review the Hartleb and Wong (2017) report.

The LCI earthquake catalog consisted of historical seismicity extending beyond the 200 km site radius and covering the years 1830 to April 2017. The catalog was compiled mostly from earthquakes from Thomas et al. (2015) and the Advanced National Seismic Service (ANSS) earthquake catalog.

LCI employed four equally weighted ground motion models (GMMs) in the PSHA and DSHA for faults within the 200 km radius and background seismicity. The GMMs included the following four (of five) NGA-West2 models (Abrahamson et al. (2014), Chiou and Youngs (2014), Campbell and Bozorgnia (2014) and Boore et al. (2014)).

Site-specific ground motion amplification potential was inferred from multiple multi-channel analysis of surface waves (MASW) seismic surveys. The survey data showed variability in the underlying site geology and shear wave velocity averaged to 30 meters depth (V_s30). To address this variability, two geological ground conditions were used to predict design ground motions: 1) Pinal Schist and Gila Conglomerate (V_s30 = 700 to 1050 m/sec), and 2) rhyolite/diabase (V_s30 = 1200 m/sec).

Probabilistic values were estimated for peak ground accelerations (PGA) and spectral acceleration (SA) periods between 0.1 and 10.0 sec at return periods of 1,000, 2,500, 4,750, and 10,000 years. LCI (November 27, 2017) concluded that the seismic hazard at the site is low and dominated by background seismicity. At a spectral period of 1.0 sec, contributions from the Cerro Prieto fault and Southern San Andreas distant fault source are also apparent.

The estimated ground motions from this study (LCI, November 27, 2017) for the Pinal Schist and Gila Conglomerate are similar to the URS (June 3, 2013) study, though slightly higher at the 10,000-year return period. In contrast, the LCI (November 27, 2017) values for the rhyolite/diabase ground conditions are lower than those reported in the URS (June 3, 2013) study. The change in values is attributed to the use of new site-specific V_s30 data (the URS (June 3, 2013) study used an average V_s30 of approximately 500 m/s) and the updated NGA-West2 GMMs. The resulting low seismic hazard for this site is consistent with the regional tectonic setting and observed low rate, scattered historical seismicity.

The deterministic analysis evaluated a hypothetical moment magnitude (M) 6.6 earthquake on the Sugarloaf fault, the nearest Quaternary fault to the site at a distance of 48.5 km; the magnitude was estimated using typical empirical correlations between fault length and magnitude (i.e., Wells and Coppersmith, 1994). The estimated 84th percentile PGA was 0.079 g for Pinal Schist/Gila Conglomerate conditions and 0.062 g for rhyolite/diabase site conditions. The 84th percentile spectra were estimated to correspond to an equivalent return period of between 2,500 and 4,750 years for both site conditions.

In addition to the PSHA and DSHA results, uniform hazard spectra (UHS) and conditional mean spectra (CMS) were calculated for a return period of 10,000 years, and seven horizontal-component time histories were developed.

2.2. Summary of LCI (January 23, 2018) Seismic Hazard Report for the Mine Site

The LCI (January 23, 2018) study provides a PSHA and DSHA for two sites at RCM. One site overlies the center of the mine, and the other is at the East Plant Site between Shafts 9 and 10.

1. Seismic source characterization
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

This study evaluates seismic hazard using a seismic source model that was previously developed for LCI (November 27, 2017). Background seismicity is included in the model through a gridded seismicity model and a regional areal seismic source zone for the southern Basin and Range (SBR). The crustal fault source model includes all known Quaternary active faults within 200 kilometers (km) of the site and longer fault sources in southern California/Baja California with high slip rates. The crustal fault source model was informed by the LCI (November 27, 2017) study, the U.S. Geological Survey's Quaternary Fault and Fold Database (https://earthquake.usgs.gov/hazards/qfaults/), and the LCI's previous PSHA performed for the APS Palos Verde NPP.

LCI compiled a catalog of historical earthquakes that extend beyond the 200 km site radius and cover a date range of 1830 to April 2017. All compiled earthquakes are shown in a figure (See LCI November 27, 2017; Figure 1). Significant events that were likely felt at the site are summarized in the report text.

Both sites overlie Apache Leap Tuff bedrock, however, no site-specific shear wave velocity measurements were available at the time of the LCI study. Laboratory measurements by Fuenkajorn and Daemen (1991) indicate the upper bound V_s of the Apache Leap Tuff unit is 2,320 m/s, and site-specific V_s measurements from the Topapah Springs Tuff, a similar unit (Fuenkajorn and Daemen, 1991) are well in excess of 1,200 m/s. Thus, for both sites, a V_s30 of 1,200 m/s was used as input for the NGA-West2 GMMs.

PSHA results for the two sites are presented in terms of annual exceedance frequency. Mean, median 5th, 15th, 85th, and 95th percentile hazard curves are presented for the peak ground accelerations (PGA) and a 1.0 sec horizontal spectral acceleration (SA). LCI (January 23, 2018) concluded that the seismic hazard at the site ranges from low to moderate when considering long return periods. Deaggregation plots for 1,000- and 2,500-year return periods show that seismic hazard is dominated by background seismicity. At a spectral period of 1.0 sec, contributions from the Cerro Prieto fault and Southern San Andreas distant fault source are apparent.

The deterministic analysis evaluated a hypothetical M 6.6 earthquake on the Sugarloaf fault, the nearest Quaternary fault to the site at a distance of 56.3 km. This magnitude was estimated using typical empirical correlations between fault length and magnitude (i.e., Wells and Coppersmith, 1994). The estimated 84^{th} percentile PGA was estimated as 0.05 g, and the 84th percentile spectra was estimated to correspond to an equivalent return period of between 1,000 and 2,500 years.

This report provides UHS for the four return periods and shows the difference between UHS for the two sites to be less than 1%. This study does not provide time histories or CMS.

3.0 BGC REVIEW OF THE RCM SEISMIC HAZARD REPORTS

BGC has reviewed and assessed the LCI (November 27, 2017) and LCI (January 23, 2018) seismic hazard studies for RCM. Comments addressing standards and guidelines, data validity and data gaps, and the seismic hazard conclusions are provided below. In general, these studies apply state-of-the-practice probabilistic procedures and defensible results. BGC does not recommend supplemental analyses for these studies.

3.1. BGC Review of the LCI (November 27, 2017) Seismic Hazard Analysis

3.1.1. Review Comments

1. The LCI (November 27, 2017) report is in general conformance with BGC's review comments provided in BGC (BGC, January 25, 2017) for the URS (June 3, 2013) report.
2. BGC's review is limited to the LCI (November 27, 2017) report document and does not include review of the associated Hartleb and Wong (2017) reconnaissance-level fault study.

3.1.2. Regulatory Guidance and Standards of Practice

The PSHA and DSHA results provided by LCI adhere to the applicable guidance pertaining to TSF and other associated mine facilities (See Section 1.3) described by ADEQ (2004). The study was performed using state-of-practice methods similar to those outlined by USBR and USACE (2015) (see Section 1.3).

3.1.3. Defensible and Appropriate Analysis Conclusions

The results reported in the LCI (November 27, 2017) study were derived from analyses which meet ADEQ (2004) regulatory guidance, evaluated 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 Near West TSF site.

The data compiled and utilized for this study are from current up-to-date references. They included active fault inventories, historical seismicity, appropriate GMMs, and 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 6.6 rupture of the Sugarloaf fault addresses the MCE. Historical earthquake magnitudes and distances to the site are shown in figures and seven horizontal-component time histories for the UHS at a return period of 10,000 years are provided.

The LCI (November 27, 2017) report compares their estimated PGA and 1.0 sec SA for a 2,475-year return period against the 2014 USGS NSHM (Petersen et al., 2014). The comparison shows that LCI (November 27, 2017) values are slightly lower than those published by Petersen et al. (2014). The differences are attributed to the smaller SBR background source zone used by LCI (November 27, 2017), minimum rates used for background events, and the maximum magnitude (Mmax) used. The USGS NSHM (Petersen et al., 2014) sets the Mmax at M 7.45, and LCI (November 27, 2017) uses a weighted distribution of magnitudes ranging from M 6.2 to M 6.8 based on their previous work in the region.

When compared against the URS (June 3, 2013) study, LCI (November 27, 2017) reports larger ground motions for the Pinal Schist and Gila Conglomerate site conditions and lower values for rhyolite and diabase site conditions. These changes are attributed to updated GMMs, an updated seismic source model, and updated site conditions.

LCI performed their analysis using state-of-the-practice methods and current information, and their results adhere to regulatory guidance. BGC finds these results to be defensible and appropriate for the RCM study. Based on the information currently available, BGC does not recommend further supplemental analyses for this study.

3.2. BGC Review of the LCI (January 23, 2018) Seismic Hazard Analysis

3.2.1. Review Comments

1. LCI (January 23, 2018) does not include a detailed fault parameter table or details about the earthquake catalog; however, LCI states that these inputs were derived from their previous study (LCI November 27, 2017).

3.2.2. Regulatory Guidance and Standards of Practice

The PSHA and DSHA results provided by LCI adhere to the applicable guidance pertaining to TSF and other associated mine facilities (See Section 1.3) described by ADEQ (2004). The study was performed using state-of-practice methods similar to those outlined by USBR and USACE (2015) (see Section 1.3).

3.2.3. Defensible and Appropriate Analysis Conclusions

The results reported in the LCI (January 23, 2018) 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 center of the mine, and the East Plant Site between Shafts 9 and 10.

The data compiled and utilized for this study are from current up-to-date references. They included active fault inventories, historical seismicity, GMMs, and estimates of V_s30. Probabilistic ground motions for PGA and 1.0 sec SA 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 6.6 rupture of the Sugarloaf fault addresses the MCE. Historical earthquake magnitudes and distances to the site are shown in figures within the study. UHS for four return periods of 1,000, 2,500, 4,750, and 10,000 years are provided.

The results from this analysis indicate that seismic hazard for these sites is low to moderate, including long return periods of 10,000 years. These results are consistent with the previous RCM study (LCI November 27, 2017) and reasonable considering sparse historic moderate seismicity and an absence of nearby crustal fault sources.

LCI performed their analysis using state-of-the-practice methods and current information, and their results adhere to regulatory guidance. BGC finds these results to be defensible and appropriate for the RCM study. Based on the information currently available, BGC does not recommend further supplemental analyses for this study

4.0 REVIEWER/AUTHOR 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 17 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.

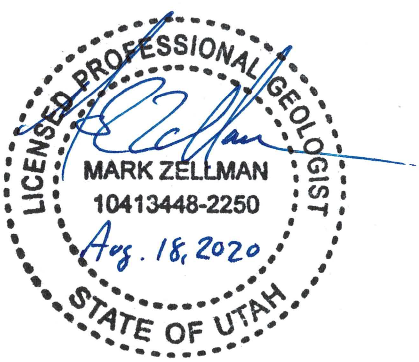
5.0 CLOSURE

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.

As a mutual protection to our client, the public, and ourselves all documents and drawings are submitted for the confidential information of our client for a specific project. Authorization for any use and/or publication of this document or any data, statements, conclusions or abstracts from or regarding our documents and drawings, through any form of print or electronic media, including without limitation, posting or reproduction of same on any website, is reserved pending BGC's written approval. A record copy of this document is on file at BGC. That copy takes precedence over any other copy or reproduction of this document.

Yours sincerely,

BGC ENGINEERING USA INC.
per:



Mark Zellman, P.G. (UT, WY), C.PG., GISP.
Senior Geologist

Diana I. Cook, Ph.D., P.E..
Senior Geological Engineer

Reviewed by:

Martin Zaleski, M.Sc., P.G., C.E.G. (CA)
Senior Engineering Geologist

MZ/MZ/rm/am

REFERENCES

Arizona Department of Environmental Quality (ADEQ). (1998). Arizona Mining Guidance Manual BADCT, Publication #TB 04-11.

Arizona Public Service (APS). (2015a). Seismic Source Characterization for the Palo Verde Nuclear Generating Station, SSHAC Level 3.

Arizona Public Service (APS). (2015b). Seismic Hazard and Screening Report for the Palo Verde Nuclear Generating Station Units 1,2, and 3. Revision 0, March 2015.

BGC Engineering, Inc. (BGC). (2017, January 25). Summary of Geotechnical Reports for the Resolution Copper Mine, Project Memorandum prepared for SWCA Environmental Consultants.

DuBois, S.M., Smith, A.W., Nye, N.K., and Nowak, T.A. (1982). Arizona earthquakes, 1776-1980: Arizona Bureau of Geology and Mineral Technology Bulletin, v. 192, 456 p.

Fuenkajorn, K. and Daemen, J.J.K. (1991) Mechanical characterization of densely welded apache leap tuff: report prepared for U.S. Nuclear Regulatory Commission, NUREG-CR 5688.

Hartleb, R., and Wong, I. (2017). Reconnaissance-level fault investigation of Resolution Copper Mining's Near West site, Pinal County, Arizona, unpublished report prepared by Lettis Consultants International.

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, Final 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, Final Report, Prepared for Resolution Copper.

Petersen, M.D., Frankel, A.D., Harmsen, S.C., Mueller, C.S., Haller, K.M., Wheeler, R.L., Wesson, R.L., Zeng, Y., Boyd, O.S., Perkins, D.M., Luco, N., Field, E.H., Wills, C.J., and Rukstales, K.S. (2008). Documentation for the 2008 update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2008-1128, 61 p.

URS. (2013, June 3). Site-Specific Seismic Hazard Analysis for The Resolution Mining Company Tailings Storage Facilities Options, Southern Arizona, Final Report, No. 000035, Prepared for Resolution Copper Mining.

U.S. Bureau of Reclamation and U.S. Army Corp of Engineers (USBR and USACE). (2015). *Best Practices and Risk Methodology*, Chapter II-3 Seismic Hazard Analysis. Version 4.0.