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Testimony before House Natural Resources Subcommittee on
Indigenous Peoples of the United States
Hearing on "The Irreparable Environmental and Cultural Impacts
of the Proposed Resolution Copper Mining Operation"
Thursday, March 12, 2020

CONCLUSIONS

1) Predicted water consumption of the Resolution Copper Mine is 50,000 acre-feet per year.
2) Although Rio Tinto has promised water consumption of only 15,700 acre-feet per year (about one-third of industry standards), they are using only conventional technologies for achieving water efficiency.
3) Export of water of tailings alone would result in a consumption of 25,600 acre-feet per year.
4) Under the best-case scenario, the completed underground mine will encounter geothermal water at a flow rate of 3800 gpm.
5) Under the best-case scenario, the additional power requirements for mine dewatering and refrigeration will be 24 MW.
6) The worst-case scenario is difficult to estimate, but if more highly fractured rock is encountered during construction of the underground mine, the entry rate of geothermal water could easily be 100 times greater.
7) The predicted electricity consumption of the Resolution Copper Mine is 260 MW and 1900 MW under the best-case and worst-case scenarios, which are 3% and 22%, respectively, of the peak power capacity of the Salt River Project.
8) The predictions of land subsidence due to block caving cannot be verified because Rio Tinto has provided neither the input data nor the details of the modeling.
9) The only exception to the lack of data is the map of geological faults, which is inconsistent with the satellite imagery that shows a pronounced lineament nearly parallel to and offset by 2000 feet from the mapped West Boundary Fault. This lineament would most likely be the zone of structural weakness that would transmit deformation from the caved rock zone to the culturally sensitive escarpment of Apache Leap.
10) The subsidence monitoring program proposed by Rio Tinto explicitly assumes that subsidence will be slow, predictable and controlled, which is inconsistent with the past history of block caving and authoritative manuals on block caving.
11) No error bounds have been provided on the predictions of the lateral extent of the subsidence zone.
12) Based on the range in predictions of the maximum depth of the subsidence crater, the probability that the subsidence zone would reach Apache Leap can be estimated as 8.9%.
13) Using a statistical model based on previous tailings dam failures, the predicted runouts from failures of the five alternative tailings storage facilities would be in the range 200-370 miles.

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14) Although the flow potential of filtered tailings is less than that of thickened tailings, even if the failures of the dam for the filtered tailings (Silver King site) caused only slumping of the tailings, they would travel at least 10,400 feet, and would impact the town of Superior (population 2837) at a minimum distance of 2500 feet.
15) The unincorporated area of Queen Valley (population 820) would be impacted by the failures of the Near West facilities (minimum distance 19,000 feet) or of the Silver King facility (minimum distance 8.2 miles). The town of Florence (population 26,074) would be impacted by the failures of the Peg Leg facility (minimum distance 10.3 miles), either of the Near West facilities (minimum distance 16.0 miles), or Silver King facility (minimum distance 20.5 miles). The unincorporated area of Dripping Springs (population 235) would be impacted by the failure of the Skunk Camp facility (minimum distance 17,000 feet).
16) Dripping Springs, Queen Valley and Superior are all well within the "self-rescue zone" (where no rescue from the outside is possible) in recent Brazilian legislation.
17) The proximity of the tailings dams to downstream communities would be illegal in Brazil, China and Ecuador.

ABSTRACT

Rio Tinto has predicted water consumption for the proposed Resolution Copper Mine, Arizona, as 15,700 acre-feet per year, although, based on the grade and production rate, water consumption of 50,000 acre-feet per year would be more typical. The proposed technologies would result in the export of cleaner tailings with 50% water, scavenger tailings with 35% water, and copper concentrates with 9% water, resulting in water consumption of 25,600 acre-feet of water per year by the tailings storage alone. Based on the depth, grade, and production rate, the projected electricity consumption would be 236 MW. However, the discovery of geothermal water while drilling the primary access shaft could result in additional electricity consumption of 24 MW solely for mine dewatering and refrigeration under the best-case scenario and 1650 MW under the worst-case scenario, corresponding to total electricity consumption of 260 MW and 1900 MW, or 3-22% of the peak power capacity of the Salt River Project. The DEIS has predicted that the maximum depth of the crater produced by block caving will be 1115 feet, but that the subsidence zone will reach only 1115 feet from the culturally sensitive escarpment of Apache Leap, without providing the input data, the details of the modeling, or the error bounds in the prediction of the subsidence zone. The only exception is a geological fault map, for which satellite imagery shows the West Boundary Fault, which connects the footprint of the ore body with Apache Leap, being mapped in the wrong location by 2000 feet. Unanticipated subsidence occurs in 20% of block caving projects and the manual relied upon by Rio Tinto emphasizes the known risks of rapid subsidence. Based upon the uncertainty in the prediction of maximum crater depth, the probability that the subsidence zone will reach Apache Leap is 9%. Using a statistical model based on previous tailings dam failures, the runouts from the failures of the five alternative sites for the tailings storage facilities would be in the range 200-370 miles. The Silver King, Near West, Peg Leg and Skunk Camp sites would be 2500 feet, 19,000 feet, 10.3 miles, and 17,000 feet upstream from Superior (population 2837), Queen Valley (population 820), Florence (population 26,074) and Dripping Springs (population 235), respectively. The proximity of the alternative sites for the tailings dams to downstream communities would be illegal in Brazil, China and Ecuador.

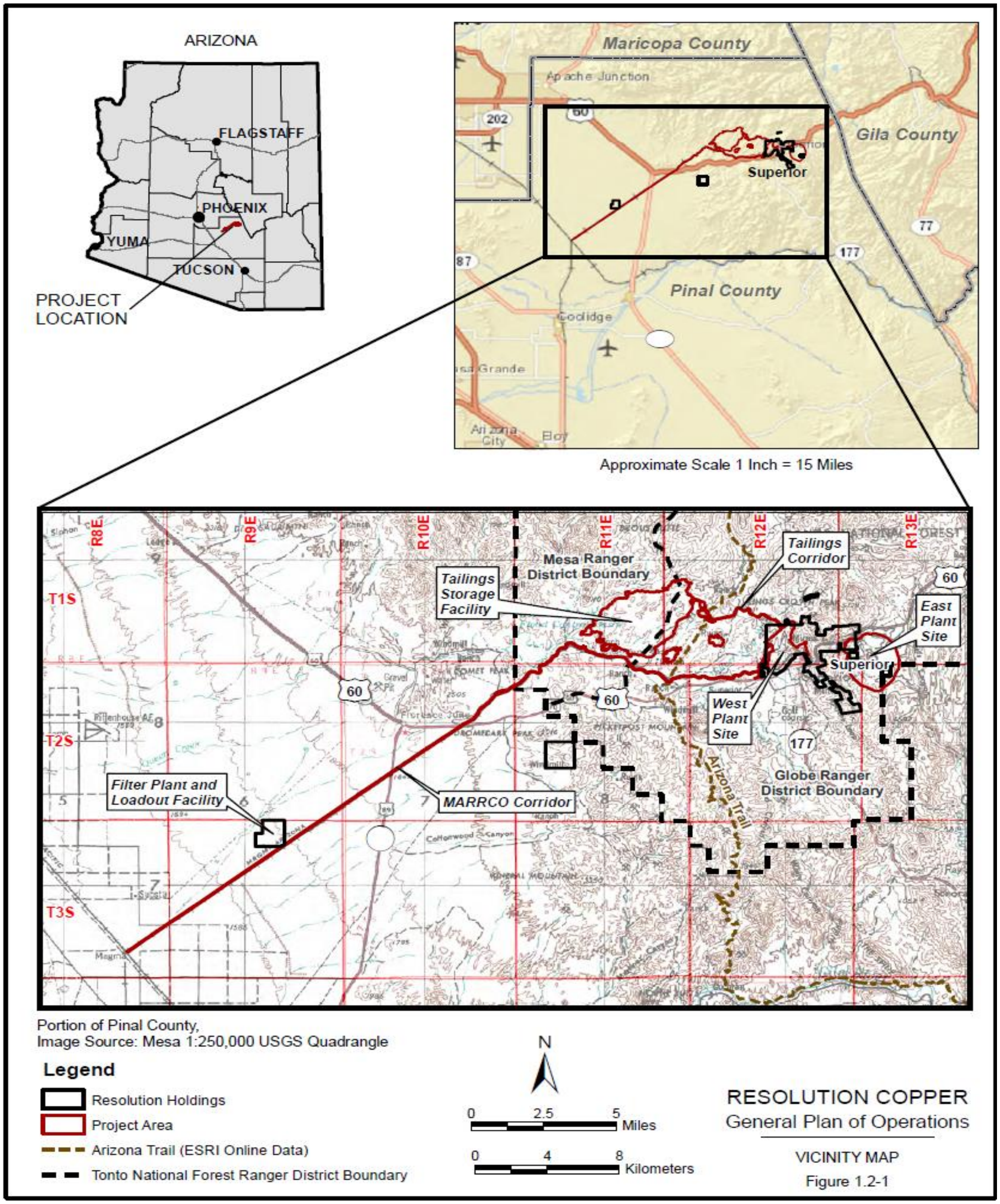

Figure 1. Rio Tinto has submitted a proposal for an underground copper mine, called the Resolution Copper Mine, within a mix of federal public land (Tonto National Forest), Arizona state trust land, and private land, which would process 120,000 metric tons of ore per day with a maximum processing rate of 150,000 metric tons per day from an ore body that lies 5000-7000 feet below the surface. Figure from Resolution Copper Mining (2014b).

INTRODUCTION

Rio Tinto has submitted a proposal to the U.S. Forest Service for an underground copper mine, called the Resolution Copper Mine, within a mix of federal public land (Tonto National Forest), Arizona state trust land, and private land (see Fig. 1). The proposal includes an exchange of 5344 acres of land privately held by Rio Tinto for 2422 acres of the Tonto National Forest. The porphyry copper deposit occurs 5000-7000 feet beneath the surface and has an inferred resource of 1790 million tons with a copper grade of 1.47%. The ore processing rate is predicted to be 120,000 metric tons per day with a maximum processing rate of 150,000 metric tons per day (Resolution Copper Mining, 2014a-c). According to Rio Tinto, the water consumption will be 15,700 acre-feet per year at full operation (Resolution Copper Mining, 2014a-c).

The Draft Environmental Impact Statement (DEIS) (USDA, 2019) estimates an electricity consumption of 250-280 MW. The estimate includes 6.45 MW and 6 MW for mine dewatering and refrigeration, respectively, but without further explanation, and without explicitly taking into account the discovery of geothermal water in December 2012. During the drilling of the 6943-foot-deep, 28-foot-diameter No. 10 shaft, geothermal water at a temperature of 170°F began entering the shaft at a rate of 460 gpm (E&MJ, 2014). According to Tom Goodell, general manager – shaft development for Resolution Copper, "Productivity flattened out at 6500 feet…The consultants told us that we would have little or no water below 4000 feet…They kind of missed that call. We hit it all in one spot and it was quite dramatic" (E&MJ, 2014). The Arizona Daily Star confirmed, "Shaft-sinking equipment had reached a depth of about 6,500 feet when water from an underground aquifer began rushing in. The miners were prepared to handle 80 gallons per minute, which is what core samples from 30 feet away predicted" (Bregel, 2016). Later reports indicated that the entry rate of geothermal water into the No. 10 shaft had increased by over a factor of three to 1400 gpm and that the temperature of the geothermal water was 180°F (Bregel, 2016; Phillips, 2016).

Mining would be carried out using block caving, a type of underground mining that involves controlled cave-ins of overlying rock, and which includes land subsidence as a typical consequence (see Fig. 2). Subsidence modeling was based upon surface mapping, core samples, and high-resolution photography from the No. 10 Shaft. Data from the drill core samples included rock strength testing, as well as observations regarding major structures, total core recovery, artificial breaks, rock quality designation, solid core recovery, solid length, minor defects, cemented joints, and open joints. According to the DEIS (USDA, 2019), the maximum land subsidence in the center of the crater would be 1115 feet, and the closest approach of the subsidence zone to the culturally sensitive escarpment of Apache Leap would also be 1115 feet (see Fig. 3). The mining proposal also describes an extensive program of subsidence monitoring before, during and after the life of the mining project (Resolution Copper Mining, 2014a-c).

The DEIS presents five alternative plans for the tailings storage facilities for the proposed mine (USDA, 2019). By DEIS conventions, Alternative #1 is the "no-action" alternative. Alternative #2, the preferred alternative that was presented in the General Plan of Operations (GPO) (Resolution Copper Mining, 2014a-c), involves storing tailings thickened into a slurry (65% solids for scavenger tailings, 50% solids for cleaner tailings) at the Near West site behind a 520-foot-high tailings dam (see Fig. 4). Alternatives #2 and #3 are nearly spatially coincident at the Near West site (see Fig. 4). Alternative #3 involves slightly thicker scavenger tailings (70% solids) and a slightly lower dam (510 feet). Alternative #4 would involve the storage of filtered tailings (86-89% solids) at the Silver King site to a height of 1040 feet (see Fig. 4, Table 1). The dam for the Silver King site would be a "structural zone" of tailings built around the perimeter (SWCA Environmental Consultants, 2018) and would be the tallest tailings dam ever constructed. (The current tallest tailings dam in the world is the 650-foot-high Quillayes Dam at the Los Pelambres Mine in Chile (Campaña et al., 2015)). Alternative #5 involves the storage of thickened tailings (60% solids for scavenger tailings, 50% solids for cleaner tailings) behind a

310-foot-high tailings dam at the Peg Leg site (see Fig. 4, Table 1). The final Alternative #6, which is the preferred alternative in the DEIS, involves the storage of similarly thickened tailings (60% solids for scavenger tailings, 50% solids for cleaner tailings) behind a 490-foot-high tailings dam at the Skunk Camp site (see Fig. 4, Table 1). The total volumes of stored tailings have been predicted as 1315.45 million cubic yards for the sites storing thickened tailings and 1188.98 million cubic yards for the site storing filtered tailings (see Table 1; USDA, 2019).

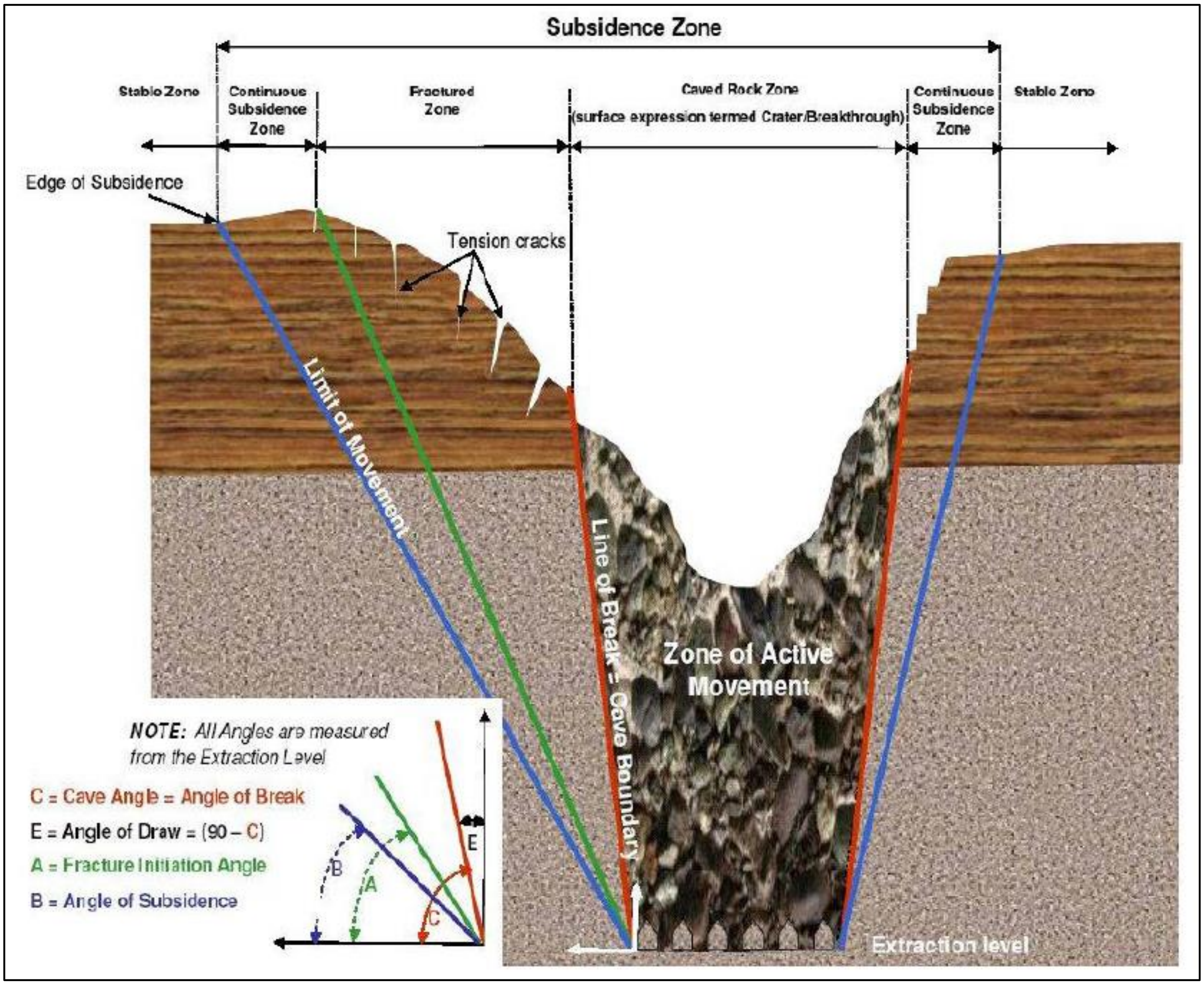

Figure 2. The subsidence zone can be divided into the caved rock zone, the fractured zone and the continuous subsidence zone. The caved rock zone is the zone of greatest vertical displacement and consists of fragmented rocks of all sizes. The fractured zone is the zone where visible deformation can be seen on the surface, including cracks and slumps. In the continuous subsidence zone, deformation can be detected only by high-resolution monitoring equipment. The region outside of the subsidence zone is called the stable zone. Figure from Resolution Copper Mining (2014c).

According to the DEIS (USDA, 2019), the design earthquake for the tailings dams would be the Maximum Credible Earthquake (MCE), which is defined as "the largest earthquake magnitude that could occur along a recognized fault or within a particular seismotectonic province or source area under the current tectonic framework" (FEMA, 2005). However, the DEIS also states without justification, "Analysis indicates Maximum Credible Earthquake is equivalent to 10,000-year return period [annual exceedance probability of 0.01%]." On the contrary, in the context of discussing criteria for determining the MCE at a particular location, FEMA (2005) states, “For high-hazard potential dams, movement of faults within the range of 35,000 to 100,000 years BP is considered recent enough to warrant an ‘active’ or ‘capable’ classification.” In other words, the MCE can be as rare as a 100,000-year earthquake, with a corresponding annual exceedance probability of 0.001%. In addition, nothing in the DEIS explains how the tailings dams will be built so that they will withstand the 10,000-year earthquake. For example, there is no seismic stability analysis of any of the proposed designs anywhere in the DEIS.

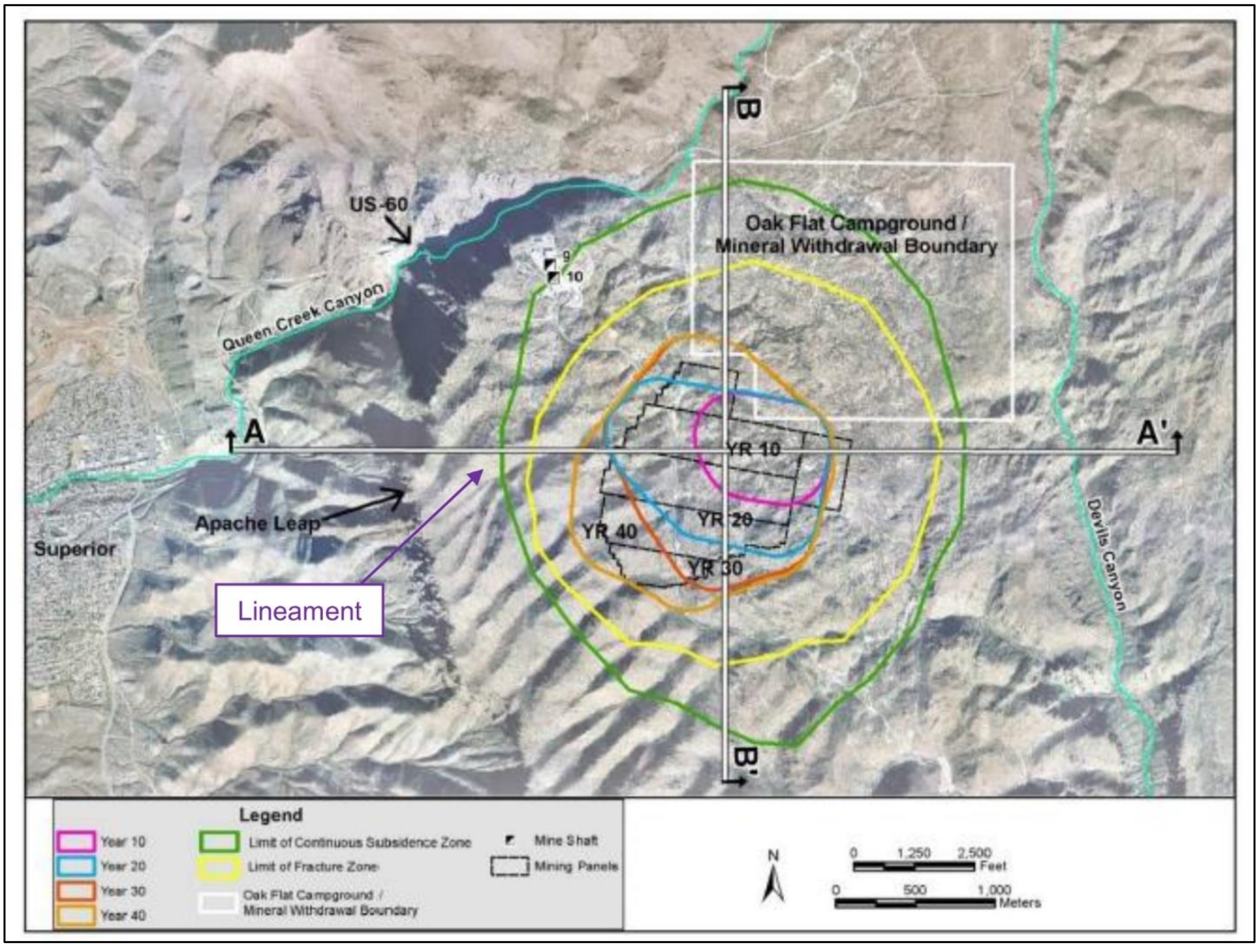

Figure 3. According to the DEIS (USDA, 2019), the culturally sensitive escarpment of Apache Leap will be 1115 feet outside of the subsidence zone even after 40 years of block cave mining. The contours marked by years indicate the limits of the caved rock zone (see Fig. 2) after 10, 20, 30 and 40 years of mining. The lineament shown in Fig. 6 can be seen to intersect the caved rock zone in the above figure. Figure modified from Resolution Copper Mining (2014a).

QUESTIONS THAT MUST BE ANSWERED ABOUT THE MINE

This testimony addresses the following pressing questions for the public:

1) What is the projected water consumption of the mine?
2) What is the projected electricity consumption of the mine?

3) Did the prediction of subsidence use correct input data, does the mining project have an adequate subsidence monitoring program, and is there a sufficiently low probability that the subsidence will impact Apache Leap?
4) What would be the consequence of failure of the tailings dams and is there an adequate distance between each of the proposed tailings dams and the downstream communities?

This testimony is a summary of four detailed reports (Emerman, 2018, 2019a-c) that are available on the web site of the Arizona Mining Reform Coalition. Those reports were based upon the GPO (Resolution Copper Mining, 2014a-c) and have been updated in this summary to include changes in the DEIS (USDA, 2019).

Table 1. Predicted Runout following Tailings Dam Failure

Alternative	Name	Tailings Type	Impounded Volume[1] (million yd^3)	Dam Height[2] (ft)	Spill Volume[3] (million yd^3)	Runout[3] (mi)
2	Near West	Thickened	1315.45	520	309.1	266.7
3	Near West	Thickened	1315.45	510	309.1	263.9
4	Silver King	Filtered	1188.98	1040	280.8	370.3
5	Peg Leg	Thickened	1315.45	310	309.1	201.2
6	Skunk Camp	Thickened	1315.45	490	309.1	258.2

[1]Impounded volumes from USDA (2019).
[2]Dam heights from SWCA Environmental Consultants (2018).
[3]Spill volume and runout calculated from statistical model in Larrauri and Lall (2018).

METHODOLOGY

The expected flow rate of geothermal water into the completed underground mine was calculated by combining the Thiem Equation with the radius of the completed mine (1400 feet). The Hazen-Williams Equation was used to calculate the power required to dewater the mine. The best-case scenario (minimum electricity consumption for dewatering and refrigeration) was based upon the following assumptions:

1) The flow of geothermal water into the No. 10 shaft has achieved a steady-state.
2) The aquifer has uniform transmissivity (product of aquifer thickness and hydraulic conductivity).
3) The recharge rate of the aquifer does not exceed 0.1 inches per year.
4) All mine dewatering can be carried out through a single vertical pipe.
5) The mine can be refrigerated with maximum theoretical efficiency.

The projected electricity and water consumption were addressed based on a literature review that considered the particular aspects of the Resolution Copper Mine (such as the depth and grade). Land subsidence was addressed using Google Earth images and <u>A Practical Manual on Block Caving</u> (Laubscher, 2000). The runout following tailings dam failure was calculated using a statistical model based on the history of tailings dam failures (Larrauri and Lall, 2018). The impact of the tailings flow on the local population was then addressed by determining whether the watersheds of local population centers intersected the footprint of the proposed tailings storage facilities within a distance that was at least as great as the predicted runout. The local population centers include the incorporated towns of Superior (population 2837) and Florence (population 26,074), and the unincorporated census-designated places of Queen Valley (population 820) and Dripping Springs (population 235) (see Fig. 4).

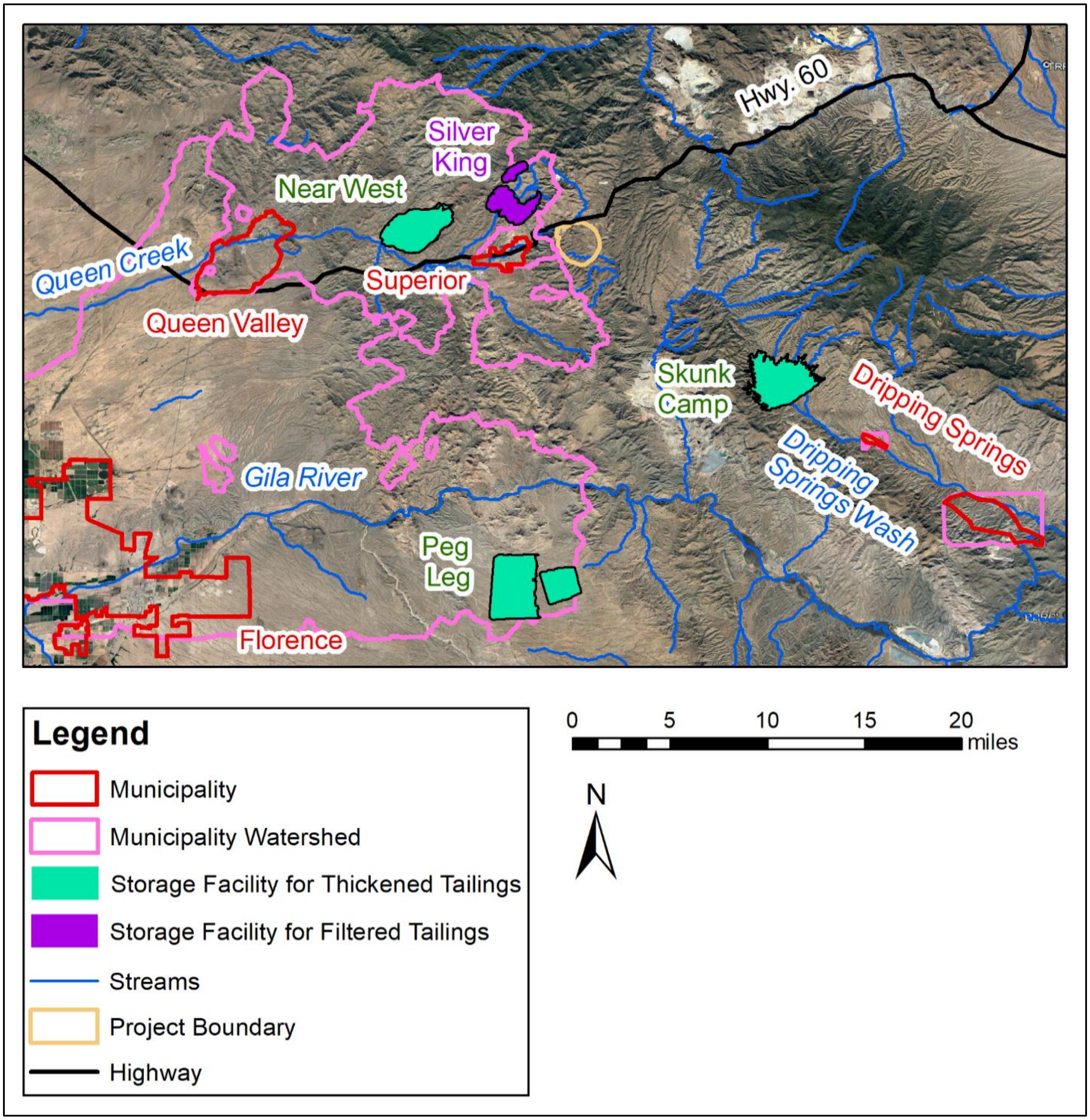

Figure 4. Out of the five alternatives for the tailings storage facilities for the proposed Resolution Copper Mine, four would store thickened tailings, while one would store filtered tailings. Two alternatives at the Near West site are nearly spatially coincident, with the alternative with thickest tailings being slightly larger. Failure of the Silver King facility would impact the town of Superior (population 2837). The unincorporated area of Queen Valley (population 820) would be impacted by the failures of the Silver King or either of the Near West facilities. The town of Florence (population 26,074) would be impacted by the failures of the Peg Leg, Silver King, or either of the Near West facilities. The unincorporated area of Dripping Springs (population 235) would be impacted by the failure of the Skunk Camp facility. Background combines Google Earth imagery from December 6, 2014, January 13, 2018, and April 6, 2018.

RESULTS AND DISCUSSION

Water Consumption

Northey et al. (2013) emphasized the large variation in water consumption among copper mines world-wide and gave 74 m^3/t Cu as a global average, corresponding to an estimate for the Resolution Copper Mine of 48,000 acre-feet of water per year. The advantage of restricting the dataset to Arizona is that it takes into account the high evaporation rates that might not be present at copper mines in the rest of the world. Using the data in Singh (2010) from seven Arizona copper mines resulted in an average water consumption of 28.3 gallons per pound of copper, corresponding to 154,000 acre-feet per year for the Resolution Copper Mine. According to the EIS, the projected water consumptions by the Safford mine (which began full production in 2008) and the Rosemont mine (which has not opened) are 7.5 and 7.4 gallons per pound of copper, corresponding to water consumption rates for the Resolution Copper Mine of 41,000 and 40,000 acre-feet of water per year, respectively. Taking into account the fact that the water consumption rates for the newer mines are only projections and not actual measurements, the best prediction for water consumption by the Resolution Copper Mine is 50,000 acre-feet per year, which is also quite close to the global average (Northey et al., 2013).

The only explanation from Rio Tinto for the above discrepancy with their prediction of water consumption of 15,700 acre-feet per year has been their promise that, "Maximizing water reuse is critical to the Resolution Project from a physical resource and cost perspective. Reuse and reclaim water supplies will be used for mine operations to the greatest extent possible, including water from mine dewatering, tailings dewatering, seepage collection, overflow water from the copper/molybdenum thickeners and tailings thickeners, and concentrate filtrate" (Resolution Copper Mining, 2014a). In opposition to the above quote, the GPO (Resolution Copper Mining, 2014a-c) describes only the most conventional technologies for water efficiency. The only areas for which specific water losses have been calculated are the water entrained with the copper concentrate (9% water), which is shipped off-site for further refining, and the water entrained with the cleaner tailings (35% water) and the scavenger tailings (50% water), which are exported to the tailings storage facility. Based upon the above values, the water exported to the tailings storage facility would be 25,600 acre-feet per year, which is already 10,100 acre-feet per year greater than the water consumption of 15,700 acre-feet per year that was predicted by Rio Tinto (Resolution Copper Mining, 2014a).

Electricity Consumption

The most reliable estimate for electricity consumption by copper mining is probably that of Koppelaar and Koppelaar (2016), who used the most recent and complete dataset, and who explicitly took depth and grade into account. Combining the depth, grade and ore production rate of the Resolution Copper Mine with Eq. (3) from Koppelaar and Koppelaar (2016) yields 236 MW. The additional electricity consumption required to dewater and refrigerate the mine due to the entry of geothermal water should be added to the above estimate, since the need to remove and mitigate the impact of geothermal water would not normally be a factor in the power requirements of a typical copper mine. Of the five assumptions that led to the best-case estimate for electricity consumption by dewatering and refrigeration, the violation of the second assumption (uniform aquifer transmissivity) would have the greatest consequences. Aquifer thickness can vary somewhat, but hydraulic conductivities of fractured crystalline rock can vary by four orders of magnitude (Charbeneau, 2000). The real worst-case scenario is that, as the underground mine expands, it encounters increasingly fractured rock. If hydraulic conductivity increases by two orders of magnitude, then the entry rate for geothermal water could increase from the 3800 gpm that would occur from expanding the mine with uniform hydraulic conductivity up to 380,000 gpm. Assuming pipes with zero head loss would result in a power requirement under the "minimum" worst-case scenario of 1650 MW (500 MW for dewatering and 1150 MW for refrigeration). Therefore, the appropriate best estimates for the electricity consumption of the Resolution Copper Mine under the best-case (minimum input of geothermal water) and worst-case (maximum input of geothermal water) should be 260 MW and 1900 MW, respectively.

The predictions of electricity consumption for the Resolution Copper Mine can now be compared with the available sources of electricity. For Fiscal Year 2018, the Salt River Project (2019) reported peak power of 7610 MW and peak power capacity of 8801 MW. The above predictions of electricity consumption correspond to 3% and 22% of the peak power capacity of the Salt River Project under the best-case and worst-case scenarios, respectively. The predicted electricity consumption for the Resolution Copper Mine would be equivalent to the electricity consumed by 219,000 and 1.6 million U.S. households under the best-case and worst-case scenarios, respectively (EIA, 2019). There is certainly no mention on the website of the Salt River Project or anywhere else for plans to increase power capacity to accommodate the Resolution Copper Mine.

Subsidence Predictions

The actual data that were used in the subsidence modeling are not presented in any documents that have been provided by Rio Tinto. On that basis, there is no way for anyone not affiliated with Rio Tinto to repeat the subsidence modeling or to carry out his or her own subsidence modeling. Even the description of the data is inadequate for assessing the validity of the subsidence modeling. The most important information that is missing are the numbers of drill cores and the depths of the drill cores. The only exception to the lack of input data is the map of the geological faults that were used in the subsidence modeling (see Fig. 5). The primary control on the ability of block caving to transmit deformation to Apache Leap should be any faults that connect Apache Leap to the surface footprint of the block caving area, so that the most important fault is the West Boundary Fault (compare Figs. 3 and 5).

The superposition of the West Boundary Fault (as mapped in Fig. 5) onto a Google Earth image shows a pronounced lineament that is subparallel to the West Boundary Fault and offset from the fault by about 2000 feet (see Fig. 6). The nearly-parallel orientations of the West Boundary Fault and the lineament are certainly suggestive that the West Boundary Fault has been incorrectly mapped, and there is no other mapped fault that could correspond to the lineament (see Figs. 5-6). Unlike the mapped West Boundary Fault, the lineament intersects the caved rock zone (see Fig. 3), so that there is potential for deformation to be transmitted from the caved rock zone to Apache Leap. On this basis, there could have been an underestimation of the extent of the subsidence zone.

With regard to the subsidence monitoring program, the primary issue is not Rio Tinto's ability to document subsidence, but their ability to take appropriate action in response to unanticipated subsidence. A comprehensive database of subsidence caused by block caving reported that unanticipated subsidence has occurred in 20% of block caving projects with most of the anomalies being related to geological faults (Tetra Tech, Inc. and R Squared, Inc., 2006; Woo et al., 2013). The connection between observation and action is based on the explicit assumption that “Subsidence is a slow and gradual process that is predicted, closely monitored, and controlled” (Resolution Copper Mining, 2014a) and that “Subsidence is a rather slow and continuous process, and as such there would be time to apply an adaptive monitoring plan if required” (Resolution Copper Mining, 2014c).

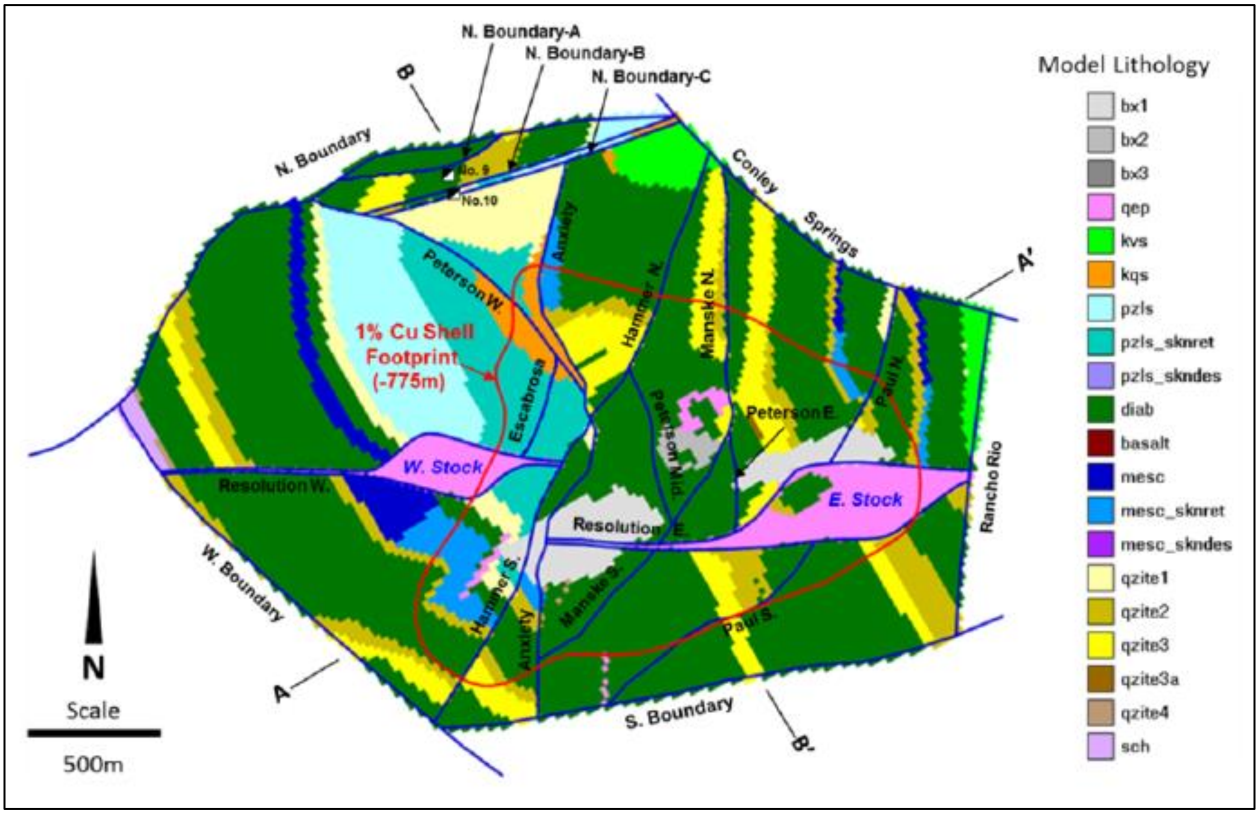

Figure 5. The most important structural controls on land subsidence caused by block caving are the locations and physical properties of geological faults. The above map shows the mapped faults that were used in the modeling (see Fig. 3). For predicting the impact of block caving on Apache Leap, the mapping of the West Boundary Fault is the most important since it connects the mining area with Apache Leap (see Fig. 3). Figure from Resolution Copper Mining (2014c).

By contrast, Laubscher (2000), the only reference on block caving that is cited in the GPO (Resolution Copper Mining, 2014c), repeatedly draws attention to the dangers of both rapid subsidence and rockbursts. Some examples of the discussion of rapid subsidence are “Lateral extension or subsidence caving as it was previously described, occurs when adjacent mining has removed the lateral restraint on the block being caved. This can result in rapid propagation of the cave with limited bulking…There can be a rapid propagation of the cave with massive wedge failures if a well developed relaxation zone has formed ahead of the cave front” (Laubscher, 2000). Some examples of discussion of the related problem of rockbursts are “The potential effects of a block cave on installations located in the peripheries of the block include…shear displacements on faults and shear zones. These could produce rockbursts…Cave mining of deep, hard rock orebodies, involving removal of large volumes of rock, will inevitably lead to the generation of mining-induced seismicity, which may lead to rockbursts…The location of the source of the seismicity and the location of the rockburst damage may or may not be coincident. In the larger magnitude events, the separation of the two locations may be hundreds of meters…Rockbursts have become a major problem on block caving mines in competent rock, where the regional principal stress is > 35 MPa" (Laubscher, 2000).

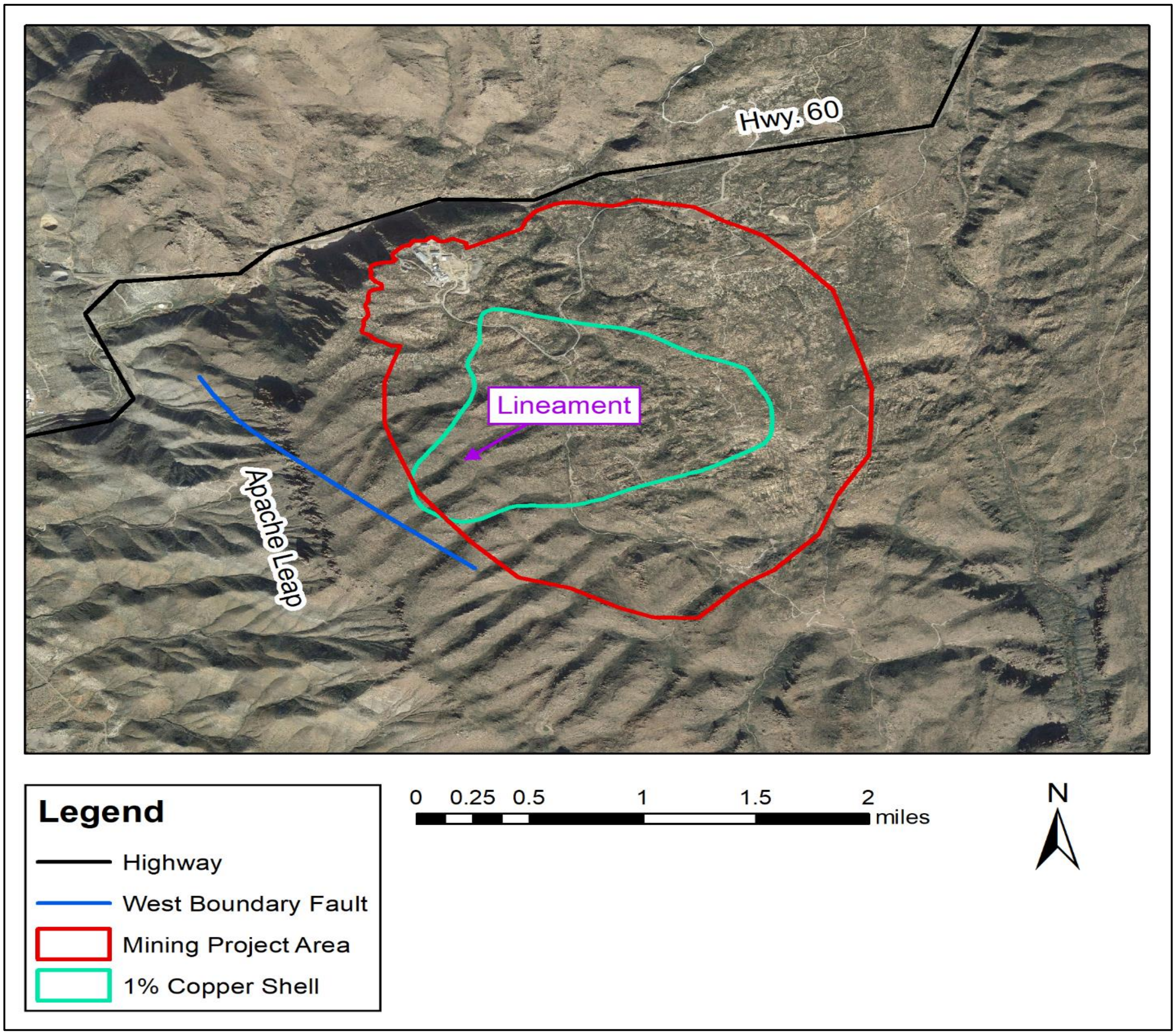

Figure 6. The West Boundary Fault (Fig. 5) is subparallel to and offset by 2000 feet from a pronounced lineament that is visible from satellite imagery. The lineament does not correspond to any other mapped fault that was used in subsidence modeling (Fig. 5), which suggests that not all geological faults have been correctly mapped. The faults and other zones of weakness that connect Apache Leap with the mining area are the most important in predicting the impact of subsidence caused by block caving on Apache Leap. Google Earth imagery is from Dec. 6, 2014.

The predictions of the limits of the caved rock, fractured and continuous subsidence zones contain no uncertainties or error bounds of any kind (see Figs. 2-3). Presumably, all predictions are simply the best estimates and not the worst-case scenarios. The only exception to the lack of error bounds in subsidence predictions are the predicted maximum depth of the crater above the ore body. According to the DEIS (USDA, 2019), the maximum depth is projected to range between 800 and 1115 feet in depth. The above range of depths could be re-expressed as a predicted depth of 957.5 ± 157.5 feet. If the uncertainty (157.5 feet) is assumed to be the standard deviation, then the coefficient of variation (ratio of standard deviation to mean) of the predicted maximum depth is 16.4%. In the absence of other information, the same coefficient of variation could be assumed to apply to other aspects of the subsidence predictions.

Based on the uncertainty in the maximum crater depth, the uncertainty in the prediction of the approach of the subsidence zone to Apache Leap can also be assessed. Based on Fig. 3, the predicted distance from the center of the ore body to the outer limit of the subsidence zone in the direction of Apache Leap is 5035 feet. Assuming a coefficient of variation of 16.4%, the standard deviation of that prediction is 828 feet. Since the closest approach of the subsidence zone to Apache Leap is 1115 feet (USDA, 2019), the distance between the eastern edge of Apache Leap and the center of the ore body is 6150 feet. Then assuming that the population of predictions of the distance of the outer edge of the subsidence zone from the center of the ore body follows a normal distribution with mean equal to 5035 feet and standard deviation equal to 828 feet, the probability that the outer limit of the subsidence zone will extend onto Apache Leap or beyond is 8.9%.

Consequences of Tailings Dam Failure

Predicted runouts due to failure of the tailings dams at each of the five alternative tailings storage facilities range from 201 miles (Peg Leg site) to 370 miles (Silver King site; see Table 1). Although the predicted runouts may seem surprisingly large, it should be noted that, compared to past tailings dam failures, the impounded volumes and dam heights are “off the charts.” For the Resolution Copper Mine, the impounded volumes are either 1315.45 million cubic yards for thickened tailings or 1188.98 million cubic yards for filtered tailings (USDA, 2019; see Table 1). By contrast, the largest volume of impounded tailings at any tailings dam that has failed thus far was 97 million cubic yards at the Mount Polley Mine in British Columbia that failed in 2014 (Larrauri and Lall, 2018). Moreover, the tallest tailings dam that has failed thus far was the 295-foot-high Fundão Dam at the Samarco Mine in Brazil that failed in 2015 (Larrauri and Lall, 2018), which was not as tall as any of the proposed tailings dams for the Resolution Copper Mine (see Table 1). Predicted spill volumes, which depend only upon the impounded volume are either 309.1 million cubic yards for thickened tailings or 280.8 million cubic yards for filtered tailings (see Table 1). Again, by contrast, the largest tailings spill that has occurred thus far was 42 million cubic yards from the failure of the Fundão Dam (Larrauri and Lall, 2018). The important point is that tailings dam failures could have very wide-ranging impacts, extending over hundreds of miles, and that the local population centers (see Fig. 4) are simply the “front line” of affected populations. It could be argued that the statistical model based upon past tailings dams failures does not apply to the Silver King site, which will store filtered tailings. However, even in the best-case scenario, a failure of the tailings dam at the Silver King site would result in the slump of the filtered tailings that would extend for a distance of roughly ten times the dam height or 10,400 feet (Klohn Crippen Berger, 2017).

All of the local population centers include at least one proposed tailings dam in its watershed, so that the failure of each of the five alternatives has the potential to result in the loss of human life. It has already been shown that the predicted runouts are so large that the ability of a tailings spill to reach the above-mentioned local population centers is not a factor. The watershed of Superior includes the Silver King site at a minimum distance of 2500 feet (see Fig. 4). Even a slump of filtered tailings with no added water would nearly cover the entire town of Superior. The unincorporated area of Queen Valley would be impacted by the failures of either of the Near West facilities (minimum distance 19,000 feet) or of the Silver King facility (minimum distance 8.2 miles; see Fig. 4). The town of Florence would be impacted by the failures of the Peg Leg facility (minimum distance 10.3 miles), either of the Near West facilities (minimum distance 16.0 miles), or the Silver King facility (minimum distance 20.5 miles; see Fig. 2). Based on the Digital Elevation Models (DEMs), the watershed of Dripping Springs does not include the Skunk Camp facility. However, Dripping Springs sits on the bank of Dripping Springs Wash, which would be quite likely to overflow following a tailings spill from the Skunk Camp site, a minimum distance of 17,000 feet from Dripping Springs (see Fig. 4).

Following the failure of the tailings dam at the Córrego do Feijão Mine in Brazil on January 25, 2019, which resulted in 308 people missing or confirmed dead, the new Brazilian mining regulations and legislation introduced the concept of "*zonas de autossalvamento*," which are literally the "self-rescue zones" or the zones in which each person must rescue himself or herself because no rescue from the outside will be possible (Agência Nacional de Mineração [National Mining Agency], 2019; Assembleia Legislativa de Minas Gerais [Legislative Assembly of Minas Gerais], 2019). This "self-rescue zone" has been defined as either 10 kilometers (6.2 miles) along the course of the valley or the portion of the valley that can be reached by the tailings flow within 30 minutes, whichever is greater (Assembleia Legislativa de Minas Gerais, 2019). That distance can be extended to 25 kilometers (15.5 miles) depending upon the population density and the natural and cultural heritage. In the Brazilian state of Minas Gerais, it is currently illegal to construct a tailings dam where there is a population residing in the "self-rescue zone" (Assembleia Legislativa de Minas Gerais, 2019). It should be noted that the town of Superior and the unincorporated areas of Dripping Springs and Queen Valley are all well within this "self-rescue zone." Ecuador (Valencia, 2019) has followed suit in adopting the same regulations. China has also considered the proximity of tailings dams to populated areas and has prohibited the construction of tailings dams within one kilometer (3281 feet) upstream of residential neighborhoods, industrial facilities, or markets (Zhang and Daly, 2019). Although of course, the U.S. Forest Service would not be bound by any legislation passed in Brazil, China or Ecuador, the proposal for a mining project in Arizona that would be illegal in a developing country should be a cause for pause and reflection.

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