Rosemont Copper Mine. Conceptual Site Model for Assessing Contaminant Transport and Pathways

Program: The Pima County International Man-Environment Observatory

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Abstract

The Rosemont Copper Project is a proposed open-pit mine located in Pima County, Arizona, with an estimated operational life of 20-25 years. Copper, and to a lesser extent molybdenum and silver are the metals of interest. During this project, approximately 546 million tons (Mt) of sulfide ore and approximately 70 Mt of oxide ore will be processed. In this process, approximately 1,232 Mt of waste rock will be produced (Tetra Tech, 2012a). The site selected for the mine resides within a sensitive region of the Santa Cruz watershed, near headwaters for tributaries. Furthermore, the Cienega Creek and Davidson Canyon are natural preserves that supply water to the Tucson Basin and host several species, such as aquatic and riparian plants and animals (Powell et al., 2014). Past mining operations in Arizona were always associated with negative impacts on the environment, both during mining and post-mining (Earthworks, 2012), with acid mine drainage and airborne particles from smelter emissions and wind erosion of mine tailings. In addition, potential human-health risks are associated with these impacts. Modern mine development requires a robust assessment of environmental and human-health impacts. The goal of this work is to identify contaminant sources and contaminants of concern, as well as to delineate their potential release mechanisms and transport pathways.

I.   Introduction

Mining activities are always coupled with negative impacts on the environment and potentially on human health. Mine tailings and rock waste can be harmful to the environment and to human health if they are not managed properly. At the Rosemont project area, copper occurs as sulfide and oxide ores (AZDEQ, 2012). Therefore, its extraction requires several actions that involve crushing, grinding, and flotation for the sulfides and acid treatment to liberate the copper ions for the oxides. During these processes contaminants can leak from storage containers, seep from tailings and waste materials, and infiltrate into the subsurface. They can also be transported by runoff into surface water, and as dust via wind. The approach we will be using is to implement a conceptual site model (CSM) for the Rosemont Copper Mine. The CSM will be used as a tool to identify the potential contaminants of concern, the potential sources of such contaminants, the transport and release mechanisms, and delineate the possible pathways of exposure.

II.   Motivation

There are several pertinent reasons to develop a CSM for the proposed Rosemont Copper Project:

- Arizona is one of the largest producers of copper nationwide (~ 65%) because of its enormous copper reserves. Therefore, the project results will be valuable and applicable for many other future mining projects in AZ and elsewhere in the world.
- The methods used in this proposed CSM will provide a tool for conducting risk assessments at the site.
- Almost all copper porphyry mines in Arizona such as Bagdad, Morenci, Ray, Sieritta, Miami, etc., experienced surface and groundwater contamination from acid mine drainage, metals leaching, and/or accidental releases of chemicals. The main pollution causes were related to pipeline spills, mine seepage, and tailing collapse and spreading (Earthworks, 2012). Therefore, the need for studying contaminant sources and transport pathways is crucial for the protection of the environment and the local communities.
- The semiarid climate in Arizona has a significant impact on the transport of dust and aerosols from mining areas. Winds can easily transport fine metal particles from mine tailings (Stoven et al., 2014) and contribute to the accumulation of contaminants in soil, water and biota (Csavina et al., 2012). This makes it one of the major exposure pathways in the context of Arizona.

III.   Site Description

The Rosemont Copper Mine is planned to be an open-pit mine that will be located in northern part of the Santa Rita Mountains, approximately 48 km southeast of Tucson, Arizona (USFS, 2013). The project will be placed on the upper Davidson Canyon watershed 402.7 ha on private land, 1485.2 ha on National Forest System (NFS) land, and 30.3 ha on Arizona State Land Department (ASLD) land (Fig. 1). The topography of the area falls from the mountains' summits of ~1.8 km above sea mean level (amsl) to the east and northeast in Cienega Creek

and Davidson Canyon watersheds (Eng. Analytics, 2012). The mine's operational life is projected to be 20 to 25 years (USFS, 2013).

1. Meteorological data

The Rosemont area has a desert climate characterized with hot summers and dry and temperate winters. The rainy season is in the summer and it is known as the monsoon in which intense rainstorms frequently occur. Five metrological stations are located within a distance of ~48.3 km from the proposed mine. An In-situ meteorological station was installed, 10 years ago, by Rosemont at ~1.6 km (amsl). The station is monitored by Applied Environmental Consultants (AEC) and has been recording the local mine weather: temperature, precipitation, wind speed, wind direction, and evaporation rate (Tetra Tech, 2012a).

1.1 Temperature

Since the installation of a weather station at the Rosemont site in 2006, the average hourly maximum temperature was 34.5˚C in July 2007 and the average hourly minimum temperature was -7.2˚C in November 2006.

1.2 2 Rainfall

The average annual precipitation at the Rosemont site from 2006 to 2008 was 17 inches. The average monthly precipitation recorded from the six meteorological stations exhibit data correlation with the maximum average precipitation in the project area recorded in July and August.

1.3 3 Wind

The general flow direction of the wind is west-east. The monsoon storms increase the amount of dust in the air, especially from a disturbed land.

2 Hydrology and Hydrogeology

There is a high variation in regional groundwater flow. In fact, groundwater gradient changes from ~1.7 km amsl to ~0.8 km amsl. This steep variation is due the change in elevation from the mountains to riparian areas, but it is more prominent within the Davidson Canyon watershed. The bedrock of the Santa Rita Mountains is essentially metamorphic rocks that are surrounded by metamorphic shell that date from the Paleozoic and Mesozoic. It includes carbonates, shales, and limestones. Bedrock material is consolidated with very low permeability. Alluvium and unconsolidated deposits cover the bedrock. Consequently, water has the potential to move faster in these materials due to their higher permeability. Groundwater in Davidson Canyon is mainly from groundwater inflows within the watershed (Tetra Tech, 2010a). There are two groundwater systems that have been identified in the Santa Rita area: the first one is the bedrock which is a deep flow system that flows predominantly through factures and has low storage capacity. The second is the basin-fill deposits. This is a shallow flow system with higher storage and where groundwater flows mainly through the unconsolidated deposits. The groundwater flow is towards the Davidson Canyon surface water drainage. Fault zone in this canyon may enhance the groundwater flow and permeability. The interaction between these two

systems may occur at certain locations. There are downward gradients on the east side of the proposed mine pit which represent recharging conditions. The regional groundwater table starts from ~6 m below surface and extends to more than 30 m below surface in the upper region of Davidson Canyon. Observations of groundwater levels underneath surface-water channels show that there is no direct connection between the surface-water flows and the regional groundwater except the upper region of the watershed where recharge is taking place from stream channels (Tetra Tech, 2010a). Discharge from regional springs in the Davidson Canyon is not significant to the general water balance. The Rosemont springs are possibly supplied by shallow water sources and not by the regional groundwater system which makes them susceptible to seasonal variations. The surface water system is disconnected from the regional water table within Davidson Canyon. In fact, the regional water table is ~2 m to ~9 m below the stream channel. In the upper portion of the watershed the shallow groundwater system is separated from the deeper groundwater system due to intermittent hydraulic flow between the two systems. Hydraulic connection between the shallow and the deep flow systems happens when there are large events of large amount of precipitation and stormwater runoff. The open-pit will generate a cone of depression that will extend in the Davidson canyon and may affect surface water flow.

IV.   Mine description

The mine infrastructure and annex facilities are: roads, open-pit, ore transportation network, ore processing facilities, waste rock and tailings facilities, leach facilities, electrical and water transmission lines, and administration building, employee change house, warehouse, analytical laboratory, vehicle servicing facilities, storage facilities, guard house, and truck scale (USFS, 2013). In this proposed copper mine, oxide and sulfide ores will be excavated using the open-pit mining technique; initially, oxide ore will be excavated since it is situated at the upper sediments layers and will be processed during the first 7 years of the operation. Then sulfide ore will be processed in-situ.

V.   Conceptual Site Model

With the CSM, we will produce a characterization of the potential contamination associated with all mining activities proposed for the Rosemont site. This model will be used as a tool to identify potential sources of contaminants, contaminants of concern, their release mechanisms in the environment, and pinpoint the receiving population or media in the environment as well as the transport pathways (Fig. 2).

1. Potential Sources of Contamination

Five main facilities will be potential sources of contamination at the Rosemont Copper Project: mine pit, heap leach facility, waste rock storage area, dry stack tailings facility, and chemical storage facility. Contaminants released from these facilities can potentially exceed Arizona Aquifer Water Quality Standards.

1.1 Pit

The mine pit diameter will be ~1.8 km to ~2 km and the depth will be ~0.5 km to ~0.9 km (USFS, 2013). After mine closure a permanent pit lake will form (~ 1000 years) which will potentially concentrate dissolved metals and other substances that will potentially decrease the pH. Potential chemicals predicted to exceed the aquifer quality standard in the pit lake are: thallium and ammonia and various surface water quality standards for cadmium, copper, lead, mercury, zinc, and selenium. However, none of these standards are applicable to the pit lake (USFS, 2013).

1.2 2 Heap Leach and Ore Processing Facility

a. Oxide Ore

Under the proposed action the heap leach facility presents a significant potential source of contamination. Oxide ore will be processed in a heap leach pad that is placed on a geomembrane liner. Oxide ore will be leached using sulfuric acid solution that is sprinkled over the heap. The leachate, which is called the pregnant solution, will be collected in a pond and will be pumped to a solvent extraction-electrowinning (SX-EW) facility for processing into copper cathodes (Fig. 3). An accidental leakage or spill of sulfuric acid, pregnant solution or petroleum compounds may occur during mining activity and could cause a major source of groundwater contamination. Under the Barrel Alternative (preferred) the proposed heap leach facility is removed and oxide ore will be processed in the sulfide flotation circuit or converted to waste rock (USFS, 2013).

b. Sulfide Ore

Sulfide ore particle size has to be reduced from rocks to sand particles. It will go through crushers, grinding mills, and ball mills. The product will go in a floatation process to concentrate and separate the copper and molybdenum from the waste material. The concentrate is dewatered, thickened, and will then be shipped to market. Tailing material will be dewatered by compression between large filters (Fig. 4). There will be no smelting on site nor in the United States. Under the proposed alternative a fraction of the sulfide ore will be processed like the oxide ore.

1.3 Waste Rock Facility

All waste rock will be transported via haul trucks to the waste rock storage plant located to the east of the mine pit in the Barrel Canyon Basin. The material collected and deposited after each mining stage will be supported with a perimeter buttress constructed from the same material for esthetic reasons. The waste rock material will mainly contain limestone and calcium-bearing calc–silicate rocks, andesite, quartz monzonite porphyry, and arkose. The identified rock types are

unlikely to generate acid rock drainage since the alkalinity associated with these rocks will act as a buffer for acid generating materials in this facility. However, waste rock will contain pyrite from localized areas in the mine which will potentially produce acid solution (Tetra Tech and Montgomery & Assoc., 2007).

1.4 Dry Stack Facility

Slurry from the thickener will be pumped to a series of cylindrical filters in order to reduce water content to 12-15 %. The dry material will be transported by conveyor, and stacked in the dry-stack tailing facility. The facility has a total holding capacity of ~500 million tons (Mt) of tailings that will be mostly stored in the north stack during the first 14 years of the mining operation. The rest of the tailings will be stored in the southern stack during the last 4 years. The dry tailings will be reinforced by the lower part of the waste rock storage area (Tetra Tech and Montgomery & Assoc., 2007).

1.5 Chemical Storage Facility

a. Explosives

While the mine is active, ammonium nitrate and fuel oil explosive will be used every day to blast rocks in the pit. Dry bulk ammonium will be stored in silos near the open-pit. Ammonium nitrate and fuel oil will be mixed in the plant site and transported by trucks. Blasting detonators such as boosters will be stored and transported separately. The main two sources of nitrogen residue will be inside the pit and the waste rock facility. Another potential source of contamination will be the leakage or spillage from storage tanks of a slurry form of explosive that will be used for wet-hole blasting purposes (USFS, 2013).

b. Sulfuric acid

Every week sulfuric acid will be delivered to the mining site 63 times and will be stored in three tanks of 900 ton capacity each.

2. Potential Chemicals and Release Mechanisms

At the Rosemont mine site there are four main mechanisms that are capable to release and transport contaminants: surface water runoff, leaching into groundwater, seeps, and wind erosion.

In porous media

2.1 Pit

The results of three groundwater modeling efforts, performed by Tetra Tech, Montgomery Associates Inc., and Tom Myers, indicate that the pit will act as a permanent regional hydraulic sink in the Davidson Canyon and Cienega Creek basin. This means a capture zone will be formed in the aquifer around the pit that will be perpetually drawing groundwater into it. In fact, groundwater will be pumped from dewatering wells during mining operation. However, after mining closure the pit will slowly refill with groundwater and establish a pit-lake (USFS, 2013).

Geochemical analysis of the pit-lake predicts the formation of acid conditions. Acid may be released due to interaction of rocks in pit walls and water. In addition, evaporation of pit water may concentrate certain elements with time. Potential acid conditions and potential contaminants released in the pit-lake are not expected to migrate into the regional groundwater since, they will be captured by the mine pit lake (Tetra Tech, 2010c). Geochemical experiments show that runoff from mine pit walls may generate acid from only one type of rock which is Bolsa Quartzite. In order to determine the geochemistry under acid generating rocks, three geochemical modeling scenarios were developed using low, average, and high content of elements in pit wall that can chemically react with water. Another geochemical model was also tested on water assuming only average loading of Bolsa Quartzite. Model predictions indicate that the effect of evaporation and the contact of mine wall rocks with water (precipitation and groundwater) will not exceed Arizona Aquifer Water Quality Standards except for Thallium (Table 1) (Tetra Tech, 2010c).

2.2 Blasting and Drilling

Each year ~20,100 tons of ammonium nitrate will be used for blasting. An accidental spillage of ammonium nitrate fuel oil mixtures could occur during mixing the products or during transportation. A non-proper storage or disposal of these hazardous waste materials can contaminate the environment especially given that ammonium nitrate is highly soluble in water. Under ideal conditions the explosive reaction between ammonium nitrate and fuel oil is complete and produces water, carbon dioxide, and nitrogen gas. However, often times incomplete detonation occurs and nitrogen residue can persist in blasted rocks (Revey, 1996). The residue can leach into the groundwater and be transported by precipitation to surface water. It can cause wildlife poisoning and exceedances of aquifer and surface water quality standards for nitrate, nitrite, and ammonia (USFS, 2013). The potential formation of nitrogen residue may include ammonium, ammonia, nitrate and, nitrite. This residue may potentially infiltrate into the groundwater underneath the pit, after which it would be anticipated to be captured by the pit-lake (USFS, 2013).

Remaining ammonia in the pit-lake will cause negative impacts on birds and wildlife. Nitrogen residue in the waste rock facility can be transported by runoff and contaminate surface water downstream from the mine. An extended contact with stormwater runoff and waste rocks can impact water quality in small streams (USFS, 2013).

2.3 Waste Rock and Dray Stack Facilities

There is no doubt that infiltration of rain or process water through tailing and waste rock materials will create seepage that will impact the groundwater. However, geochemical modeling is predicting that the transport of seepage solution will not exceed Arizona Aquifer Water Quality Standards (Table 2 and Table 3) (USFS, 2013). The rate of seepage from the dry stack facility is anticipated to be ~30 liters per minute and will travel downgradient in the shallow aquifer to ultimately join surface water by springs or seeps. The volume of seepage is estimated to represent ~1 % of the average annual runoff in Barrel Canyon, which will not likely affect surface water.

In case tailing seepage reaches water downstream, chemical concentrations will not surpass water quality standards in Barrel Canyon (Table 2). Geochemical modeling based on geochemical analyses of different rocks from the site shows that acid generation from waste rock and tailings will likely be neutralized by the buffering capacity of the total rock composition. The Rosemont Copper mine is required under the aquifer protection permit to isolate the acid generating waste rocks with acid neutralizer rocks (USFS, 2013).

2.4 Heap Leach and Ore Processing Facilities

During oxide ore processing, the leaching process seepage will be collected from the lined heap leach facility for 6 years. After closure of this facility seepage will continue to occur for more than 100 years (Tetra Tech, 2010a). Rosemont will only be collecting the seepage for 3 years after all oxide ore has been consumed. At closure of the heap leach facility, seepage flow rate is predicted to be ~38 L per min, ~19 L per min after 5 years from the closure, and ~4 L/min after 45 years. If seepage reaches the groundwater it will exceed aquifer water quality standards for cadmium, fluoride, and selenium (Table 4). Rosemont is proposing to collect this solution and then treat and release it to the environment under the Arizona Aquifer Protection Permit (USFS, 2013). Release of sulfuric acid and/or pregnant leach solution to the environment could occur due to pipeline failure and accidental discharge.

2.5 Stormwater

During mining operation, stormwater collected from the mine pit, ore processing facilities, and management plant cannot be discharged at the surface under the stormwater permit. However, runoff from waste rock and the tailing facility can be released downstream. Stormwater may accidentally be released into the environment either by violating the proper discharge of stormwater or failure of stromwater containment system.

In the air
2.6 Air Emissions

Mining activities such as construction, excavation, transportation, and reclamation activities will potentially affect the air quality by generating more dust and airborne chemicals. Pollutants released in the air include greenhouse gases: carbon dioxide ($CO2$), methane ($CH4$), and nitrogen oxides (NOx). In addition, volatile organic compounds (VOC), particulate matter less than or equal to 10 microns in diameter (PM_{10}), and particulate matter less than or equal to 2.5 microns ($PM_{2.5}$) will be released. The level of greenhouse gas emission is predicted to be insignificant compared to the level of CO_2 emission potentially released during the mining project. The effect of these gases will be a ~ 1% increase in Pima County CO_2 emissions. The emission rate of VOCs during mining operation will be ~86 tons per year, which represents less than 1% increase in Pima County. NO_x emissions are estimated to be ~1,200 tons per year during active mining which will represent 3.4% increase in Pima County NO_x emissions. The National Ambient Air Quality Standards (NAAQS) for most criteria pollutants during active mining are

anticipated to be met at the perimeter fenceline. However, PM$_{10}$ is expected to exceed NAAQS at that perimeter.

3. Receiving Milieu and Transport Pathway

- Groundwater can potentially be contaminated from seepage from waste rock, tailing facilities, and from the leaching operation.

- Accidental release of hazardous materials is mainly due to lack of training, non-appropriate storage, and handling. Hazardous materials such as ammonium nitrate and fuel oil mixtures, sulfuric acid, laboratory reagents, cleaning fluids, and solvent extraction and electro-winning reagents may be a threat to the environment.

- Accidental release of sulfuric acid or petroleum products during transportation will directly have adverse effects on plants, wildlife, and the soil in the spill area. Indirect impacts from these spills may also occur by migrating downgradient and affecting plants, aquatic life, wildlife and groundwater.

- Accidental release of sulfuric acid due to pipeline or leach pad failure will lead to groundwater contamination.

- Contaminants that will potentially form and accumulate in the pit-lake will not migrate to residents, or affect Fish, and plants outside the mine borders since the pit will play as a permanent hydrological sink. However, the pit-lake may cause undesirable effects on birds and wildlife (USFS, 2013).

- Emissions from the mine site may increase nitrogen deposition in the Saguaro Park East and West.

Risks on public health outside the site may occur from release of a plume of toxic gas in case of an ammonium nitrate explosion in-situ. The risk may be accentuated in case of sulfuric acid interaction with fire. Risks related to accidents during transportation of explosives, sulfuric acid, and ammonium nitrate can have impacts up to 1.6 km radius. Human health can be affected by particulate matter emissions since the NAAQS for human health (PM10) will not be met the perimeter fence (USFS, 2013).

VI.   Conclusion

Five main facilities will be potential sources of contamination at the Rosemont Copper Project: the open-pit, the waste rock storage area, the heap leach facility, the dry stack tailings facility (Tetra Tech, 2012a), and the chemical storage facilities. The Rosemont site, including these facilities, is located at higher elevation than the Cienega Creek and Davidson Canyon watersheds which are at approximately 1,000 m amsl (Eng Analytics, 2012). Moreover, the change in elevation from the mountains to the riparian zones is abrupt and is more prominent in the Davidson Canyon watershed (Tetra-Tech, 2010a). This might have significant impact on the transport of contaminants from the source to the potential endpoints. Therefore, leaching of contaminants into the groundwater, seepage and acid mine drainage produced from the dry stack tailing facility, waste rock storage area, and heap leach facility (Tetra Tech, 2010a) can potentially contaminate soil, surface, and groundwater downgradient. This is of concern since the regional groundwater system in Davidson Canyon watershed is being consumed by local population for their farms, residents, and private businesses (Eng. Analytics, 2012; TetraTech, 2010a). Not only humans are at risk, but also plants, aquatic species, and wildlife in the Davidson canyon and Cienega Creek preserves.

Developing a CMS is crucial to identify the potential contaminants of concern, the potential sources of such contaminants, the transport and release mechanisms, and delineate the possible receiving milieu and possible transport pathways:

- Groundwater models predict that the mine pit will create a permanent regional hydraulic sink in the Davidson Canyon and Cienega Creek basin. A permanent pit lake will form and reach steady   state after ~ 1000 years. Therefore, contaminants will not migrate to the regional groundwater outside the site.

- Geochemical modeling predicts that:

     * Evaporation and water contact with pit-wall rocks will not generate acid and will not   exceed Arizona Aquifer Water Quality Standards except for Thallium (Tetra Tech, 2010c).

     * Nitrogen residue in blasted rocks can leach into the groundwater and transported by runoff to surface water downstream and may exceed aquifer and surface water quality standards for nitrate, nitrite, and ammonia.

     * Seepage waste rock and dry stack facilities will not exceed Arizona Aquifer Water Quality Standards.

     * Acid generation from waste rock and tailings will be neutralized by the buffering capacity of the total rock composition.

     * After closure of heap leach seepage will continue to happen for more than 100 years. If seepage reaches groundwater it will exceeds AAWQS for Cd, F, and Se.

- Air quality modeling predicts that PM_{10} will exceed NAAQS at the fence-line of the site.

- Any accidental release of hazardous materials such as ammonium nitrate and fuel oil mixtures, sulfuric acid, laboratory reagents, cleaning fluids, and solvent extraction and electro-winning will present a direct/indirect threat to human and the environment.
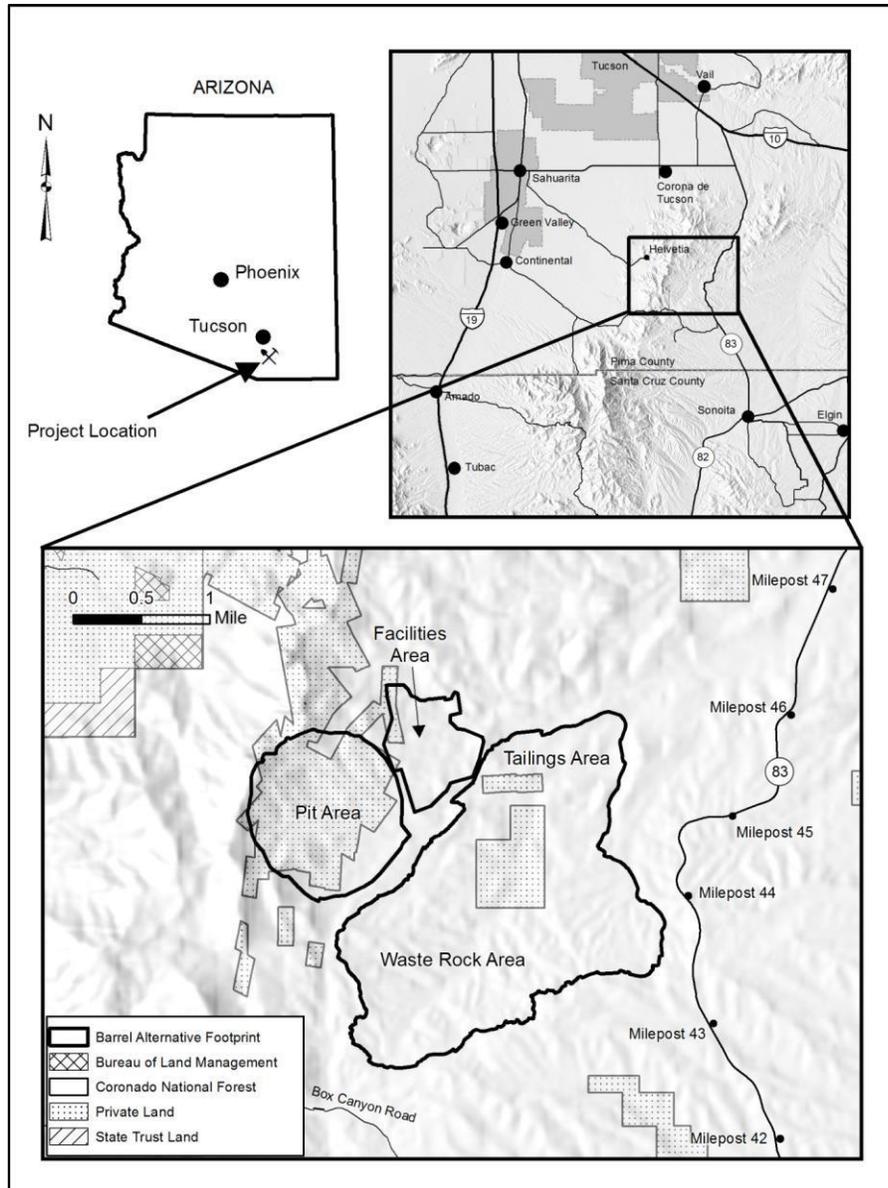
Figure 1: Rosemont Mine Location (USFS, 2013).
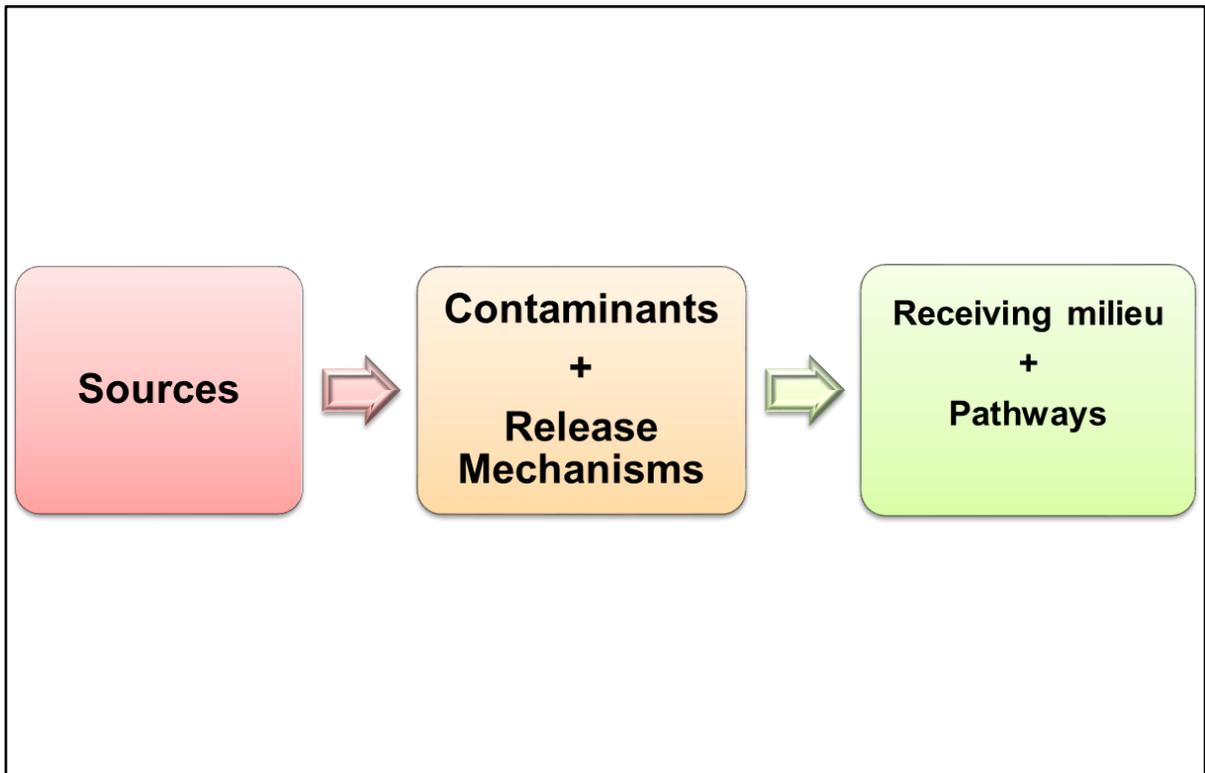
Figure 2: Conceptual Site Model.
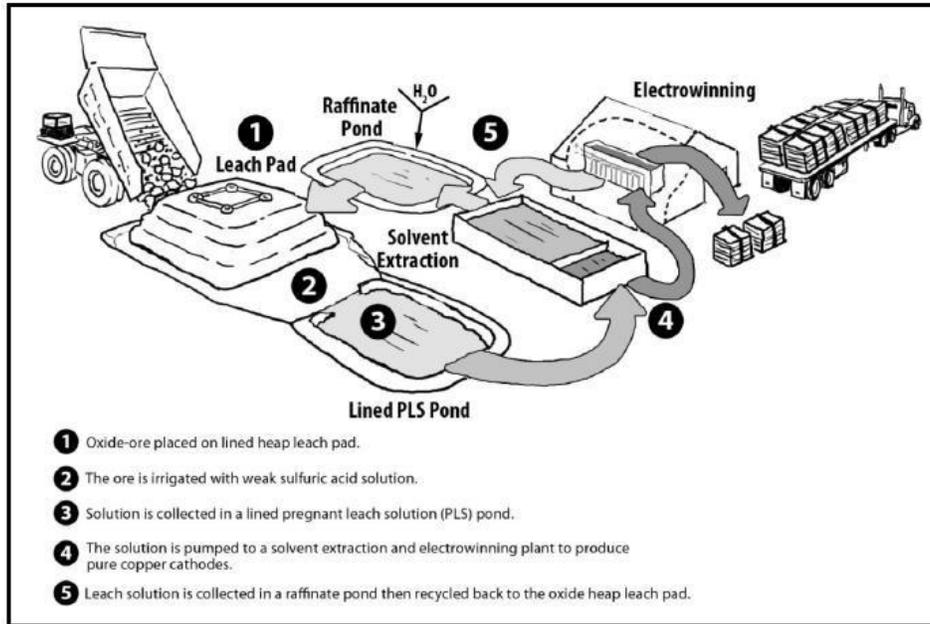
Figure 3: Oxide ore processing (USFS, 2013).

1. Oxide-ore placed on lined heap leach pad.
2. The ore is irrigated with weak sulfuric acid solution.
3. Solution is collected in a lined pregnant leach solution (PLS) pond.
4. The solution is pumped to a solvent extraction and electrowinning plant to produce pure copper cathodes.
5. Leach solution is collected in a raffinate pond then recycled back to the oxide heap leach pad.
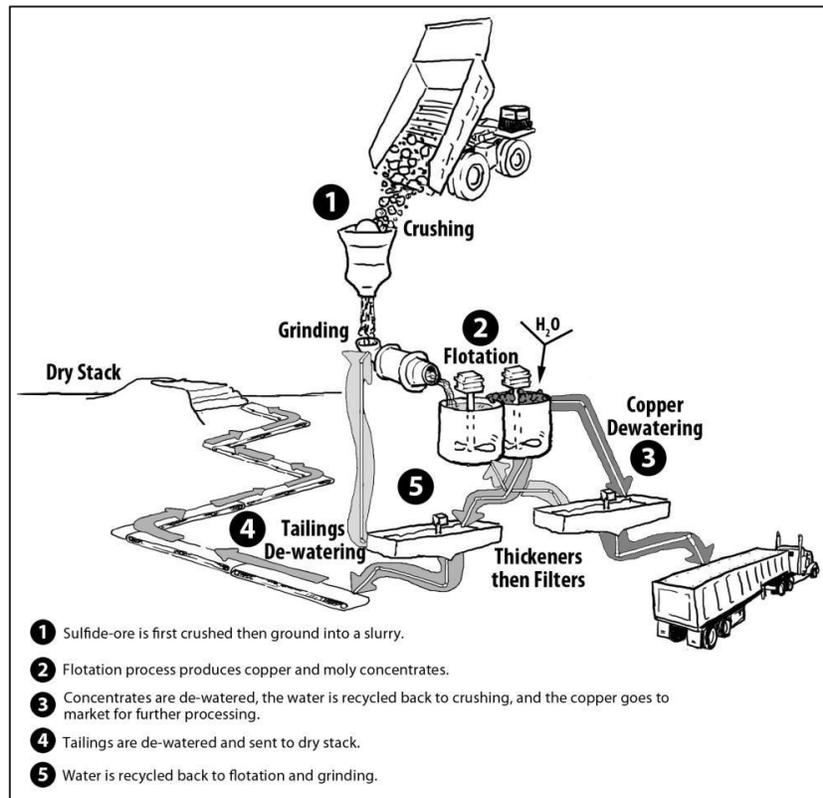
Figure 4: Sulfide ore processing (USFS, 2013).

1. Sulfide-ore is first crushed then ground into a slurry.
2. Flotation process produces copper and moly concentrates.
3. Concentrates are de-watered, the water is recycled back to crushing, and the copper goes to market for further processing.
4. Tailings are de-watered and sent to dry stack.
5. Water is recycled back to flotation and grinding.

Table 1: Results of geochemical modeling for mine pit lake at 200 years (USFS, 2013).

Constituent	Numeric Arizona Aquifer Water Quality Standards	Scenario 1: Low Geochemical Loading	Scenario 2: Average Geochemical Loading	Scenario 3: High Geochemical Loading	Scenario 4: Average Loading with Bolsa Quartzite
Magnesium	No standard	22.7	25.7	30.1	25.6
Manganese	No standard	0.229	0.255	0.243	0.254
Mercury	0.002	0.002	0.001	Not present	Not present
Molybdenum	No standard	0.137	0.150	0.192	0.154
Nickel	0.1	0.005	0.006	0.007	0.010
pH	No standard	8.1	8.0	8.0	8.0
Potassium	No standard	5.1	5.7	6.3	5.4
Selenium	0.05	0.013	0.014	0.016	0.014
Silver	No standard	0.004	0.004	0.005	0.004
Sodium	No standard	31.9	35.9	38.6	35.3
Sulfate	No standard	330.6	374.1	518.5	375.8
Thallium	0.002	**0.005**	**0.006**	**0.007**	**0.006**
Total Dissolved Solids		527	589	751	590
Uranium		0.005	0.006	0.006	0.006
Zinc		0.745	0.847	0.959	0.862

All results are in mg/L. **Boldfaced** numbers indicate an exceedance of the aquifer water quality standard.
Not present = Constituent was not modeled to be present at concentrations above three decimal places.

Table 2. Expected water quality from waste rock seepage (USFS, 2013).

Constituent	Arizona Aquifer Water Quality Standard (mg/L)	Predicted Waste Rock Seepage (mg/L)	Ambient Groundwater Quality (mg/L)*
pH	No standard	7.73	8.1 (5.7 to 9.5)
Antimony	0.006	Not present	<0.0004 (<0.0004 to 0.0044)
Arsenic	0.05	0.013	0.0032 (<0.0005 to 0.067)
Barium	2	0.013	0.050 (<0.003 to 0.206)
Beryllium	0.004	Not present	<0.0001
Cadmium	0.005	0.0004	<0.0001 (<0.0001 to 0.001)
Chromium	0.1	Not present	<0.003 (<0.003 to 0.01)
Fluoride	4.0	1.18	0.7 (<0.1 to 3.6)
Lead	0.05	0.003	<0.0001 (<0.0001 to 0.0049)
Mercury	0.002	Not present	<0.0001 (<0.0001 to 0.0003)
Nickel	0.1	Not present	<0.005 (<0.005 to 0.03)
Nitrate and Nitrite (as N)	10	0.018	0.44 (<0.02 to 8.4)
Selenium	0.05	0.036	<0.0001 (<0.0001 to 0.0055)
Thallium	0.002	Not present	<0.0001 (<0.0001 to 0.0012)

Table 3: Expected water quality from tailings facility (USFS, 2013).

Constituent	Arizona Aquifer Water Quality Standard (mg/L)	Predicted Tailings Seepage (mg/L)	Ambient Groundwater Quality (mg/L)*
pH	No standard	5.87	8.1 (5.7 to 9.5)
Antimony	0.006	Not present	<0.0004 (<0.0004 to 0.0044)
Arsenic	0.05	Not present	0.0032 (<0.0005 to 0.067)
Barium	2	0.017	0.050 (<0.003 to 0.206)
Beryllium	0.004	Not present	<0.0001
Cadmium	0.005	Not present	<0.0001 (from not detectable to 0.001)
Chromium	0.1	Not present	<0.003 (<0.003 to 0.01)
Fluoride	4.0	2.37	0.7 (<0.1 to 3.6)
Lead	0.05	Not present	<0.0001 (<0.0001 to 0.0049)
Mercury	0.002	Not present	<0.0001 (<0.0001 to 0.0003)
Nickel	0.1	Not present	<0.005 (<0.005 to 0.03)
Nitrate and Nitrite (as N)	10	0.001	0.44 (<0.02 to 8.4)
Selenium	0.05	0.006	<0.0001 (<0.0001 to 0.0055)
Thallium	0.002	Not present	<0.0001 (<0.0001 to 0.0012)

Note: Not present – constituent was either not detected for the analysis of the waste rock samples and therefore was not modeled or was below laboratory detection limits in the modeled seepage.
* Median result from all well and spring samples, with range shown in parentheses. For samples without detections of contaminants above laboratory detection limits, the smallest detection limit is shown. If no range is shown, then all samples were below laboratory detection limits.

Table 4. Expected water quality from heap leach seepage (USFS, 2013).

Constituent	Arizona Aquifer Water Quality Standard (mg/L)	Predicted Heap Leach Facility Seepage (mg/L)	Seepage through Engineered Biological System (mg/L)	Seepage through Crushed Limestone (mg/L)
pH	No standard	3.23	6.31	6.59
Antimony	0.006	Not present	Not present	Not present
Arsenic	0.05	0.003	0.003	0.002
Barium	2	0.013	0.013	0.011
Beryllium	0.004	Not present	Not present	Not present
Cadmium	0.005	**0.307**	0.002	**0.305**
Chromium	0.1	0.034	0.009	0.034
Fluoride	4.0	**5.23**	2.64	1.96
Lead	0.05	Not present	Not present	Not present
Mercury	0.002	Not present	Not present	Not present
Nickel	0.1	Not present	Not present	Not present
Nitrate and Nitrite (as N)	10	Not present	Not present	Not present
Selenium	0.05	**0.099**	Not present*	**0.099**
Thallium	0.002	Not present	Not present	Not present

Notes: Boldfaced numbers indicate an exceedance of the aquifer water quality standard.

Not present = Constituent was either not detected for the analysis of the leached rock samples and therefore was not modeled or was below laboratory detection limits in the modeled seepage.

* Modeled seepage was reported but with an extremely low concentration (7.6×10^{-13} mg/L), effectively not present in the solution.

References:

AZDEQ (2012). https://www.azdeq.gov/environ/air/permits/rcc.html

Arizona Geological Survey (AZGS) http://www.azgs.az.gov/minerals_mining.shtml

Csavina, J., Field J., Mark P,T., Song G., Andrea L., A,B., Betterton E,A., and Eduardo A,S. (2012): A Review on the Importance of Metals and Metalloids in Atmospheric Dust and Aerosol from Mining Operations Sci Total Environ. 1; 433C: 58–73. doi:10.1016/j.

Earthworks (2012): U.S. Copper Porphyry Mines. The track record of water quality impacts resulting from pipeline spills, tailings failures and water collection and treatment failures. https://www.earthworksaction.org/files/publications/Porphyry_Copper_Mines_Track_Record_-_8-2012.pdf.

Engineering Analytics (2012): Davidson Canyon Groundwater monitoring plan. Project No. 110195. http://www.rosemonteis.us/files/technical-reports/engineering-analytics-davidson-canyon-groundwater-monitoring%20plan-20120330.pdf

US Forest Services (2013): Final Environmental Impact Statement for the Rosemont Copper Project (FEIS): A   Proposed Mining Operation Coronado National Forest Pima County, Arizona. Volume 1.

US Forest Services (2013): Final Environmental Impact Statement for the Rosemont Copper Project (FEIS): A   Proposed Mining Operation Coronado National Forest Pima County, Arizona. Volume 2.

Myers, T. 2010). Memorandum Updated Groundwater Modeling Report Proposed Rosemont Open Pit Mining Project. Prepared for: Pima County Flood Control District. Consultant, Hydrology and Water Resources. Reno, NV.

Powell, B., Orchard L., Fonseca J., and Postillion F. (2014): Impacts of the Rosemont Mine on hydrology and threatened and endangered species of the Cienega Creek Natural Preserve. Pima County, Arizona.

Revey, G.F. (1996): Technical papers: Practical methods to control explosives losses and reduce ammonia and nitrate levels in mine water. *Mining Engineering* 61–64.

Stovern, M., Betterton E,A.,Villar O,I,F., Russell M, R., King M. (2014): Modeling the emission, transport and deposition of contaminated dust from a mine tailing site. *Rev Environ Health*. 29(0): 91–94. doi:10.1515/reveh.

Tetra Tech, Inc. (2010a): Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts. Tetra Tech Project No. 114-320869. Prepared for Rosemont Copper. Tucson, Arizona. July

Tetra Tech. (2010c): Geochemical *Pit Lake Predictive Model* Revision 1. Tetra Tech Project No. 114-320884. Prepared for Rosemont Copper. Tucson, Arizona. November.

Tetra Tech. (2012a): Infiltration, Seepage, Fate and Transport Modeling Report, Revision 2, Rosemont Copper Project. Tetra Tech Project No. 114-320884. Prepared for Rosemont Copper Company. Tucson, AZ: Tetra Tech. June.

Tetra Tech and Montgomery & Associates Inc. (2007): Groundwater Protection Plan. Prepared for Augusta Resource Corporation. Project No. 320614. June 2007.