Pit Slope Stability Monitoring Plan

As Required By: Mitigation Measure FS-SR-04

October 2018

Prepared by:

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Monitoring and Reporting Schedule

Task Schedule	Purpose/ Description/Timing	Active Mining Phase/ Operations Phase				Closure Phase[1]			
		AN	C	D	Q	AN	C	D	Q
Determine locations, type, and installation of monitoring equipment	Detect potential movement of the high wall	X							
Inspection of working faces	Monitor safety of personnel			X					
Inspection of pit walls	Monitor general pit conditions			X					
Monitoring of pit geometry	Determine adherence to design constraints	X							
Monitoring of final high wall	Assess risk of high wall collapse		X						
Assess condition of final high wall	Determine need to continue monitoring					X			
Reporting	To Forest Service				X	X			

AN = As Needed; C = Continuous; D = Daily; Q = Quarterly; [1] = Monitoring past the Active Mining Phase to be determined.

Revision Log

Revision Number	Revision Lead	Purpose of Revision	Revision Date
1	Rosemont	Based on Forest Service review of June 2017 MPO submittal.	March 2018
2	Rosemont	Based on Forest Service review of June 2017 MPO submittal.	March 2018
3	Rosemont	Added Data Management Language per FS	October 2018

Table of Contents

Appendices

Appendix A	Memorandum titled Slope Monitoring Considerations for the Planned Rosemont Open-Pit Mine (Call & Nicholas, 2018)

Appendix B	Workplace Examination Form

1.0 PLAN OBJECTIVES AND DESCRIPTION

This *Pit Slope Stability Monitoring Plan* (Plan) was developed as a mitigation and monitoring measure (Mitigation Measure) requirement of the U.S. Forest Service's (USFS, Forest Service) Coronado National Forest (Coronado) Final Environmental Impact Statement (FEIS; USFS, 2013) for the Rosemont Copper Project (Project). This Mitigation Measure requirement is specified as "FS-SR-04: Slope stability monitoring" on pages B-15 and B-16 in Appendix B of the FEIS. Corrections to any of the mitigation measures listed in Appendix B are provided in an Errata to the FEIS (USFS, 2017a). The Record of Decision (ROD; USFS, 2017b) for the Rosemont Project also lists the required mitigation measures.

Mitigation Measure FS-SR-04 calls for monitoring to begin when pit construction advances to the final pit walls limits below the Santa Rita ridgeline. However, general pit slope stability monitoring will begin, as needed, at some point following the start of pit development and will consist of various methods depending on the development stage. Regardless, continuous monitoring methods would be employed once the pit advances to the final configuration along the west wall. The need for continued monitoring past the Operations Phase would be assessed in the Final Reclamation and Closure Phase (Closure Phase).

1.1 PLAN OBJECTIVES

The objectives of Mitigation Measure FS-SR-04 are to:

- Determine whether the mine pit wall geometry is within design constraints and that those constraints are regularly reviewed and updated, as needed, by the mining/geotechnical engineers in order to facilitate safe operations throughout the life of the pit; and

- Assess the risk of collapse of the high wall and alteration of the Santa Rita ridgeline.

1.2 PLAN DESCRIPTION

The remainder of this Plan includes the following sections:

- Section 2.0: Plan Details;

- Section 3.0: Monitoring and Reporting;

- Section 4.0: Closure and Bond Release;

- Section 5.0: Data Management; and

- Section 6.0: References.

Appendix A provides a generalized list of considerations associated with developing a pit slope monitoring program (Call & Nicholas, 2018). Also included is an example layout anticipated slope monitoring equipment applied to the Rosemont Open Pit. The program will be adjusted to match or anticipate the conditions encountered in the field, either from visual observations or from information gathered by means of boreholes, mapping, instrumentation, etc.

2.0 PLAN DETAILS

The details associated with this Plan are listed below.

2.1 MINE PLANNING

Open pit design not only takes ore grade into consideration but also the strength and competency of the materials making up the pit walls, including structural features that may create zones of weakness. Both intermediate and final pit wall slopes are determined in advance based on minimum factors of safety. These determinations are based on a comprehensive geotechnical approach that incorporates mapping of surface features, logging of drill holes/core, and material testing. As needed, adjustments are made as the pit progresses and new information becomes available. In terms of the final pit wall on the west side, mining of the high-wall in the final west pit face would not begin until about Year 8 of operations based on the current mine plan.

2.2 VISUAL INSPECTIONS

Regardless of the location and mining phase, daily visual inspections will be part of the overall site safety program. Visual inspections will include an overview of the pit walls with special emphasis on high walls associated with working faces. Inspections could include evidence of the following:

- Tension cracks;
- Rockfall, rock noise;
- Groundwater seeps;
- Toe heave; and
- Change in any previous observed expression in slope movement.

Based on the inspection results, additional monitoring and/or stabilization activities may be warranted such as:

- Flagging off area;
- Slope dewatering;
- Slope manipulation (cut down/remove rubble or highwall);
- Increased Inspections; and
- Development of a location-specific monitoring program.

Workplace inspections are performed at the beginning of each work shift. For pit operations, this would generally be a twice-daily inspection of the working faces by a shift foreman (supervisor) or other designated competent person. Additionally, a general overall inspection of the pit would be performed daily from a remote viewpoint or viewpoints. Both the working face inspections and the overall pit inspections would be increased in frequency should conditions warrant.

2.3 MONITORING POINT SETUP

Monitoring equipment and stationing will be selected to meet the conditions encountered in the field as the pit develops as well as to meet the intent of the monitoring. For example, the general monitoring of a slope could involve the regular spacing of monitoring stations while monitoring a specific fault zone would likely require a more targeted approach. For the final west wall, the approach would be geared toward establishing regularly spaced monitoring locations as dictated by access restrictions. Should zones of weakness be encountered, additional monitoring locations would be installed.

2.4 REMOTE MONITORING

A remote monitoring station would be installed on the east side of the pit following exposure of the final west wall. The remote station would be equipped with a data-logger and transmitter for automatic recording and data transmittal. Data tags could be setup to automatically inform mine personnel of recorded displacements/readings that are outside of an anticipated range. Determination of these allowable displacement ranges would be site-specific and determined based on on-going data gathering and analysis. As noted, Appendix A provides an example layout of monitoring equipment applied to the Rosemont Open Pit.

3.0 MONITORING AND REPORTING

The monitoring and reporting requirements for Mitigation Measure FS-SR-04 are listed below.

3.1 MONITORING

Monitoring for Mitigation Measure FS-SR-04 will consist of the following:

- Inspections;
- Summary of stations set up on final slopes of west wall; and
- Record of displacements.

As noted, inspection of the working faces by a shift foreman (supervisor) would occur at the beginning of each work shift. An example workplace inspection form is provided in Appendix B. Appendix A also contains an example of a more detailed bench face inspection form.

In most cases, it is anticipated that monitoring will continue through five (5) years into post-closure activities. Prior to the completion of the monitoring period, Rosemont will consult with the Forest Service to discuss if there is a need for extended monitoring prior to the end of the five-year post-closure monitoring period.

3.2 REPORTING

Reporting on Mitigation Measure FS-SR-04 to the Forest Service will include the following once the final west pit wall is exposed and will consist of the following:

- Type and location of monitoring stations installed on the west wall;
- Tabulation or graphical representation of monitoring data;
- Summaries of data; and
- General summary monitoring results/concerns/actions taken.

Data generated will depend upon the technology chosen at the time of monitoring and may involve pore pressure information, prism information, strain and displacement detector data, or survey or LIDAR data comparisons. Because monitoring technologies related to geotechnical stability are being updated fairly rapidly, Rosemont will re-evaluate the appropriate technology to be deployed in the field. As noted, decisions regarding technology will be site-specific and will be made based on on-going data gathering and analysis. The technology will also determine what data will be available for reporting. Rosemont will keep the Forest Service apprised of any changes to planned slope monitoring activities, especially as it relates to monitoring associated with the final pit wall and protection of the ridgeline.

4.0 CLOSURE AND BOND RELEASE

This section addresses closure activities associated with this Plan as well as the approach for funding of those activities and bond release of those funds. If bonding is set for one year or less (i.e., simply completing testwork or finalizing reporting) no bond release is proposed. For longer periods, the bonding terms and application for bond release, as well as the mechanism for that release, are included.

4.1 INTERIM CLOSURE

Continued monitoring and reporting costs have been estimated and are included in the interim closure bonding costs provided in the *Reclamation and Closure Plan* (MPO Volume III-a).

4.2 FINAL CLOSURE

Final closure costs associated with pit stability include an evaluation of monitoring and tolerance regarding pit configurations and are provided in the *Reclamation and Closure Plan* (MPO Volume III-a). No work is planned for closure on the mine pit as the construction is designed to be safe and stable; however, as discussed in Section 3.1, at post-closure the need for additional bonding will be reviewed.

4.3 BOND RELEASE

Because the activities associated with this measure are operational requirements, there is no bonding associated with this measure. This may change at post-closure when a re-evaluation is completed.

5.0 DATA MANAGEMENT

Rosemont currently maintains data in various formats including logbooks, electronic logbooks, spreadsheets, hardcopy and database formats. Rosemont will collaborate with the Forest Service to ensure that the reporting format used will satisfy reporting requirements and that Forest Service concurs with the format prior to the first reporting deadline. It is Rosemont's intent that, ultimately, a robust database will be used to house all data collected for the various monitoring programs. Numeric data ultimately will be stored in a database and spatial data will be maintained in an ESRI database.

Depending upon the type of data to be reported, Rosemont will develop custom reports displaying required information in table or figure format. Rosemont will collaborate with the Forest Service to ensure that the reporting format used will satisfy reporting requirements and that the Forest Service concurs with the format prior to the first reporting deadline. Electronic submittals will be provided in pdf format to provide a permanent record of the submittal and "raw" data will be maintained on-site for review by the Forest Service. If the Forest Service requests numeric data, it may include information such as cumulative results documenting the monitoring history and include baseline data for the resource.

Electronic submittals will be made on the reporting period specified. Reports will be submitted in hardcopy form with a duplicate electronic pdf file. Delivery of the electronic files will depend upon the size of the file and will either be made via email, via a CD/DVD or thumb drive, or via a website set up and maintained for delivery of files to the Forest Service. Details regarding access will need to be worked out so transmittals can take place seamlessly.

6.0 REFERENCES

USFS, 2013. *Final Environmental Impact Statement for Rosemont Copper Project, Appendix B Mitigation and Monitoring Plan*. December 2013.

2017a. *Errata – Rosemont Copper Project Final Environmental Impact Statement*. April 26, 2017.

2017b. *Record of Decision – Rosemont Copper Project and Amendment of the Coronado Land and Resource Management Plan*. June 2017.

APPENDIX A

Slope Monitoring Considerations for the Planned Rosemont Open-Pit Mine

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MEMORANDUM

To: Mr. Fermin Samorano, Mine Manager / Rosemont Copper Company
Mr. David Krizek, Environmental Manager / Rosemont Copper Company

From: Mr. Robert Pratt, P.E.

Date: 21 March 2018

Subject: Slope Monitoring Considerations for the Planned Rosemont Open-Pit Mine

1.0 INTRODUCTION

This memorandum presents a discussion of open pit slope monitoring considerations for the proposed Rosemont open pit mine. This memorandum includes:

1. A discussion of slope monitoring philosophy and techniques
2. A discussion of slope monitoring technologies, including the applicability of various technologies to Rosemont
3. A geotechnical mapping data form to be used for mapping of bench faces and anticipation of potential slope instability
4. Examples of the type and number of technologies used at various active open pit mines
5. An example of slope monitoring equipment anticipated for Rosemont, based upon equipment used at other large open pit mines and areas of slope stability concern from previous geotechnical drilling and slope stability analysis work

The primary purpose of slope monitoring is to maintain safe working conditions by providing warning of slope failures. The sudden displacement of large volumes of material can pose an imminent safety risk to equipment operators, blasting crew, surveyors, and other personnel working in the open pit. Minimization of the adverse effects of slope instability can be accomplished through monitoring, judicious mine planning, and establishment of operational contingencies.

A slope displacement does not occur without warning. Prior to major movement, there is measurable deformation and other observable phenomena, such as the development of tension cracks, rock noise, and changes in groundwater-related pore pressure. These phenomena occur from hours to years before a major displacement. In general, smaller slides (bench-scale) develop much more rapidly than larger slides. For this reason, small sloughs of material can be the largest slope-related hazard to mine workers. While a slope failure does not occur without warning, deformation and tension cracks can occur without major displacement.

1.1 Miner Safety

To provide notification of slope movements, displacing slopes must first be identified using a combination of visual inspections and slope monitoring equipment. With the use of monitoring data, the magnitude and character of slope movements are analyzed. In the event that slope acceleration creates an imminent threat, miners must be notified with sufficient time to evacuate the area. A berm should be placed to prevent access to the hazardous area and mine plans should be modified accordingly. To provide timely warning to ensure safety, real-time monitoring data is required, whereby instrumentation sends immediate notification of slope movements. Section 2 of this memorandum presents a discussion of instrumentation capable of providing real-time monitoring data.

1.2 Slope Engineering

A secondary goal of slope monitoring is to acquire displacement data for use in geotechnical analysis and slope engineering. These data include the history of slope displacements indicating cycles of acceleration and deceleration, and point-movement trajectories for calculation of displacement vectors. This information is used for understanding the response of slope movements to mining, for analyzing slope displacement mechanisms, for designing appropriate remedial measures, and for conducting future redesigns of the slope to ensure safe working conditions within the open pit.

2.0 SLOPE MONITORING

A slope monitoring program may consist of the following components (whole or in part):

1. Regular visual inspections of pit slopes
2. Monitoring of surface slope movements using a variety of equipment
3. Subsurface monitoring equipment installed in drill holes

4. A response protocol that is dependent upon the rate of slope displacement and the risk to miners
5. Rainfall and groundwater monitoring to provide notification of potential causes of slope displacement

2.1 Slope Inspections

Daily visual slope inspections of the crest and toe areas will be performed by supervisors to identify unstable slopes and potentially hazardous areas. Visual inspections of all working slopes will also be conducted regularly by engineers and geologists who are responsible for monitoring, analyzing data, and reporting to management. Bench slopes should be kept clean and free of rubble. Crest and toe lines should also be clean and be constructed per design. Any obstructions restricting visual assessments of the slope should be avoided. Slope inspections should include notes on the following:

1. Tension cracks
2. Rockfall, rock noise
3. Groundwater seeps
4. Toe heave
5. Changes in any previously observed expression of slope movement
6. Bench-face scaling
7. Adherence to the slope design

Because of the large size of the planned Rosemont mine, it is not realistic for a limited staff of engineers and geologists to be cognizant of all indicators of slope movement as mining progresses. It is therefore the responsibility of all operations personnel working in the open pit to take responsibility in identifying and reporting slope hazards. Pre-shift slope inspections are an industry standard practice and should be conducted by shift-managers and equipment operators who should also take note of changing slope conditions during the course of a shift. All mine personnel should be trained in the identification of slope hazards and should be capable of reading charts of slope monitoring data. Large-screen monitors showing slope-monitoring data should be placed in a centralized location so that mine workers can review the data as needed.

2.1.1 Slope Inspection Form

An example slope inspection form is presented in Figure 1. The intent of an inspection form is to document and ensure completion of the inspection process. If a slope hazard is identified as part of an inspection, reporting of the hazard and the proper response to the hazard are needed to ensure that the correct precautions are taken. The response protocol is discussed in Section 2.5.

2.2 Monitoring Devices

A variety of slope monitoring devices are commercially available, covering a wide range of costs and technology. To detect slope movements in time to provide adequate warning, slope monitoring devices must be placed as needed through proper analysis prior to the formation of tension cracks and other signs of displacement.

In addition, a list of commercially available monitoring systems is presented in Table 1. It is a partial list and is only intended to provide some indication of available products. Table 1 is not meant to be an endorsement for any specific company or product. A discussion of various monitoring systems, both surface and subsurface, is presented in the following subsections.

2.2.1 *Surface Monitoring Devices*

2.2.1.1 Automated Prism Monitoring

Monitoring prism targets with an Automated Motorized Total Station (AMTS) provides a detailed movement history of displacement directions and rates in unstable areas. AMTS devices are optical and laser-based survey devices that can be programmed to automatically target and measure prisms within line-of-sight of the instrument. AMTS units operate on the same principle as a surveyor-operated instrument. The benefit from the AMTS device is that measurements have better precision and are generally more accurate than manual surveying, and can operate continually, providing essentially real-time data.

Global Navigation Satellite Systems (GNSS) can be combined with AMTS systems to improve the accuracy in the event that reference points or the total station points are moving. Software is utilized to calculate the displacement velocity and issue alerts when movement thresholds are exceeded. For line-of-sight coverage for the entire open pit, multiple AMTS units are typically required. These AMTS units are typically placed in powered enclosures to protect the units from the weather. It is important that annealed glass is used in these enclosures, as other types of glass can distort the survey laser, resulting in erroneous readings.

Prism monitoring data provide point information rather than full-face monitoring data, and because of this limitation can miss smaller areas of instability if prisms are not placed on the moving slope. However, prism monitoring provides a full three-dimensional displacement vector, which is essential for slope engineering and remediation of the hazards associated with slope instability. In comparison, full-face monitoring technologies are not capable of providing displacement vectors.

It is important that prisms are placed on benches as mining progresses to ensure safe access. The spacing of prisms is ideally no greater than twice the bench height. When an area of instability has been identified, additional prisms are placed to improve the monitoring coverage and to identify the limits of the moving slope.

2.2.1.2 Slope Stability Radar

Slope radars are used to provide full-face monitoring and have the ability to detect sub-millimeter-level slope movements. These devices are commonly used for monitoring in large open pits and are the best means of providing real-time, full-face slope displacement data. Portable radar units can be maneuvered to a viewpoint to scan slopes above active mining areas and can collect data in rainy, foggy, or dusty conditions. The primary advantages of radar units are the ability to detect both large and small slope movements in real-time, and the ability to provide a detailed outline of the extent of the displacing slope. Small slides can present a high risk to miners, since early signs of displacement may not be evident and the amount of displacement prior to collapse is relatively small. The primary disadvantage is the high cost of slope stability radars.

Radars subdivide scan areas into pixels. Pixel size is dependent upon the range or distance from the radar to the slope. The parameters below are measured by slope stability radars and can be used to set warning alarm thresholds. The warning threshold is specified for each parameter over a specified area of typically multiple pixels:

1. Deformation or total displacement
2. Velocity specified over a certain time period
3. Inverse velocity, which is used to estimate time to collapse

4. Velocity ratio or the quotient of consecutive velocity readings, which is comparable to acceleration
5. Coherence which is a measure of the radar signal strength in terms of the change in amplitude and range. As a slope displaces, coherence decreases.

Comparison of radar monitoring data with photographs and geologic maps of pit slopes is a useful means of understanding the geologic controls on slope stability and providing data for assessing risks.

2.2.1.3 Wireline Extensometers

Portable telemetry wireline extensometers can be used to provide real-time monitoring in areas of active instability. These monitoring devices can be quickly positioned and easily moved and are best utilized in situations where active slope failures have been identified. The extensometer is positioned on stable ground behind the last visible tension crack, and a stake attached to a cable leading from the instrument is placed in the unstable area. As the slope displaces, the rate at which the cable is drawn indicates the rate and magnitude of slope movement. Telemetry extensometers can transmit data to a central office where the data is analyzed with specialized software. Some systems offer the ability to transmit alerts through computer networks and email. A disadvantage of extensometers is that data is provided for essentially one point.

2.2.1.4 Global Positioning Systems

Manufacturers of satellite-based global positioning systems (GPS) offer instruments that monitor a specific point on a slope. These solar-powered units are usually grouted in place and contain a GPS receiver and a radio to transmit coordinate data to a central office. These systems offer highly accurate displacement data. A disadvantage is that GPS units are typically lost if localized movement occurs.

2.2.1.5 LiDAR

Light Detection and Ranging (LiDAR) is a laser surveying technology that has been applied to slope monitoring. Commercially available mobile LiDAR units have the ability to provide full-face surveying data similar to slope stability radar output. LiDAR data has the advantage over radar of providing surveyed point clouds, which allows for volumetric calculations and other advantages. However, LiDAR can be influenced by atmospherics (fog, rain, dust), which can result in data scatter and limits the effective range.

2.2.1.6 Additional Surface Monitoring Technologies

Additional surface slope-monitoring devices and technologies include tiltmeters, microseismic arrays, and satellite interferometry (InSAR). These methods of slope monitoring are best utilized in specialty applications and are not typically relied on as a primary method of collecting slope displacement data in open-pit mining.

2.2.2 Subsurface Monitoring Devices

2.2.2.1 Inclinometers

An inclinometer system is utilized to measure subsurface deformation. These systems are useful for identifying the geologic causes of slope displacement in addition to identifying whether movement is constant or accelerating. Inclinometers consist of grouted-in-place grooved casing installed in a drill hole. A probe, which measures casing deflection, is lowered down the hole and retrieved. The relative change between readings indicates the magnitude and location of slope movement. This allows for identification of the base of an unstable mass. Comparison of this information with geologic cross sections can be used to identify contacts, faults, or other geologic features which may be the cause of instability.

In-place inclinometer (IPI) systems are utilized when real-time data are required for safety reasons. The in-place system consists of one or more sensors connected to a data logger. Real-time transmission of the data can be set up to provide immediate notification of slope movements. IPI sensors are positioned to span the zones or geologic features where deformation is expected to occur.

2.2.2.2 Time-Domain Reflectometry

Time Domain Reflectometry (TDR) is a technology useful for monitoring subsurface displacement. The TDR system consists of a coaxial cable installed in a vertical drill hole that passes through a region of concern with respect to slope stability, typically a known plane of weakness such as a geologic contact or a fault. The coaxial cable is grouted in place so that subsurface deformations are transmitted directly to the cable. An electronic pulse is transmitted down the cable; reflection of the signal from areas damaged due to slope movement, as indicated by an oscilloscope, indicates the location and relative change in slope movement. TDR systems are relatively inexpensive and can be set up to transmit data for real-time monitoring.

2.3 Redundancy in Monitoring Is Recommended

No single device or technique can completely characterize the displacement of a slope. All monitoring devices have limitations. A single extensometer or survey point cannot indicate the area involved in an instability, and if it is damaged or destroyed, the continuity of the record is lost. Limitations in the capabilities of monitoring equipment are best overcome by utilizing data from multiple devices.

Redundant monitoring equipment are also needed to ensure that mechanical failure of a particular device, or the failure of a functioning device to detect slope movement, does not result in a slope failure taking place without warning. The geotechnical team will recommend which systems are complementary to the types of displacement being monitored.

2.4 Response Protocol

Operational pressures and lack of awareness of slope hazards can lead to a poorly coordinated and ineffective response to slope movements. It is therefore prudent to require input from all parties in developing a Trigger Action Response Plan (TARP) that establishes operational responses to slope movement. Inclusion of the following is recommended:

1. Establish protocol for reporting signs of slope movement observed by any miner.
2. Establish criteria for issuing alarms (displacement criteria, radar coherence, rainfall criteria, and radar functioning). Slope acceleration, regardless of displacement magnitude, should be an evacuation criterion.
3. Develop a responsibility matrix for reporting and execution of the plan presented by the geotechnical team or responsible/qualified person.
4. Establish response protocols (areas requiring evacuation, safe evacuation areas, criteria for re-entry) regarding alerts issued by geotechnical engineers or other qualified personnel. Response protocols should vary based on area and alarm level.
5. Provide a slope hazard map to all mine departments that includes evacuation areas. This will improve awareness.
6. Provide slope hazard training for all mine staff that work in the pit.
7. Implement restrictions regarding re-entry of a hazard area after an evacuation has been issued.

Install large-screen monitors in a central location to allow miners, including supervisors, foremen, and engineering staff, to view slope monitoring data.

2.5 Rainfall Monitoring

Rainfall can lead to slope instability. It is therefore important to monitor rainfall and correlate this information with slope monitoring data. Mine sites will typically have multiple weather stations, which record rainfall in addition to other data.

2.6 Groundwater Monitoring

Pore pressure due to high groundwater levels can also lead to slope instability. It is therefore important to measure pore pressure to understand the potential impact on slope stability and to track depressurization efforts. Groundwater monitoring is typically done using standpipe and vibrating-wire piezometer sites.

Standpipe piezometers (monitoring wells) consist of gravel-packed slotted PVC casing installed in a drill hole. Standpipe piezometers are typically used to record direct measurements of the phreatic surface and to obtain samples for water quality testing. A water level meter is lowered into the hole to record the static phreatic surface. Transducers can also be installed to provide real-time continuous readings. Vibrating-wire piezometers are grouted, in-place transducers, which are installed in drill holes. These devices provide a direct measurement of pore pressure (rather than water level) at specific locations.

3.0 ROSEMONT SLOPE MONITORING PLAN

This section presents an estimate of the slope monitoring equipment needs based on the planned size of the Rosemont final pit, an understanding of potential areas of instability from previous geotechnical drilling and slope stability analysis work, and a review of slope monitoring equipment needs at other active large open pit mines.

3.1 Slope Design and Mine Planning

The first step in slope engineering is the identification of areas where adverse geology can lead to slope instability. This includes areas where faults, bedding, and/or joints are daylighted or areas where weak rock and high pore pressure occurs. Data for this identification is taken from drilling, geologic pit mapping, laboratory testing of rock properties, and the past history of instability. These data are utilized to perform engineering analyses of the stresses imposed by a pit slope in comparison with the strength of the rock. The planned pit slope configuration is modified and reanalyzed until an acceptable factor of safety is met. An acceptable slope configuration, as determined by geotechnical engineers performing these analyses, is conveyed to mining engineers who use this information to design and plan mining of the final pit.

Prior to the startup of mining, geologic data for design of a pit slope are collected from field mapping and core drilling. Data can be verified or improved during the excavation of the pit, and as the pit is deepened, invaluable operational experience is gained. Mining of phases internal to the final pit allows for an opportunity to collect data prior to mining of the final slopes. Thus, the slope-design process is iterative, with ongoing re-evaluation throughout the mine life, in conjunction with the acquisition of new data and experience, resulting in increased confidence in the assessment of slope stability.

3.2 Slope Stability Issues for Rosemont

As part of the planning of the Rosemont open-pit mine, geotechnical investigations have been undertaken to address potential slope stability issues prior to mining. As part of these studies, the following areas of concern have been identified and have been accounted for in the mine plan:

1. High pore pressure, shallow-dipping bedding and the Low-Angle fault, the Backbone fault, the Weigles-Butte fault, and other faults in the west and northwest walls
2. Low-strength alluvium in the south wall
3. Low-strength Willow-Canyon arkose in the east wall
4. The Paleozoic/ Pre-Cambrian unconformity in the northwest wall

These walls have been designed taking into account these identified concerns. More recent drilling and mapping data collected in 2014-15 targeted these areas to improve Rosemont’s understanding of potential areas of concern. This information/ data reinforced Rosemont’s plan to monitor these areas as the pit develops.

3.2.1 Ridge Restriction

Of particular concern is the requirement of avoiding excessive movement of the ridgeline of the Santa Rita Mountains immediately west of the mine. Slope monitoring will be conducted and geotechnical and geologic data will be gathered from pit phases leading up to final mining of the west wall, which is scheduled to begin in year 7 of the current mine plan. This information will be utilized to re-evaluate the slope design and incorporate any design modifications needed prior to the start of final west wall mining. Throughout the final west wall mining, the ridgeline and the west wall pit slope below the ridge will be monitored. Further modifications to the slope design may be incorporated during final wall mining to mitigate any signs of instability indicated by the slope monitoring equipment.

3.3 Example Monitoring System

In the early stages of mining, excavated slopes will be short and the potential for instability will be low. Therefore, instrumented slope monitoring may not be needed until pit slopes reach a substantial height (approximately 300 to 500 feet). It is important that a well-functioning array of slope monitoring equipment and a well-trained staff are in place once the pit reaches a size where slope instability has the potential to impact miner safety and mine production.

A typical large open-pit mine, such as the planned Rosemont open pit, would incorporate several of the monitoring devices listed in Section 2. Radar units would be utilized as the best means of alerting miners in the event of a sudden slide of material. The radar monitoring would be complemented by an array of prisms surveyed by AMTS stations. Multiple AMTS units will be needed to access various parts of the pit. Prisms would be placed at a regular spacing in a grid pattern equal to approximately twice the bench height (both horizontal and vertical spacing) as mining progresses. This is done because mine benches can become inaccessible, precluding placement of prisms later on in the mine life when they may be needed. In addition to providing near real-time monitoring, prism data would provide three-dimensional movement trajectories useful for analysis and design of mitigation measures, which are not provided by radar data.

Additional monitoring equipment would be installed on actively displacing slopes that are potentially hazardous, and in areas of heavy traffic (haul roads, above the pit bottom, etc.). Additional equipment, could include wireline extensometers, GPS units, and more prisms.

In-place inclinometers and TDR cables would be installed in drill holes early in the mine life in the northwest, west, and southeast walls, where faults and other geologic contacts have been identified as potential areas of slope instability.

Monitoring of groundwater pore pressure would be done with vibrating-wire piezometer and monitoring well sites located around and internal to the pit. Data from the piezometer sites would be used to monitor the progress of slope depressurization and to identify areas where groundwater could contribute to slope instability.

A communications system would be needed to transmit data from monitoring sites to the central office so that the data could be viewed in real time. Commercially available software would be used to simultaneously plot and analyze data from multiple types of sensors.

Technicians and engineers would be needed to install monitoring equipment, service and troubleshoot technical issues with deployed sensors, interpret monitoring data, and advise mine operations of slope hazards. Any installed system will be recommended by the geotechnical team or qualified persons based on the data collected and required application.

3.4 Slope Monitoring Equipment Needs

Table 2 presents a summary of slope monitoring equipment utilized at other large open pit mine sites. Based on this information and the anticipated slope stability concerns, an estimate of the slope monitoring equipment needs for Rosemont is also presented in Table 2. An example layout of this equipment is shown in Figure 2 on the year 7 pit layout of the current mine plan. This layout shows the approximate number and location of equipment.

This is an estimation of the slope monitoring needs once the pit reaches a substantial size. This estimate can be used for preliminary budgeting and planning purposes. As the pit increases in size, actual equipment needs will become evident and decisions regarding the appropriate type and location of equipment will be made by on-site geotechnical engineers or other qualified personnel. In addition, slope monitoring technologies improve rapidly and it is likely that new technologies will be commercially available once slope monitoring is needed at Rosemont. Throughout the course of the mine life, and through multiple phases of mining, much of the equipment will need to be replaced, potentially multiple times, as technologies become dated or new recommendations are made. It is expected that there will be a need for an annual evaluation of the monitoring equipment.

4.0 SLIDE MANAGEMENT

A large slope failure can negatively impact a mine operation. If an unstable slope can be identified in the early stages of instability, implementation of appropriately timed and well-planned engineering solutions can stabilize the slope. This section presents a discussion of slide management practices.

4.1 Mitigation/Mine Planning Considerations

When mine slope instability occurs, several responses are possible:

1. Leave the unstable area alone
2. Continue mining without changing the mine plan
3. Unload the displaced area through additional stripping
4. Leave a step-out
5. Do a partial cleanup
6. Mine out the instability
7. Support the unstable ground with cable bolts (this usually cannot be done successfully after significant slope movements have started).
8. Dewater the unstable area if groundwater has been established as contributing to slope instability

The appropriate response or combination of responses depends on the nature of the instability and its impact. Each case should be evaluated individually, and the following guidelines should be observed:

1. When the instability is in an abandoned or inactive area, it can be left alone.
2. If the area must be mined and the displacement rate is low and predictable, monitoring the displacement while continuing to mine may be the best action. Establishing the slope response to mining in this situation is critical.
3. Prior to implementing remedial measures to stop slope movements such as toe buttressing, unloading, or dewatering, geotechnical analysis must be done to confirm that these measures will be effective in improving stability. Otherwise, it is possible that these efforts could result in a negligible improvement or even trigger additional slope movement, wasting the expenditure and allocation of resources.
4. Incorporating a wide catch bench, also known as a stepout, adds a buttress of material to an unstable slope. Stepouts have been used successfully in several mines to mitigate slope displacement.
5. When the instability occurs on a specific structure and there is competent rock behind the structure, mining out the slope displacement may be the optimum choice.
6. Mechanical support (cable bolts) may be an option in limited cases. This is only effective in specific situations where geologic structure (faults, bedding,

or joints) can be bolted and the bolts are able to retain the stresses imposed by the weight of the moving slide mass.

7. In areas where high water pressure exists, dewatering is an effective method of stabilization that may be used in conjunction with other options.

4.2 Contingency Planning

To avoid a poor "after-the-fact" crisis response to forced deviation from an established mine plan, contingencies should be incorporated to allow flexibility in mine planning to respond to slope instability. These contingencies should be incorporated into normal mine planning schedules. The key components of a contingency plan with regard to maintaining production goals include:

1. Adequate ore exposed and accessible in multiple locations so that production can continue despite interruptions due to slope instability.
2. Dual ramp access to the pit bottom in the event that a slide blocks a ramp.
3. Provisions for slide cleanup in production scheduling and budgeting, including equipment allocation, deferred resource recovery, and other costs associated with slope instability.

If an unstable slope can be identified well in advance of the anticipated date of failure, it is possible to develop plans for remediation and cleanup with sufficient time to implement plans soon after the slide has taken place, minimizing the disruption to mine production. With the use of monitoring data and geotechnical analysis, a prediction can be made regarding the tonnage of material encompassing the slide mass and the expected runout distance. Based on this prediction, plans can be made to clean up the failure debris and resume mining. However, smaller slides often occur in the aftermath of a larger slide, emphasizing the importance of continue slope monitoring during cleanup of the slide.

Table 1. Commercially Available Slope Monitoring Technologies

Instrument	Manufacturer	Website
Automated Motorized Total Station (AMTS) for Prism Monitoring	Leica Geosystems AG	www.leica-geosystems.com
	Geodimeter® / Trimble Navigation Ltd.	www.trimble.com
Automatic Slope Extensometer	Call & Nicholas Instruments, Inc.	www.slideminder.com
	Modular Mining Systems, Inc.	www.mmsi.com
GPS	Leica Geosystems AG	www.leica-geosystems.com
	Pinnacle Technologies, Inc.	www.3dtracker.com
	Orion Monitoring Systems, Inc.	www.orionmonitoring.com
Slope Stability Radar	Groundprobe Pty Ltd	www.groundprobe.com
	IBIS Radar Systems by IDS Corporation	https://www.idscorporation.com/safety-protection-systems/
	Reutech Radar Systems (Pty) Ltd.	http://www.reutechradar.com/products/mining
Slope Stability LiDAR	Maptek Sentry	https://www.maptek.com/products/sentry/
Interferometric Synthetic Aperture Radar (InSAR)	3VGEOMATICS	www.3vgeomatics.com
TDR	RST Instruments Ltd.	www.rstinstruments.com
	Call & Nicholas Instruments, Inc.	www.cnitucson.com
Inclinometer	RST Instruments Ltd.	www.rstinstruments.com
	Slope Indicator Co.	www.slopeindicator.com
Borehole Extensometer	RST Instruments Ltd.	www.rstinstruments.com
	Slope Indicator Co.	www.slopeindicator.com
Vibrating-Wire Piezometers	RST Instruments Ltd.	www.rstinstruments.com
	Geokon, Inc.	www.geokon.com
	Slope Indicator Co.	www.slopeindicator.com

NOTE: This is a not a complete list of all commercially available systems and services. The appearance of a particular product or company in this table does not represent an endorsement.

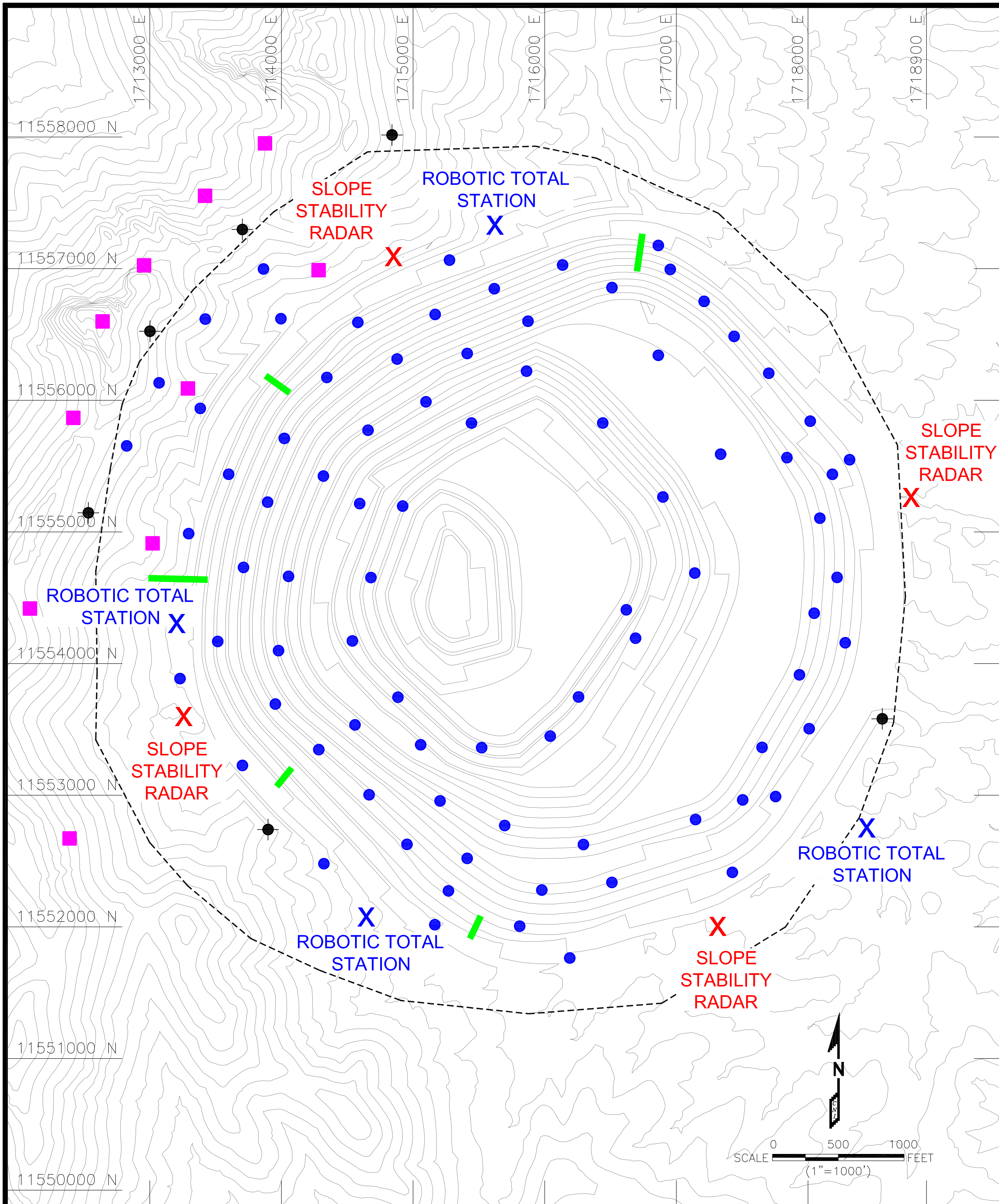
Table 2. Slope Monitoring Equipment for Example Large Open Pit Mines
Rosemont Copper Project

		Rosemont (estimated needs)	Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7
Approximate Open Pit Dimensions	Length (ft.)	---	5600	---	2200	---	---	11000	9000
	Diameter (ft.)	6200	---	10200	---	3900	8500	---	---
	Height (ft.)	3000	900	3600	800	1400	2200	1700	800
Slope Monitoring Equipment	# of Automated Total Stations	4	2	5	2	3	3	4	4
	# of Survey Prisms	500	75	600	150	300	1000	749	1000
	# of Slope Stability Radars	3	--	8	3	1	3	4	1
	# of Slope Stability LiDAR Units	---	1	---	---	---	---	---	---
	# of GPS Monitoring Sites	10	--	30	---	---	3	6	---
	# of Wireline Extensometers	5	10	18	---	2	5	7	3
	TDR Holes	5	---	---	5	7	?	?	20
	InSAR	---	---	---	Dual Pass	---	Dual Pass	Dual Pass	Dual Pass
	Vibrating Wire Piezometers	10	3 (3/ hole)	?	5 (3/ hole)	7 (19 VWPs)	18 (3/ hole)	?	20 (2/ hole)

BENCH FACE INSPECTION FORM

Date	
Name	
SURVEY	
General location	
Northing	
Easting	
Elevation	
BENCH GEOMETRY	
Bench height	
Bench face angle	
Strike of bench face	
GEOLOGY	
Lithology	
Alteration	
Average rock hardness	
GEOLOGIC STRUCTURE	
Strike and dip of primary joint set	
Average joint length	
Average joint spacing	
Coating of joints	
Number of joint sets	
Indications of groundwater	
INDICATORS OF SLOPE MOVEMENT	
Monitoring data comments	
Tension cracks	
Dilated fractures observed in bench face	
Rockfall, rock noise	
Other signs of movement	
Changes from previous inspection	
MINING	
Crest dug to drop flags	
Need for scaling	
Recommended means of scaling	
Method of blasting	
Half barrels observable on bench face	

Figure 1. Example Bench Face Inspection Form
Rosemont Copper Project



LEGEND

- PRISM LOCATIONS
- GPS STATIONS
- WIRELINE EXTENSOMETERS
- TDR
- FINAL PIT PERIMETER

CALL & NICHOLAS, INC.

TUCSON, ARIZONA USA

DRAWN	DATE	REVISED
LMC	03/18	3/20/2018 12:42 PM

\2018\SLOPE_MONITORING\MEMO\REV5\FIG2_YEAR_7_PIT.DWG

EXAMPLE SLOPE MONITORING LAYOUT YEAR 7 PIT

ROSEMONT COPPER PROJECT

SCALE		
	1"=1000'	FIGURE 2

APPENDIX B

Workplace Examination Form

HUDBAY

Notes:

WORKPLACE EXAMINATION

DATE (mm/dd/yy): ____________________ TIME (24-HR): ____________________

LOCATION(s) EXAMINED: ____________________

EXAMINER (print): ____________________

No.	ADVERSE CONDITION(S)	CORRECTIVE ACTION(S)

Was an IMMINENT DANGER CONDITION observed / reported? Y ☐ N ☐

If so, explain:

Reported to:

EXAMINER (signature): ____________________ DATE/TIME: ____________________

SUPERVISOR (print): ____________________ DATE/TIME: ____________________

SUPERVISOR (sign): ____________________ DATE/TIME: ____________________

White Copy to Main Office Retain Yellow Copy