TECHNICAL MEMORANDUM

DATE January 14, 2015 **REFERENCE No.** 1410944-004-TM-Rev0-7000

TO Karen Furlong
Faro Mine Remediation Project Assessment and Abandoned Mines

FROM Ryan Preston and Al Chance **EMAIL** rpreston@golder.com; achance@golder.com

STUDY OF ALTERNATIVE SLOPE MONITORING METHODS FOR FARO AND GRUM PITS

Dear Karen,

Golder is pleased to provide this technical memorandum that provides a review of potential open pit slope stability monitoring systems that could be implemented at the Faro Mine Complex in the Yukon Territory.

1.0 BACKGROUND

The Faro Mine Complex is located approximately 350 kilometres northeast of Whitehorse, Yukon, and consists of the inactive Faro, Grum, and Vangorda Pits. The mine closed in 1998 and is currently undergoing closure remediation under the oversight of the Yukon Government.

The east walls of the Faro and Grum Pits experienced instability while the Faro Mine Complex was in operation. Currently, monitoring of crest regression and overall slope stability is being carried out in these instability zones. Crest regression is measured monthly by site personnel in the Grum Pit, and twice annually in the Faro Pit. Slope stability monuments in the Faro and Grum Pits are surveyed annually by Yukon Engineering Services (YES). The crest regression and slope stability monitoring data are reviewed annually by a geotechnical engineering consultant.

The crest regression measurements require site personnel to access the area behind the backscarps of the instability zones on the east walls of the Faro and Grum Pits. To carry out the crest regression measurements in certain areas of the Faro Pit, personnel must stand close to the edge of the very steep backscarp. In the Grum Pit, the instability zone has exhibited on-going deformation in the backscarp, and cracks, ravelling, and sloughing have been observed at the crest. For these reasons, site personnel have expressed concerns regarding the safety of accessing the instability zones to collect monitoring data. To address these concerns, the Government of Yukon has requested Golder Associates Ltd. (Golder) to carry out a study to investigate alternative pit slope and crest regression monitoring methods that would satisfy the monitoring requirements and minimize or eliminate the hazards related to accessing the instability zones. The scope of work and our approach to carrying out the study are outlined in the following section.

2.0 SCOPE OF STUDY

A desktop study has been carried out to evaluate the short and long-term slope monitoring requirements for each pit, and to identify potential crest regression and overall slope stability monitoring methods that would incorporate the following elements:

- satisfy the short and long-term monitoring requirements;
- provide sufficiently accurate and consistent results for data analysis;
- be acquired at reasonable capital and operating cost;
- be simple to install and implement;
- be easily used in both the Faro and Grum Pits;
- be easy for site personnel to operate; and
- would minimize or eliminate the requirement for site staff to access the instability zones.

The study has been carried out with the assumption that site personnel will operate the system and assess the data independently, while relying on periodic assistance and review from a geotechnical engineer. Based on this assumption, the systems were further classified based on complexity of operation, using the following criteria:

- the number of steps involved in data collection and processing;
- the software skills required;
- the data post-processing requirements;
- the level of technical background required to understand and operate the systems and processing software; and
- the initial and on-going training requirements, given the potential for a high turnover rate of site staff.

The short and long-term monitoring requirements for each pit are discussed in the following section.

3.0 PIT SLOPE MONITORING REQUIREMENTS

3.1 Faro Pit

The primary concern in the Faro Pit east wall is failure of the steep back scarp at the crest of the east wall failure zone, which could undermine the access road and the Faro Creek Diversion Channel (FCDC) (Golder 2014). The FCDC collects surface water runoff from the Faro Creek catchment, and diverts it above and around the east side of the pit. Water in the pit requires treatment before it can be released to the environment, and diverting surface water away from the pit reduces the water treatment costs. Failure of the back scarp and the FCDC would direct the collected surface water runoff directly into the pit over the east wall. A number of remedial options have been proposed for the FCDC in order to address the probable eventual loss of the existing diversion channel.

The original intent of the Faro monitoring system was to provide sufficient advance warning of crest regression or overall slope instability such that one of the remedial options could be implemented in sufficient time to prevent the loss of or to replace the existing diversion system. At the time that the monitoring system was implemented, it was our understanding that the most viable remedial option was to excavate a tunnel through the hill behind the east wall, and direct the Faro Creek runoff flows through the tunnel. It is likely that such a tunnel would require a year or two to excavate, and at least a year or two of advance engineering, planning and procurement. Consequently, the monitoring system, and the associated analyses and interpretation of the monitoring data should ideally be able to provide at least 4 to 5 years advance warning of the potential loss of the existing FCDC. Even if the current plan no longer considers a tunnel, a 4 to 5-year advance warning would still be appropriate, to allow for design, planning, procurement and implementation of an alternate solution.

The stability of the back scarp along the east wall has been monitored using crest regression measurements and survey monitoring points. The crest regression at the north and south instability zones is currently monitored by measuring the shortest distance from the crest to reference pins located at a given distance behind the crest. Currently, nine pins are being measured for crest regression. Based on the measurement data, crest regression appears to be occurring, but is limited to two gullies in the backscarp of the north instability zone (Golder 2014). Overall stability is monitored using nine monitoring pins that are surveyed annually. Since slope stability monitoring of the instability zones began in 2006, and up to the 2014 annual inspection, no displacements beyond the accuracy of the pin monitoring system have been observed. However, the 2014 monitoring data indicate possible displacements in three of the monitoring pins, 13874, 13875 and 13876 (Golder 2014). Golder has recommended that the frequency of the crest regression monitoring in the Faro Pit be increased to a monthly basis, while the overall slope stability monitoring can continue to be carried out on an annual basis using the current system (surveys by YES) (Golder 2014).

3.2 Grum Pit

The east wall of the Grum Pit has been affected by slope instability of the overburden slope for many years, resulting in a large, deep-seated failure in the thick overburden soils that are exposed along the east wall of the Grum Pit. Crest regression is associated with on-going raveling and slumping of the oversteepened backscarp, and it is occurring in several areas along the length of the instability zone, rather than in specific locations as in the Faro Pit. Crest regression in the Grum Pit is currently monitored using a similar system to the Faro Pit, and also requires site personnel to access the area behind the crest. However, instead of measuring reference pins, distances are measured between the crest and two arrays of reference bars. As there is no important infrastructure near the crest of the east wall of the Grum Pit, the consequences of crest regression are not as high as in the Faro Pit.

Since mining operations were stopped in 1998, an in-pit lake has accumulated in the pit. The water level in the pit has been continuously rising, as shown in Figure 1-1 in Attachment 1. The Grum Pit instability zone continues to exhibit ravelling, cracks, and slumping at the crest, and ongoing displacement may further contribute to the rising water levels in the pit. Furthermore, it is not known whether the slide mass at the base of the backscarp is at equilibrium or whether it could remobilize suddenly, possibly creating a large wave in the pit lake. There is a concern that the rising water level could cause a sudden and significant ground movement within the failure zone that could cause an overflow into the outlet channel on the south side of the pit. It is understood that an overflow of pit water could potentially affect the surface water quality and the management plan of the mine site. Moreover, a sufficiently large overflow event could potentially find its way into the natural watercourse system, where it could possibly reach the town of Faro (Figure 1-2 in Attachment 1). Determining the flow path and the extent of possible damage from a pit lake overflow event is beyond the scope of this study. However, as shown in Figure 1-2, the town of Faro appears to be downstream of the Grum Pit, and the water course to the south of the pit could eventually converge to flow past the north edge of the town. Therefore, an estimate of the following targets is considered valuable to the ongoing closure planning:

- the maximum pit lake level that could contain the volume of a large-scale failure without overtopping the outlet at the south end of the pit, and
- the approximate date the lake will reach the maximum level indicated above.

In order to estimate these targets, we assumed that a portion of the oversteepened backscarp could fail and that this failed mass could then mobilize the existing slide material at the base of the backscarp. The volume of existing failure debris below the outlet elevation at 1,230 meters will not change or displace any water volume below this outlet elevation, even if it were to be displaced further into the pit. This is because this volume is already below the ultimate pit water level. However, the volume of the existing slide mass that is above the outlet water level, combined with material failed from the backscarp would displace an equal volume of water in the lake. At a given lake elevation, this displaced volume of water would overtop the outlet elevation of 1,230 meters. The following calculations were carried out to estimate this volume.

- The estimated volume of existing failure debris above the outlet elevation at the 1,230 meter elevation is approximately 483,969 cubic meters (Golder 2010).
- To mobilize this material, a volume of material failing in the overburden backscarp was estimated based on the following.
  - For simplicity, we assumed a wedge-shaped failure in the backscarp with a cross sectional area of 1051.2 m^2 as shown in Figure 1-3. The backscarp was assumed to be approximately 50 metres high and the failure surface would extend approximately 41 metres behind the crest.
  - The extent of the backscarp along the crest of the east wall was estimated to be approximately 120 metres.
  - The resulting volume, if the full extent of the backscarp fails, is approximately 126,144 m^3.

This volume, combined with the volume of existing slide material above the 1,230 meter elevation, results in a total volume of 610,113 m^3. For this volume to result in an overflow event, it would have to exceed the available storage volume in the pit below the 1,230 meter elevation.

The total storage volume in the pit, below 1,230 meters elevation, was estimated to be 8,314,102 m^3 (Golder 2010). The difference between the total amount of storage and the volume of failed material is 7,703,989 m^3. The graph in Figure 1-4 shows the approximate storage available by elevation in the pit. For a storage volume of 7,703,989 m^3, the pit lake elevation is expected to be between 1,227 and 1,228 metres. Therefore, when the pit lake level exceeds 1,228 metres elevation, a potential failure could cause an overflow event.

The rate at which the pit lake has risen has varied over the last 10 years. The flooding rate that Golder used in 2009 was slightly lower than the current estimate, and the estimated date to reach the overflow elevation was reported as occurring in the year 2020. Based on curve-fitting the data from the last 10 years, and assuming the current flooding rate and no pumping, the lake elevation is now estimated to reach 1,228 metres in early 2019 (Figure 1-1), or in about 2 years from now. Until that time, a slope failure is not expected to cause overtopping of the pit lake. Therefore, provided that the pit lake continues to rise at similar rates, overall slope stability monitoring of the existing failure debris or of the back scarp is not considered to be an immediate concern with respect to an overflow event, but will likely be required before the pit lake reaches 1,228 metres elevation in approximately 2 years. This estimate assumes similar freshet flows and that no pumping occurs over the next two years, but it is recognized that YG may pump periodically thus extending the time to reach 1,228 metres, or YG may pump the lake back down to the maximum recommended elevation of 1,213 metres and maintain it at that level. The maximum recommended elevation of 1,213 metres was established based on the lowest elevation of the till/bedrock contact in the pit.

Based on the discussion above, the overall slope stability monitoring system requirements for the Grum Pit in terms of the extent of coverage and the amount of advance warning required will depend on the likelihood and consequences of a potential outflow event from the south end of the pit. The consequences of an outflow event will depend on the volume of water that is released from the pit, and could possibly vary from minor erosion and environmental damage immediately beyond the pit, to property damage and possible risk to life within the town of Faro. A downstream inundation study would be required to determine the range of possible impacts of a water release event from the pit. Consequently, it is not possible to determine the optimum monitoring system requirements for the Grum Pit until such a study has been carried out, and this is discussed in further detail in Section 5.2.

Although an inundation study is recommended before designing the Grum Pit monitoring system, the information on the various monitoring methods outlined in the following sections can provide context in terms of the range in degree of coverage and monitoring frequency that is available. Once the consequences of an overflow event are better defined, this information can be used to design the appropriate overall slope monitoring system for the Grum Pit.

4.0 MONITORING SYSTEMS REVIEW

This section provides brief descriptions of the monitoring systems that were evaluated for this project. Where cost was considered prohibitive or other aspects made a system unsuitable, the system was not investigated in detail. The applicability of systems for either crest regression or overall slope stability monitoring was determined based on their expected accuracy. For crest regression, an accuracy of 0.2 to 0.3 m was considered acceptable, while an accuracy of less than 0.1 m was considered acceptable for overall slope stability systems. The systems have been grouped into either remote sensing systems or instrumentation systems. In addition, comments have been provided as to whether the method is suitable for crest regression monitoring, overall slope stability monitoring, or both.

The following remote sensing systems were reviewed:

- Photography;
- Photogrammetry;

- Laser Scanning;
- Scanning Reflectorless Total Station;
- Terrestrial Radar; and
- Satellite Radar.

The following instrumentation systems were reviewed:

- Monitoring Prisms;
- Wireline Extensometers;
- Time Domain Reflectometry (TDR) cables; and
- GPS Stations.

Each of these monitoring methods is discussed further in the following section. A summary table of all the systems, the approximate costs, the set up or installation requirements, and other considerations, is provided in Table 2, in Section 4.4.

4.1 Remote Sensing Systems

The following systems do not require installation of equipment on the slope, and all data collection can be conducted from the far side of the pit. However, some systems would require initial access to slope crests for installation of reference objects prior to the initial survey.

4.1.1 Photograph Comparison

In addition to the current monitoring systems, the pit wall stability is also qualitatively reviewed using photographs that are regularly taken from similar locations each time. This system can be improved with the addition of permanent scale bars and the use of a high resolution camera and lens to allow for quick, yet quantitative, measurements of crest regression in both the Faro and Grum Pits.

The photograph comparison approach that was evaluated would consist of placing long objects, such as telephone poles, perpendicular to the edge of the crest and extending towards the access road. The poles would be clearly marked in increments of 20 cm, such that they could serve as a measurement scale in a photograph. The poles would be secured to the ground to prevent lateral displacement. Then, periodic photographs would be taken using a professional digital single lens reflex (DSLR) camera and fixed focal-length lens. Permanent camera mounting stations placed at designated locations would allow photographs to be taken from the same location, thus reducing parallax-related errors between data collections. The mounting stations would be placed so the photographs are taken oblique to the slope, to be able to compare the crest location relative to the marks on the poles. The crest regression could be estimated by comparing the location of the crest to the distance marks on the poles.

In the Faro Pit, the photographs would likely be taken from locations at the north and south ends of the pit. If a full frame camera with a 200 mm lens (e.g., Canon 5D Mk II camera with a Canon EF 200 mm f/2.8 II USM lens or equivalent camera) was used, a single pixel on the camera's sensor would cover approximately 3.2 cm of ground surface on the east wall, which should allow for reading of the 20 cm markings on the poles. This would result in a minimum regression accuracy of 20 cm at the location of the poles. Given the well-constrained locations of maximum regression around the gullies in the east wall, poles could be strategically positioned to collect data in the most critical areas.

This same system can be used to monitor crest regression in the Grum Pit. In this case, however, photographs could likely be taken from a single location at the north end of the pit, and an 85 mm lens is recommended so that the entire area of interest could be covered in a single photograph. Using the 85 mm lens in the Grum Pit would result in each pixel of the camera's sensor covering approximately 3.6 cm, providing a similar resolution of monitoring as in the Faro Pit.

Monitoring the overall stability of the slide material encountered in the Grum Pit will be more difficult using this system, however, as scale bars and similar markers cannot be easily placed on the slide material. In addition, the displacement mode is likely more complex, and would require sensitive measurements of vertical displacement and relative displacements between points.

Based on the criteria for complexity of operation outlined in Section 2.0, photograph comparison is considered relatively simple to operate. Data collection and processing both consist of single steps. Software and technical skill requirements are limited to the ability to take high quality photographs and compare them using default viewer software. As a result, training new staff should be simple, especially if permanent camera mounts are installed at the monitoring stations to reduce variability between operators.

Because site staff can be trained to collect and process this data easily, ongoing costs are expected to be limited to occasional external geotechnical review and equipment maintenance. Equipment maintenance is expected to cost approximately $100 per year. Third-party geotechnical review of the photographs, together with a summary memorandum, is estimated to cost around $1,500 per review.

Based on the review above, it is our opinion that the photograph comparison system is not recommended for monitoring overall slope stability in the Grum Pit or in the Faro Pit. However, it would be acceptable for monitoring crest regression as discussed above.

4.1.2 Photogrammetric Comparison

Using the same DSLR and fixed focal length lenses recommended for the photograph comparison method, it is possible to generate full three-dimensional (3-D) models of the pit slopes for each observation and measure changes over the entire slope area covered by the photographs.

This system works by collecting sets of photographs of the area of interest using a specified procedure to enhance the consistency of results. The photographs are then loaded into a commercial photogrammetry software package that is capable of generating 3-D surfaces, largely automatically, with minor user input to identify control points.

To set up the first survey, a geotechnical engineering contractor would require a site visit to establish data collection and processing procedures and provide training to site staff. In addition, a survey contractor would be required to determine the optimal locations for the camera set-up and the control points. After the initial set up and training, site staff could work independently.

The projected distance accuracy of this system is approximately 0.1 m, making it well suited to monitoring crest regression. However, this resolution may be insufficient to detect critical displacements in the slide mass of the Grum and Faro Pits. If this system is implemented, we recommend that it be coupled with a proven instrumentation system to confirm the accuracy of initial readings before it is depended on exclusively. This could produce savings in the future by reducing surveying expenditures if the photogrammetry system is proven in the field.

Another advantage of photogrammetry is that the equipment is easily portable and can be utilized over multiple areas. This system could easily be applied to monitor the Vangorda Pit as well, should it ever be required.

In terms of complexity of operation, photogrammetry is more complex than the simple photograph comparison method, but offers the potential for increased measurement accuracy and overall slope stability monitoring. The data collection process requires collection of multiple photos from numerous areas following a prescribed method; however, equipment operation remains relatively simple. The software for processing is relatively user friendly and fairly automatic. However, troubleshooting would require more advanced knowledge of photogrammetry and the software. As a result of the increased complexity, training requirements would be more intensive, which could be problematic in the event of high staff turnover. Site visits for staff training are expected to cost at least $5,000 per visit. The cost of the initial survey of camera locations and control points was not included in this study.

If site personnel are able to collect and interpret these data, ongoing costs will be similar to photographic comparison with occasional costs for software updates.

4.1.3 Laser Scanner

Terrestrial laser scanners, also known as terrestrial LiDAR, use the time of flight of a laser beam to measure distances between the instrument and an object. Measurements are made by collecting location data of points on a dense, uniform grid over an area of interest. The location in space of the grid points can be determined from the instrument location, the shot distance, and the shot vertical and horizontal angles, much like conventional surveying techniques. The resulting 3-D grid data can be used to create a 3-D surface of the object of interest. Changes in the shape or the location of the object can be determined by examining the differences between successive scans.

Laser scanners offer a higher degree of precision than photogrammetry. In addition, data collection is less intensive because all the data can often be collected from a single viewpoint. Laser scanning has been shown to effectively monitor slope displacements in multiple case studies (Abellan et al., 2009; Brodue & Lague, 2012; Oppikofer et al., 2009) and complete packages of a scanner and specialized software are available, which function in a similar way to slope stability radar. Therefore, this approach would be suitable for both crest regression and overall slope stability monitoring, and would provide full slope coverage. However, based on discussions with a service provider, the equipment would represent a significant cost at approximately $200,000 for an appropriate scanner and approximately $20,000 for specialized software. Some service providers will also collect and process data, and a single site visit was quoted to be on the order of $10,000. The estimated cost of each site visit could likely be reduced based on actual travel costs and time on site; however, as visits would be required on a monthly basis, the cost is still considered high.

In addition to the expense for purchasing the equipment, operating a laser scanner involves significant training and effort. The complexity of operation is reduced compared to photogrammetry by requiring single survey locations per pit. However, laser scanners are significantly more complex to operate compared to cameras and will require special operator training. Post processing of scan data requires specialized software which benefits from a technical background when operating. Moreover, unlike slope stability radar monitoring, successive image processing and comparison is not automatic, and must be carried out manually. Similarly manual interpretation of the results is required to determine if significant displacements of potential concern have occurred between successive surveys. Due to the extensive training and experience required, laser scanning is not recommended if high staff turnover is expected.

4.1.4 Scanning Total Station

Scanning total stations combine the functions of a laser scanner and a traditional surveying total station. Like a laser scanner, they produce a powerful enough beam that they can collect accurate survey data without the aid of a prism and can collect approximately 1,000 3-D points per second, covering an entire slope. They can also be used like a traditional total station to survey single points such as prisms. They are controlled from a graphic user interface where the user selects an area of interest from a photograph of the slope. The scanning station then collects points on approximately 4 cm spacing. These data can be compared to an initial scan to detect displacements. An advantage of this system over monitoring prisms (discussed in section 3.2.1) is increased automation and full coverage of the slopes. This system would be appropriate for both crest regression and overall slope stability monitoring.

Scanning station systems are more expensive compared to traditional total stations, and a complete system including specialized software, training, and installation is expected to cost approximately $90,000. However, this system would not require personnel to access the east wall slope at any time. If a scanning total station were operated by site staff, it would eliminate the cost of repeat visits by a surveying contractor. Scanning total stations are sensitive digital instruments, which require specialized training to operate. In the event of high staff turnover, additional training sessions by the equipment manufacturer would be required at a cost of at least $5,000 per session.

Scanning total stations provide similar results to laser scanners at a reduced resolution and cost. However, they are equally complex in operation and data processing, which requires specialized software. Given the complexity of this system it is better suited to dedicated staff or a trained third party to operate the equipment.

4.1.5 Terrestrial Radar

Both real and synthetic aperture radar systems are commercially available for monitoring slope stability. They work by scanning a radar beam over an area of interest and measuring the change in phase of the return signal between readings. Therefore, this system would be appropriate for both crest regression and overall slope stability monitoring. Radar systems offer the most precise distance measurement of the systems discussed and are used extensively in large open pit mines. In addition, the data processing and reporting of slope displacements is automated and occurs in real time, so unlike LiDAR and Scanning Total Stations, manual post processing image comparisons are not required. However, the systems are more difficult to set up and are significantly less portable compared to laser scanners and photogrammetry systems. In addition, radar systems are the most expensive of the remote sensing systems, costing approximately $300,000 to $1,000,000 to purchase. If purchasing is not an option, specialized contractors are available to conduct surveys at a cost of approximately $25,000/month, not including mobilization and demobilization costs.

Radar data collection is largely automated and requires little user input. However, operation of the system software and interpretation of the results requires extensive training in use of specialized software and a technical background, respectively.

4.1.6 Satellite Radar

Satellite-based radar platforms use the same technology as their terrestrial counterparts and are capable of delivering similar centimetre accuracy. The advantage of satellite based systems is that they don't require installation or operation of equipment on site. They are not commonly used at active mine sites because, as a result of the satellite's orbit, there is a time lag of approximately one month between readings. However, a monthly reading frequency is considered acceptable at the Faro Mine Complex. This system would rely on an external satellite radar specialist contractor to collect and process the data from the satellite, and to provide it to a geotechnical specialist for review and interpretation on a monthly basis. It would not require any effort on the part of site personnel and is capable of measuring both crest regression and overall slope stability in the Faro and Grum Pits, and, if desired, the Vangorda Pit. A provider has indicated that the cost of this system would be between $40,000 to $75,000 per year, depending the on satellite(s) used. There would likely be an additional cost for review by a geotechnical engineer, so total costs could reach between $58,000 and $93,000 annually.

An alternative way to measure crest regression using satellite data would be to set up a change detection system using very high resolution satellite imagery. A provider has indicated that acquisition, processing and interpretation would cost about $8,000 per month.

The following sections discuss monitoring systems based on instrumentation rather than remote sensing.

4.2 Instrumentation Systems

The following instrumentation systems require access to the slope at least once for installation of equipment and also potentially on multiple occasions for care and maintenance. These systems collect data at single points, and, therefore, have potential blind zones which must be taken into account when designing the monitoring network. However, an advantage of instrumentation systems is that, with the exception of TDR cables, relative to the remote methods, they require very little post processing of data prior to interpretation. The following sections discuss monitoring prisms, wireline extensometers, TDR cables, and GPS stations.

4.2.1 Monitoring Prisms

The overall stability of the Faro and Grum pit walls is currently monitored using survey pins. Survey prisms are mounted on the pins once per year, and the new geodetic coordinates are measured. The coordinate data are examined for changes between successive readings that may be result of slope displacements.

Of the four monitoring points (not prisms) currently installed in the Grum Pit, one is located on the slide debris and the remaining three are located on along the back scarp crest. Monitoring points such as these are expected to provide sufficient coverage in the Grum Pit, provided the remaining previously recommended 10 monitoring points are installed and monitored on a regular basis. However, monitoring point installation will require personnel to access the slide debris both to install the remaining points and to survey them each time.

The installed monitoring points at the Faro Pit are currently surveyed annually by Yukon Engineering Services (YES), at a cost to the project for each visit. Currently, they set up a prism at each monitoring point to survey it.

In both pits, the installation of permanent monitoring prisms would reduce the need for repeat access to the slope and also likely allow for data collection from a single point across the pit. Instead of repeat visits by YES, a robotic total station and monitoring prisms could be purchased and installed, and staff could be trained in operation of the total station. Although the initial layout would be on the order of $60,000 for a robotic total station, the cost would include software, professional setup, and training. Robotic total stations have the same functionality as basic total stations with the added ability to assist the user to locate and lock onto prisms, which reduces errors between surveys. Unlike scanning total stations (discussed in Section 4.1.4), they only collect data on single prisms and do not provide full slope coverage. The cost provided for the robotic total station system does not include the purchase of the prisms, at a cost of approximately $200 per prism, or the installation of the prisms.

Prisms cannot be effectively used to monitor crest regression; however, some total stations, like the robotic one quoted for $60,000, have a long-range reflectorless survey mode, similar to laser scanners, and are capable of collecting data without the aid of prisms. A total station with long-range reflectorless survey capabilities could be used to monitor points on the crest for regression. In this way a total station could address all the monitoring needs for the project in all the pits. The robotic total station quoted would use its reflectorless surveying capabilities to measure the coordinates of the pit crest in discrete locations selected by the user. To reduce variability between surveys, targets could be placed along the crest to allow staff to survey the same location each time.

Operation of any total station, even with robotic assist capabilities, to survey prisms and crest locations is similarly complex to operating the scanning total station described in Section 4.1.4, and requires training and experience with sensitive digital instruments. Depending on the level of automation employed to survey individual prisms, the data collection could require significant user input to align the station and survey each prism. This system would benefit from training of dedicated, long term staff members to improve consistency of results. Data processing is typically conducted in Microsoft Excel, which is less specialized than scanning station software. However, a geotechnical background is required when interpreting results. Consequently, a geotechnical contractor would be required to assist with the data interpretation on at least an annual basis, and possibly on an on-call basis if slope movements are suspected by site personnel.

If a robotic total station were operated by site staff, it would eliminate the cost of repeat visits by a survey contractor. However, if high staff turnover rates are expected it would likely require additional training sessions by the equipment manufacturer at a cost of at least $5,000 per session. Given the complexity of this system and to reduce retraining costs, it is recommended that dedicated staff or a trained third party, such as YES, operate the equipment.

4.2.2 Wireline Extensometers

Extensometers work in a similar way to prisms by providing displacement data at discrete locations over a slope. A pin is installed on the slope and attached to a tripod located behind the crest via a wireline. Changes in distance between the tripod and the pin cause the wireline to extend, and a scale installed adjacent to a marker on the wireline is used to measure the displacement. The advantage of wireline extensometers is that they can easily be read by site staff with minimal training. However, unlike prisms, they only measure displacement as a change in distance, and they are best used for measuring displacements behind the crest of a slope that are typically caused by the formation of tension cracks.

Automated wireline extensometers, which upload readings to a server and can automatically trigger alarms, are available but cost on the order of $14,400 per unit and require a specialized technician to install. Given their cost, automated extensometers are not discussed further. Instead, manual units, which cost approximately $1,200 per unit, are discussed below.

Since extensometers measure the change in distance between two points behind the crest, they are not suited for measuring crest loss or regression at the edge of the crest. In addition, accuracy is best and damage is minimized if the wirelines are short. Consequently, they will be applicable to changes in distance between two points over relatively short distances, less than 15 to 20 metres. Stretching them any further would leave them susceptible to wind damage or damage from animals and they would require frequent repair. Therefore, placing them on the slide mass in the Grum Pit and stringing them up and over the crest would not likely be successful over the long term. In addition, similar to prisms, installation of extensometers would require personnel to access the slide area if there were installed to monitor the slide mass. An alternative option is to install them behind the crest, similar to the monitoring arrays that have been installed at the crest of the Grum Pit east wall, to monitor for tension cracks related to instability of the oversteepened backscarp. However, even in this case, access to the crest would be required occasionally to maintain the instruments.

The cost of installing and maintaining the extensometers was not included in this study.

The advantage of wireline extensometers is that they are one of the least complex systems for slope monitoring. Data collection consists of reading a value from each extensometer and inputting it into a database. The values can then be compared between readings to determine if displacements exceed a pre-determined value. No technical background or special equipment is required and new staff can be quickly trained. The resilience and simplicity of the equipment means that ongoing costs will be negligible if site staff collect and interpret the data.

4.2.3 Time Domain Reflectometry

Time domain reflectometry (TDR) works by sending an electrical signal through a coaxial cable that has been grouted into a borehole. Any bends or pinches along the cable create reflections of the signal, which can be used to measure the downhole location and the qualitative magnitude of the deflection. TDR cables can provide an indication of displacement within a borehole at a single location. In this regard, they can be used detect deep displacements that may be indicative of overall slope instability. However, multiple installations would be required on a slope to provide adequate coverage. These instruments are not applicable to measuring crest regression.

A basic system with four cables, two installed to 40 m depth at mid height on the slope and two installed to 80 m depth from the crest of the slope, would cost approximately $27,000 for the cables and a data logger. The advantage of TDR cables with a data logger is that they provide continuous data over a profile, which can be useful for assessment of displacement mechanisms. Additional costs to consider include drilling and installation as well as any preparation of the slope required to mobilize a drill rig.

TDR data collection requires use of specialized digital equipment, and the data interpretation requires a technical background as well as specialized software training. The complexity of this system would therefore require geotechnical review for each survey with an ongoing cost of approximately $1,500 per survey.

4.2.4 GPS Stations

Global positioning system (GPS) monitoring stations produce 3-D displacement data at a point, similar to monitoring prisms, but with the added advantage of a remote data download. This system would involve installing several stations over the potentially unstable area of the Grum Pit slope and reviewing remotely retrieved data on a personal computer. However, the GPS equipment is expensive, costing approximately $15,000 per station.

The complexity of collecting data from this system is relatively low as data are automatically uploaded to a personal computer. However, installation and maintenance would require a specialized contractor. Data processing could be conducted in a similar matter to monitoring prisms using Microsoft Excel but would equally benefit from a trained, dedicated staff member.

GPS units are applicable to monitoring overall slope stability, but are not applicable to monitoring crest regression.

4.3 Summary of Ease of Use

One of the goals of this study was to identify monitoring systems which could be implemented by site staff with limited training. Table 1 summarizes the systems reviewed along with their related complexity in operation and interpretation, and whether the system is recommended for use by site staff. Of the ten systems reviewed, photograph comparison and wireline extensometers are recommended and photogrammetry is provisionally recommended. Photogrammetry is recommended provisionally because of the training requirements and specialist knowledge required to troubleshoot any issues.

Table 1: Summary of Systems Recommended for Use by Site Staff

System	Data Collection Complexity	Data Processing Complexity	Specialized Software and/or Instrument Operation	Recommended for Site Staff
Photograph Comparison	Low	Low	No	Yes
Photogrammetry	Moderate	Moderate to High	Yes	Provisionally
Laser Scanning	Complex	Moderate to High	Yes	No
Terrestrial Radar	Low	High	Yes	No
Satellite Radar	NA	High	Yes	No
Scanning Total Station	Complex	Moderate	Yes	No
Monitoring Prisms and Robotic Total Station	Complex	Moderate	Yes	No
Wireline Extensometers	Low	Low	No	Yes
Time Domain Reflectometry (TDR)	Moderate	High	Yes	No
GPS Stations	Low	Moderate	Yes	No

4.4 Summary Table of Slope Monitoring Systems

Table 2 summarizes the systems discussed in this memo, and includes approximate cost, advantages and disadvantages, and whether or not each system is recommended for use at the Faro Mine Complex.

Table 2: Summary of Reviewed Slope Monitoring Systems

System	Estimated Initial Equipment and/or Contractor Operation Cost	Included in Initial Cost	Not Included in Initial Cost	Estimated Ongoing Costs per Year	Application	Advantages	Disadvantages	Recommended
Photograph Comparison	$3,000	Camera, lens	Construction and installation of mounting stations and scale bars, training	■ $100 for equipment maintenance	Crest regression	■ Minimal cost, effort, and training requirements	■ Point measurements rather than coverage of the full area ■ Qualitative overall slope information	Yes, if combined with another system
Photogrammetry	$11,500	Camera, lens, software, training	Installation and survey of control points	■ $100 for equipment maintenance ■ Possible software upgrades at less than $3500 per upgrade ■ At least $5000 for retraining of site staff	Crest regression and potentially slope stability	■ Full slope coverage ■ Simple data collection.	■ Less accurate than laser and radar ■ Requires survey support to setup ■ More complex processing	Yes
Laser Scanning	■ $220,000 to Purchase or ■ $10,000/month - operation by a specialized contractor	Laser scanner and specialized software	Training, and construction and permanent installation of mounting stations	■ At least $5000 for retraining of site staff ■ Maintenance costs were not estimated.	Crest regression and slope stability	■ Full slope coverage ■ Doesn't require survey support	■ Requires installation of mounting stations ■ Increased training effort ■ More complex processing	No
Scanning Total Station	■ $90,000 – Purchase or ■ $2,000/month - operation by a specialized contractor	Total station, specialized software, training, and professional setup	Construction and installation of mounting stations	■ At least $5000 for retraining of site staff ■ Maintenance costs were not estimated.	Crest regression and slope stability	■ Increased data detail compared to prisms	■ Requires installation of mounting stations ■ Increased training effort ■ More complex processing	Yes
Terrestrial Radar	■ $300,000 to $900,000 – Purchase or ■ $25,000/month - operation by a specialized contractor	Radar equipment or monthly slope monitoring by a specialized contractor	Training, maintenance and technical support	■ Did not investigate further. ■ Would require ongoing maintenance costs if purchased.	Crest regression and slope stability	■ Full slope coverage ■ Highest accuracy ■ Continuous coverage	■ Cannot share between pits ■ Requires significant operator training	No
Satellite Radar (InSAR)	$40,000 to $75,000 per year depending the on satellite(s) used	Monthly slope monitoring by a specialized contractor	No installation or set up required	■ Would require periodic review from a geotechnical engineer.	Crest regression and slope stability	■ Full slope coverage ■ High accuracy ■ No effort required from site staff	■ Ongoing cost ■ Requires specialist contractors for entire system	No
Optical Satellite Imaging	$8,000/month	Monthly slope monitoring by a specialized contractor	No installation or set up required	■ Did not investigate further. ■ Would require periodic review from a geotechnical engineer.	Crest regression	■ Full slope coverage ■ High accuracy ■ No effort required from site staff	■ Ongoing cost	No

System	Estimated Initial Equipment and/or Contractor Operation Cost	Included in Initial Cost	Not Included in Initial Cost	Estimated Ongoing Costs per Year	Application	Advantages	Disadvantages	Recommended
Monitoring Prisms and Robotic Total Station	■ $60,000 – Purchase or ■ $2,000/month operation by a specialized contractor	Total station, software, professional setup, and training	Purchase and installation of survey prisms at $100 each	■ At least $5000 for retraining of site staff. ■ Maintenance costs were not estimated.	Crest regression and slope stability	■ Proven reliability and detail of data ■ Continuous coverage	■ Requires access to unstable area for initial setup ■ Installation and occasional maintenance of survey prisms	Yes
Wireline Extensometers	$12,000 (manual)	Ten wireline extensometers at $1,200 each	Installation and set up	■ Maintenance costs were not estimated. Would require periodic review from a geotechnical engineer.	Tension cracks related to slope stability	■ Simple to read by site personnel from a safe distance behind crest	■ Requires access to unstable area for initial setup ■ Least detailed displacement data	No
Time Domain Reflectometry (TDR)	$27,000	Four cables and a data logger	Contract a drill rig, drilling and installation costs, preparing access costs	$18,000 per year, for monthly geotechnical reviews of data at approximately $1,500 per month.	Slope stability	■ Provides data at depth ■ Can be read from safe distance behind crest	■ Requires drilling for installation and repeated access to slope for maintenance ■ Data must be reviewed by a geotechnical consultant on a monthly basis ■ No crest regression monitoring ■ Ongoing costs	No
GPS Stations	$150,000	Ten GPS stations at $1,500 each, for the Grum Pit	Installation and set up	■ Maintenance costs were not estimated. Would require periodic review from a geotechnical engineer.	Slope stability	■ Remote data acquisition ■ Data detail comparable to prisms	■ Requires access to unstable area to install and intermittently for maintenance ■ No crest regression monitoring	No

5.0 RECOMMENDATIONS

The following sections provide our recommendations for monitoring crest regression and overall slope stability in the Faro Pit and the Grum Pit. A visual pit slope stability inspection should be carried out by a geotechnical engineering consultant at least every two to three years. In addition to the site visits, a review of all of the pit slope monitoring data should be carried out annually by a qualified geotechnical engineer.

5.1 Recommendations for the Faro Pit Slope Monitoring System

Currently, the monitoring system for the Faro Pit instability zones consists of the following:

- crest regression monitoring by measuring the distance from the crest to pins installed behind the crest, carried out twice yearly, and
- overall slope stability monitoring by surveying monitoring pins, carried out once a year by YES.

The last annual pit inspection report (Golder 2014) recommends increasing the crest regression monitoring to once a month due to the critical nature of the FCDC. In addition, based on the results of this study, we recommend the following modification:

- crest regression monitoring once a month, using the photograph comparison method, or the photogrammetric comparison method.

The overall slope stability monitoring can continue to be carried out by surveying monitoring pins, once a year by YES.

The monthly monitoring should also include visual monitoring of the wall face and the area behind the crest (keeping a distance of 5 metres from the crest) for evidence of cracking, excessive recent raveling or other signs of instability. If signs of instability are observed, the emergency response plan should be consulted to provide guidance to site personnel on who should be informed and how. Response actions would be established in the Response Plan and may include an inspection by a qualified geotechnical engineer and/or resurveying of the monitoring pins by YES to assess the overall stability of the slope.

5.2 Recommendations for the Grum Pit Slope Monitoring System

Currently, crest regression at the Grum Pit is measured once per month. Golder 2014 recommends monitoring crest regression twice annually, and surveying the Grum Pit monitoring pins once per year.

Based on the results of this study, we recommend that crest regression monitoring be carried out using the same photograph or photogrammetric comparison method that is selected for the Faro Pit. However, the frequency of monitoring can be reduced to twice annually, rather than monthly.

With respect to monitoring overall slope stability, the following provides a discussion of the previous recommendations and the current recommendation.

As discussed in Section 3.2, when the pit lake level exceeds 1,228 metres elevation, displacement of the existing failure debris or additional failure backscarp above 1,230 metres elevation could cause a pit lake overflow event. Until the water level reaches the 1,228 metre elevation, a slope failure is expected to cause little to no overtopping of the south rim of the pit. Therefore, overall slope stability monitoring is not considered to be an immediate concern with respect to an overflow event, but will likely be required once the pit lake reaches 1,228 metres elevation. Based on recent pit lake water elevation observations, the pit lake is estimated to reach the 1,228 metre elevation in approximately 2 years, assuming similar freshet flows and that no pumping occurs.

Golder 2010 recognized that, in the short-term, a rapid failure of the back-scarp and the existing failure debris in the lower portion of the slope would not likely result in a pit wave that would overtop the outlet on the south side of the pit. However, a pit wave from such a rapid failure would present a significant hazard to any water pumping or treatment facilities that are located within the pit and to any personnel that may be temporarily working within the pit limits. Therefore, Golder previously recommended the installation of monitoring prisms at the crest and on the slide mass for slope stability monitoring (Golder 2010, 2013).

Currently, overall slope stability is monitored using four survey monuments (in the form of rods): three on the slope crest and one on the slide mass about halfway down the slope. A total of 14 monuments were planned to be installed to provide adequate slope coverage, but the remaining 10 monuments were not installed due to concerns with accessing the lower portion of the instability zone.

Given the discussion in Section 3.2 and above, and provided that the following conditions are met, we consider that overall slope monitoring in the Grum Pit is not presently required:

- the instability zone will be visually inspected and monitored for signs of instability using a spotter any time workers are working in the pit, or near or behind the east wall;
- the personnel in the pit will be in direct radio communication with the spotter;
- personnel will be made aware of and activate slope stability emergency procedures if required, and
- the risk of damage to any water pumping or treatment facilities due to a wave caused by slope instability is considered acceptable.

As discussed in Section 3.2, the future requirement for overall slope monitoring will depend on the consequences of a pit lake outflow event and on the degree of advance warning that is required. Potential systems could vary from:

- visual observations or displacement monitoring using wireline extensometers or prism systems; to
- real-time, full slope monitoring systems (such as radar systems) if property damage and/or personal injury on site or in the town of Faro is a real possibility.

Before the pit lake level reaches the critical elevation, an understanding of the full extent and impact of an overflow event would prove valuable to provide suitable recommendations for monitoring the overall slope stability. Therefore, Golder recommends that an inundation study be carried out as soon as practicable. If the inundation study indicates that the risks are high to the environment or the town of Faro, then full and continuous monitoring of the slope to provide early warning or complete remediation of the slope to remove the hazard would be required before 2019. Should the study indicate low risk or that the volume of water could be contained and managed on site, then only a simple monitoring system with a low monitoring frequency may be suitable.

Other alternatives that could eliminate the need for overall slope stability monitoring in the Grum Pit are as follows.

- Put in place a fail-safe system to keep the Grum Pit lake elevation below 1,228 metres elevation. Ideally, the pit lake would be kept at or below the current maximum recommended elevation of 1,213.4 metres, thus reducing the likelihood of the pit lake reaching 1, 228 metres elevation. If this can be implemented and maintained, then overall slope stability monitoring for an overflow event would not be required. It is our current understanding that approximately 587,000 m^3 of water was removed from the Grum Pit in 2014, and that the current plan is to keep the pit lake elevation below the maximum recommended elevation of 1,213.4 metres, which is based on the lowest elevation of the till/bedrock contact.
- Remove the failure debris that is currently above the pit outlet level of 1,230 metres, and re-slope the oversteepened backscarp to a stable slope angle. This would eliminate entirely the need to monitor crest regression and overall slope stability.

5.3 Recommendations for Update to Emergency Response Plan

It is recommended that the updated slope stability monitoring program be incorporated into the existing Emergency Response Plan, to give site personnel a basic understanding of the signs of slope instability that can be determined from visual observations and the monitoring data, and a framework for the communication of and response to potential slope hazards. The preparation of this portion of the Emergency Response Plan can be carried out once the monitoring methods have been selected and implemented.

Finally, it must be reiterated that regardless of the monitoring system in place, and whether or not it requires access to the east walls of the pits, without a timely and thorough review of the monitoring data, significant changes in the stability of the slope may not be detected in sufficient time to activate the emergency response plan or to implement remedial measures. It is the combination of an appropriate monitoring system with a timely and thorough data review that allows the monitoring system to provide adequate warning of conditions that warrant a response.

6.0 CLOSURE

We trust that this memorandum addresses your needs for a review of slope stability monitoring systems for implementation in the Faro and Grum Pits. Please do not hesitate to contact us if you have any questions or comments.

GOLDER ASSOCIATES LTD.

Ryan Preston, M.Sc., EIT
Intermediate Geotechnical Engineer

Jennifer Ramesch, M.Sc.
Geotechnical Specialist

Al Chance, P.Eng.
Principal, Mining Division

John Hull, P.Eng.
Principal, Mining Division

PROFESSIONAL ENGINEER YUKON TERRITORY JOHN A. HULL January 14/15

RP/JJR/AVC/rs/ls

Attachments: Study Limitations
Figures 1 to 4

\\golder.gds\gal\burnaby\final\2014\dynamics numbers - mining division\1410944\1410944-004-tm-rev0-7000\1410944-004-tm-rev0-7000-faro mine complex slope monitoring memo 14jan_15.docx

REFERENCES

Abellán, A., Jaboyedoff, M., Oppikofer, T., & Vilaplana, J. M. 2009. Detection of millimetric deformation using a terrestrial laser scanner: experiment and application to a rockfall event. Natural Hazards and Earth System Science,9(2), 365-372.

Brodu, N., & Lague, D. 2012. 3-D terrestrial lidar data classification of complex natural scenes using a multi-scale dimensionality criterion: Applications in geomorphology. ISPRS Journal of Photogrammetry and Remote Sensing, 68, 121-134.

Golder Associates Ltd. 2010. Phase 1A Geotechnical Slope Stability Assessment of the East Wall of the Grum Pit, Faro Mine, Yukon. Report prepared for Faro Project Management Team, Government of Yukon. Submitted March 23, 2010.

Golder Associates Ltd. 2013. Faro Mine Complex Annual Pit Slope Stability Inspection. Report prepared for Yukon Government. Submitted February 7, 2013.

Golder Associates Ltd. 2014. Annual Pit Slope Stability Inspection, Faro Mine Complex. Draft report prepared for the Government of Yukon. Submitted October 21, 2014.

Oppikofer, T., Jaboyedoff, M., Blikra, L., Derron, M. H., & Metzger, R. 2009. Characterization and monitoring of the Åknes rockslide using terrestrial laser scanning. Natural Hazards and Earth System Science, 9(3), 1003-1019.

STUDY LIMITATIONS

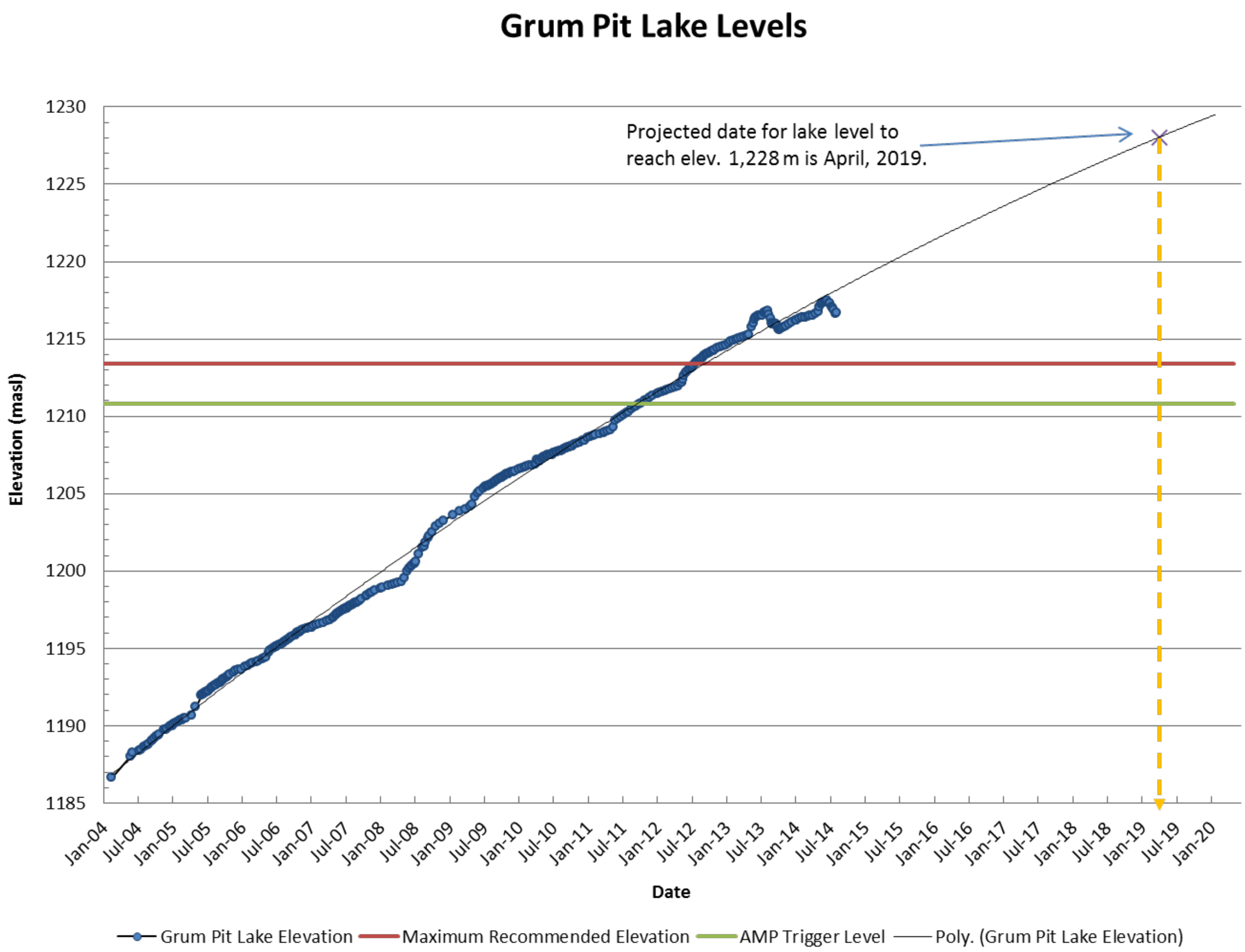
Golder Associates Ltd. (Golder) has prepared this document in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practising under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this document. No warranty, express or implied, is made.

This document, including all text, data, tables, plans, figures, drawings and other documents contained herein, has been prepared by Golder for the sole benefit of the Yukon Government. It represents Golder's professional judgement based on the knowledge and information available at the time of completion. Golder is not responsible for any unauthorized use or modification of this document. All third parties relying on this document do so at their own risk.

The factual data, interpretations, suggestions, recommendations and opinions expressed in this document pertain to the specific project, site conditions, design objective, development and purpose described to Golder by the Yukon Government, and are not applicable to any other project or site location. In order to properly understand the factual data, interpretations, suggestions, recommendations and opinions expressed in this document, reference must be made to the entire document.

This document, including all text, data, tables, plans, figures, drawings and other documents contained herein, as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder. The Yukon Government may make copies of the document in such quantities as are reasonably necessary for those parties conducting business specifically related to the subject of this document or in support of or in response to regulatory inquiries and proceedings. Electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore no party can rely solely on the electronic media versions of this document.

O:\Active_2014\1426\1410944 YG 2014 Faro Pit Slopes\07 Deliverables\Doc 004 Slope Monitoring\Rev. 0\Attachment 1



REV	DATE	DESCRIPTION	DRW	DES	CHK	RVW
0	09/JAN/15	FIGURE	JJR	JJR	AVC	AVC

CLIENT
YUKON GOVERNMENT

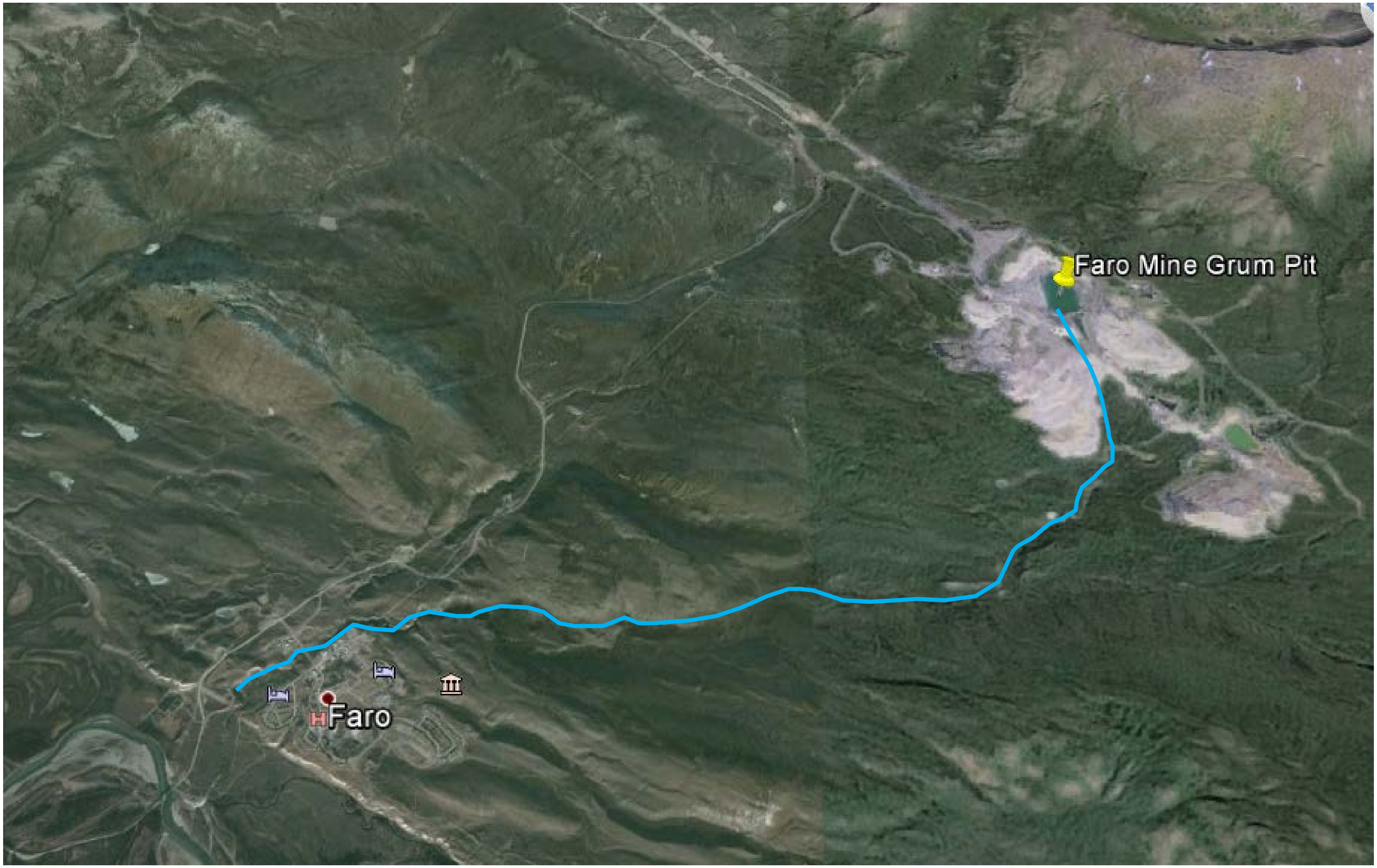
CONSULTANT
Golder Associates

PROJECT 1410944/6000
FARO MINE COMPLEX
REVIEW OF PIT SLOPE MONITORING METHODS

TITLE
GRUM PIT LAKE LEVELS AND PREDICTED DATE OF RISK OF OVERTOPPING

FIGURE No. 1-1

O:\Active_2014\1426\1410944 YG 2014 Faro Pit Slopes\07 Deliverables\Doc 004 Slope Monitoring\Rev. 0\Attachment 1



REV	DATE	DESCRIPTION	DRW	DES	CHK	RVW
0	09/JAN/15	FIGURE	JJR	JJR	AVC	AVC

CLIENT

YUKON GOVERNMENT

PROJECT 1410944/6000

FARO MINE COMPLEX
REVIEW OF PIT SLOPE MONITORING METHODS

CONSULTANT

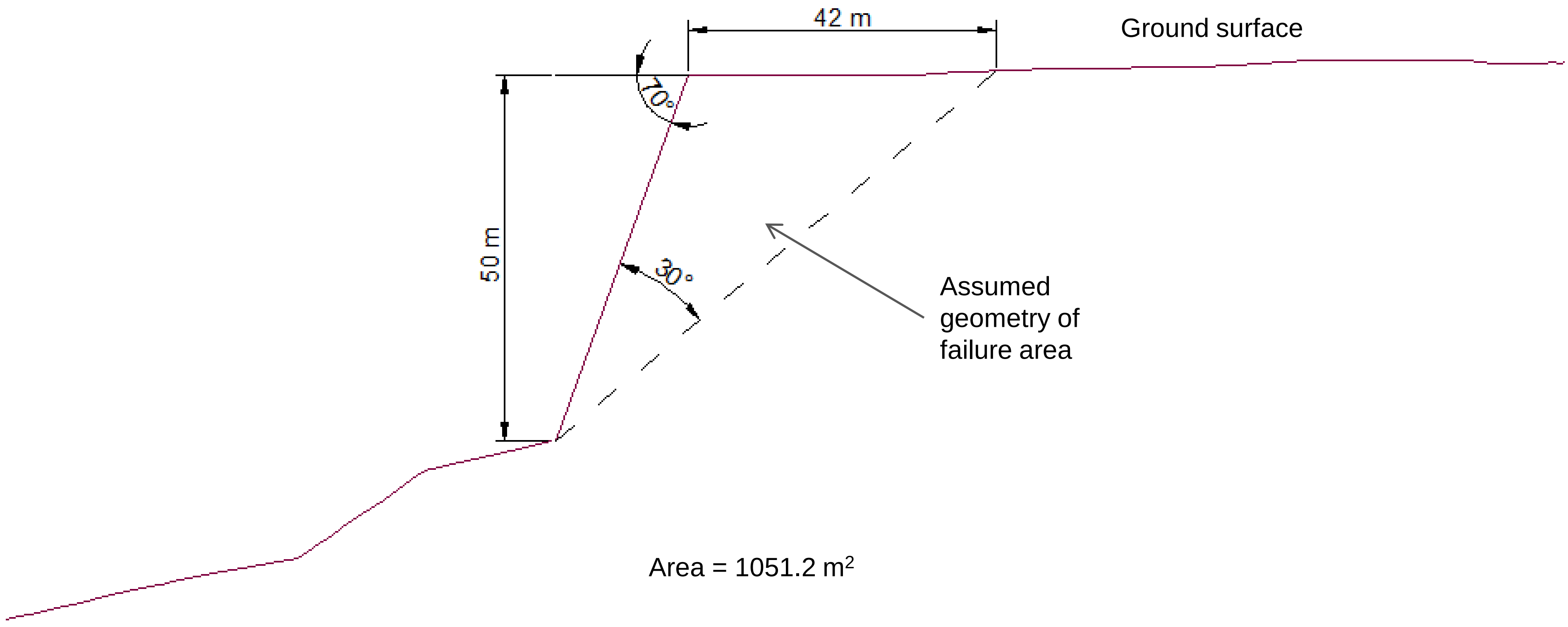
Golder Associates

TITLE

POSSIBLE PATH OF WATER FROM OVERTOPPING OF GRUM PIT LAKE

FIGURE No. 1-2

O:\Active_2014\1426\1410944 YG 2014 Faro Pit Slopes\07 Deliverables\Doc 004 Slope Monitoring\Rev. 0\Attachment 1



REV	DATE	DESCRIPTION	DRW	DES	CHK	RVW
0	09/JAN/15	FIGURE	JJR	JJR	AVC	AVC

CLIENT
YUKON GOVERNMENT

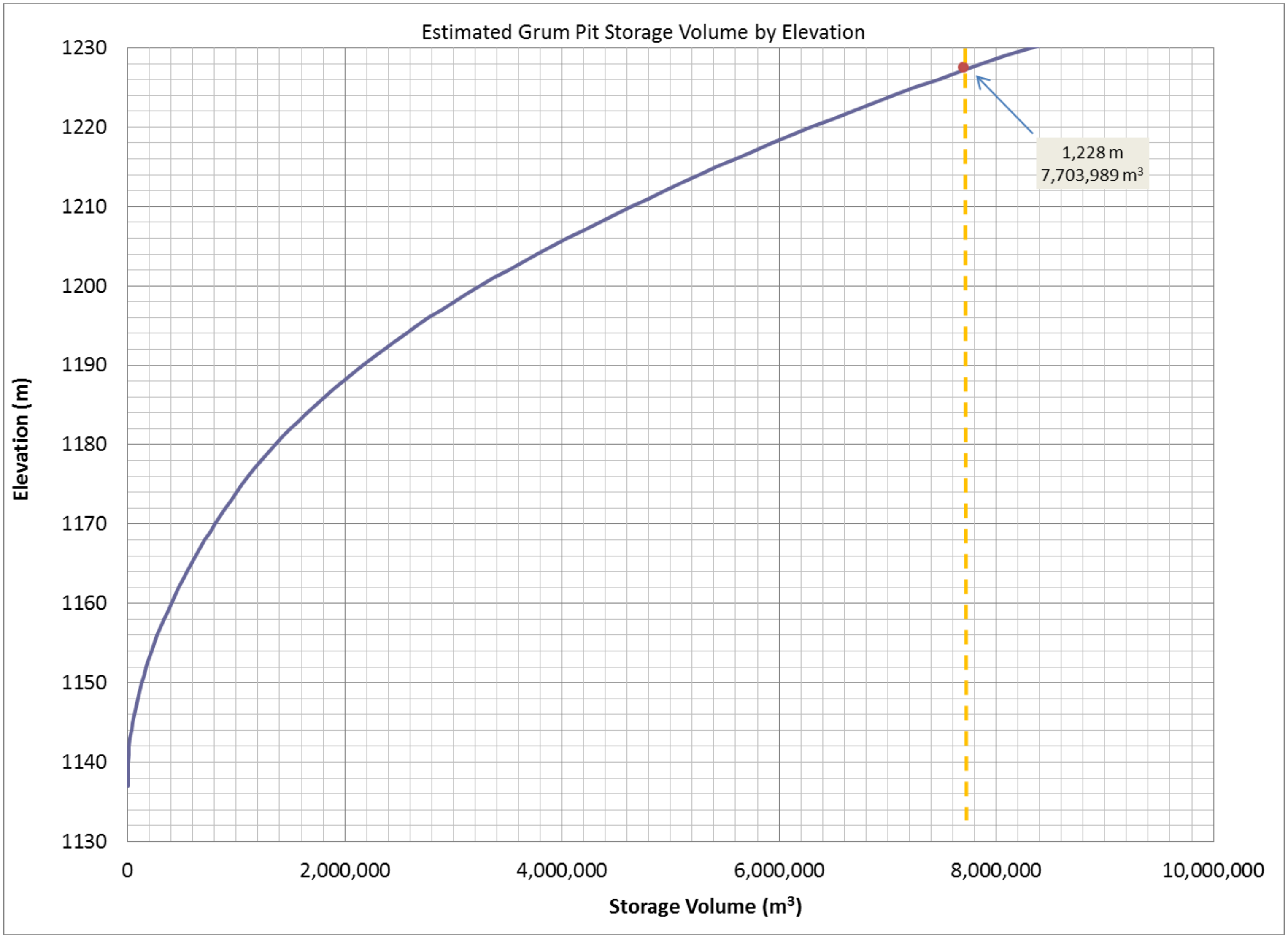
CONSULTANT
Golder Associates

PROJECT 1410944/6000
FARO MINE COMPLEX
REVIEW OF PIT SLOPE MONITORING METHODS

TITLE
SCHEMATIC SHOWING ESTIMATE OF AREA OF FAILURE IN OVERSTEEPENED BACKSCARP

FIGURE No.
1-3

O:\Active_2014\1426\1410944 YG 2014 Faro Pit Slopes\07 Deliverables\Doc 004 Slope Monitoring\Rev. 0\Attachment 1



REV	DATE	DESCRIPTION	DRW	DES	CHK	RVW
0	09/JAN/15	FIGURE	JJR	JJR	AVC	AVC

CLIENT: YUKON GOVERNMENT

CONSULTANT: Golder Associates

PROJECT: 1410944/6000

FARO MINE COMPLEX
REVIEW OF PIT SLOPE MONITORING METHODS

TITLE

GRUM PIT ESTIMATED STORAGE UP TO 1,230 M ELEVATION

FIGURE No. 1-4