# TECHNICAL MEMORANDUM

| | | | |
|---|---|---|---|
| **DATE** | 6 January 2017 | **REFERENCE No.** | 1410944-013-TM-Rev1-2016 |
| **TO** | Ms. Carrie Gillis<br>Faro Mine Remediation Project | | |
| **FROM** | Ryan Preston and Al Chance | **EMAIL** | Ryan_Preston@golder.com;<br>Al_Chance@golder.com |

**FARO MINE REMEDIATION PROJECT PIT SLOPE MONITORING PLAN**

## 1.0 INTRODUCTION

As per work plan # 001 and standing offer agreement AAM-13008-GOLD, Golder Associates Ltd. (Golder) have prepared the following Pit Slope Monitoring Plan for the Faro Mine Remediation Project. The following memorandum summarizes pit slope monitoring activities, trigger events and responses.

### 1.1 Pit Slope Stability Background

Monitoring of the overall pit slope stability of the east wall of the Faro Pit has been carried out by surveying an array of survey pins installed along the crests of the pit. These pins have been surveyed by a survey contractor (Yellowhead Engineering Services, YES) on an annual basis.

The overall stability of the east wall of the Grum Pit has been monitored using a series of tall metal rods that have been inserted into the ground behind the crest of the slope. The distance between the rods and between the crest of the slope were measured on a monthly basis by site personnel. Measurements of crest regression were also recorded on the east wall of the Faro Pit, by site personnel.

Stability of the Vangorda Pit has been largely monitored through visual inspection by Golder and Parsons Personnel, particularly the west wall where instability has been observed in the past. For all three pits, a need has been identified for a formal and prescriptive pit slope monitoring plan. In 2014, safety concerns from site staff related to accessing the crests of the pits resulted in the discontinuation of monitoring by site personnel. At that time, Golder investigated potential alternative pit slope monitoring options (Golder 2015). The goal of the new monitoring options was to provide information on overall slope stability as well as pit crest regression without the need for site staff to work near the pit crests. It was desirable to have a system that site staff with no survey background could operate and train new staff on.



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The alternative monitoring recommendations included a combination of photogrammetry monitoring to assess crest regression and overall stability for the Faro and Grum Pits, and the ongoing surveying of the existing crest survey pin array for the Faro Pit by a contractor. The photogrammetry monitoring networks were intended to monitor pit crest regression and overall stability both through visual comparison of photos on a monthly basis from April to October and, generation of 3D models twice annually after June and October monitoring as well as if required for review during trigger action response. The surveying of the existing monitoring pins is intended to provide actual displacement measurements at the crest of the slope.

Based on discussions with Karen Furlong of the Yukon Government, it is Golder's understanding that additional survey pins will not be installed in the Grum Pit, the existing reference pins and monitoring points will no longer be surveyed, and that the 3D photogrammetry models will be used for overall slope stability and crest regression monitoring. It should be noted that the displacement detection threshold of the 3D models is approximately an order of magnitude higher (less accurate) than survey points.

## 2.0 PHOTOGRAMMETRY MONITORING NETWORK

A photogrammetry monitoring network was installed in the Faro, Grum, and Vangorda pits over 7 to 9 September 2016 by Golder in co-operation with Parsons Canada Ltd. (Parsons), the site care and maintenance contractor. The network consists of five monitoring stations per pit, fifteen total (Figures 1 to 3), and is described in the September 2016 site visit memorandum (Golder 2016b). Instructions for collecting data using the network are provided in the Photogrammetry Training Manual (Golder 2016c).

The accuracy of models generated from the Photogrammetry Network is controlled largely by the resolutions of the photos and the spacing of the tripods. Photo resolution is controlled by distance to the slope face which varies between each photograph due to rotation of the camera across the slope face and variability of tripod locations. However, model accuracy can be calculated using the average distance, resolution and camera separation. Based on the range of camera separations between approximately 1/8 to 1/2 of distance to the slope face, an average ratio of 1/5 was used for accuracy calculations. Photogrammetry bundle adjustments for all three pits returned re-projection errors between 0.332 and 0.359 pixels. It is expected that future models can maintain an average accuracy of 0.35 pixels which is used to estimate local model accuracy. Absolute model accuracy is dependent on the accuracy of the tripod survey and is not important to slope stability monitoring, which is largely concerned with relative change. Table 1 summarizes the average working distance, photograph resolution and estimated accuracy parallel and normal to the slope faces.

**Table 1: Average Resolution and Estimated 3D Model Accuracy**

| Pit | Average Working Distance (m) | Average Photograph Resolution (cm/pixel) | Estimated Accuracy Parallel to Slope Face (cm) | Estimated Accuracy Normal to Slope Face (cm) |
|---|---|---|---|---|
| Faro | 825 | 2.67 | 0.93 | 4.67 |
| Grum | 594 | 1.90 | 0.67 | 3.33 |
| Vangorda | 414 | 3.39 | 1.19 | 5.93 |

This resolution and accuracy is considered acceptable to measure crest regression and/or displacements in each of the pits, but is not as accurate as a conventional prism monitoring system.

There is a critical portion of the Faro pit crest that is exhibiting crest regression adjacent to the Faro Creek Diversion Channel (FCDC) (Figure 4). It is desirable to be able to accurately measure the crest regression in this area. In order to increase the accuracy of the photogrammetry monitoring in this area, a large, long object which will be visible from across the pit (i.e. section of thick pipe or a telephone pole), marked in 20 cm increments could be lain behind the area of maximum crest regression in the Faro pit, perpendicular to the slope, such that approximately 1 m of the pole extends over the crest, beyond the regression (Figure 4). This will serve as a scalar reference during photograph comparison and, when combined with the high resolution photos (approximately 3 cm ground coverage per pixel), will allow for remote measurement of the regression. Large objects such as telephone poles and HDPE pipes are advantageous because they are visible from across the pit and can be placed using an excavator or similar large equipment to manipulate the far end of the pole/pipe while maintaining clearance from the pit crest. If this is considered unfeasible or unsafe, the crest regression in this area can be estimated using the photogrammetry system only. However, the addition of the marked large object provides a known reference to confirm the displacements indicated by photogrammetry. Having this reference point will improve the accuracy of crest regression estimates at this critical location.

When not in use, and particularly during wet months, the installed tripods should be covered with tarps to protect from moisture and precipitation. As tarps were not provided during installation of the network, Parsons should procure small tarps appropriate for covering the tripods. Alternatively, Golder can co-ordinate purchase and delivery with an appropriate purchase order.

## 3.0 FARO PIT SURVEY PIN MONITORING

Given the favorable ongoing slope stability performance of the pit walls, in 2015 it was agreed that Golder would carry out pit slope inspections every two years, rather than on an annual basis. This schedule is contingent on the slope continuing to remain stable and not exhibiting a rapid increase in crest regression. It was agreed that the survey pins behind the east wall of the Faro Pit would continue to be read on annual basis by YES.

We also understand that in late 2015, a slope inclinometer was installed behind the crest of the east wall of the Faro Pit. It is Golder's understanding that BGC are receiving and interpreting data from the Faro Pit inclinometers on a regular basis.

In view of the above considerations, given that the photogrammetry monitoring system is now operational, and in the interest of reducing costs, it is recommended that the survey pins be read by YES every second year in conjunction with Golder's pit slope inspection site visit.

## 4.0 STABILITY MONITORING AND MOVEMENT CRITERIA

### 4.1 Photogrammetry Monitoring Schedule

Pit slope monitoring is most critical during the spring thaw and summer/fall rain storms. As such, it is recommended that photogrammetry data be collected from each monitoring station in each pit, on a monthly basis between April and October. Concurrent to photo data collection, the crests should be inspected from a safe distance to check for ponding water and new or expanded tension cracks. To ensure worker safety, personnel should not pass beyond the first observed tension crack and should always maintain a safe clearance from the pit crest as dictated by relevant local regulations and company policy .

Photogrammetry monitoring should ideally be conducted on evenly spaced intervals, i.e., the first day of the month. However, the schedule should be adjusted so that photos can be collected during times of good visibility. Photogrammetry data should not be collected during heavy rain, snow, fog or other weather which may obscure the view of the slope.

In addition to the monitoring detailed above, in the event of an earthquake which is felt on site, regardless of magnitude, etc., or a 30 mm rainfall event within a 24 hour period as reported by one or more nearby weather stations, a crest inspection and photo comparison should be conducted as soon as possible following the event.

Parsons staff suggested that panorama photographs from each pit could be posted in the common area of the mine office. Alternatively, the panoramas could be presented at morning safety meetings, such that other site personnel can review and comment on any changes from historic conditions.

## 4.2 Trigger Action Response Plan

Within a day following photo data collection, site staff should compare the current photos between previous months and years to detect changes such as sloughing, bulging, and changes in seepage patterns. Figures 5 to 10 present examples of changes in slope condition which should be noted.

### 4.2.1 Low Alarm

In the event of any of the following conditions, Golder and the Yukon Government should be notified as soon as possible:

- Any crest regression in the critical area of the Faro Pit crest observed from photo comparison or crest tours (Figure 4).
- Any regression or sloughing affecting an area of 5×5 m or greater in any of the pits (Figures 5 to 8). The 3D PDF models provided in Golder's site visit report (Golder 2016b) can be used to measure affected areas (Figure 9).
- Increases in pit wall seepage above those normally experienced for the time of year (Figure 7). Photo data from the preceding year and site personnel experience can be utilized to determine if observed seepage is unseasonal.
- New or growing cracks are observed in the pit crest (Figure 10).
- If BGC report displacements observed in the Faro Pit inclinometer data.

During low alarms, care and maintenance operations within and around the pit areas may continue. Golder will endeavour to provide guidance within the next business day of receiving notice. A spotter should be used whenever personnel are working within the affected pit or along the affected pit crest during Low Alarm periods. The spotter's purpose is to scan the pit walls and crest, especially in areas of previously observed deformation or slope instability activity, for signs of rapidly changing ground conditions. The intent of the spotters is to provide advance warning to staff working in the pit who may not be aware of rapidly changing conditions that warrant a rapid evacuation of the pit.

### 4.2.2 High Alarm

In the event that slopes are observed to be undergoing daily change, such as continual slumping, growth of seepage areas or a slump of 10×10 m or greater area, operations in the pit and along the pit crest should cease until the pit wall stability is reviewed by Golder.

## 4.3 Communications with Golder

Unless any of the triggers discussed in Section 4.2 are observed following monthly data review by Parsons, data should be sent to Golder twice per year, after the June data collection and again after the October data collection.

From discussion with Karen Furlong, it is Golder's understanding that slope inclinometers have been installed at the pit crest by BGC Engineering (BGC), with the data being reviewed by BGC on a regular basis. The inclinometer data should also be sent to Golder, so that Golder can also review these data to assist in the assessment of the Faro pit east wall overall slope stability.

Twice yearly, after receipt of April to June data and again after receipt of July to October data, Golder will review the photo data, generate 3D photogrammetry models and compare them to the September, 2016 and subsequent models to analyse for potential large scale slope stability. The results of this review will be summarized in a technical memorandum with 3D pit models provided as 3D PDFs for site personnel's reference. It should be noted that budget for this work is not provided under work plan #001, and a new scope of work, budget and authorization to carry out the work will be required.

## 5.0 CLOSURE

The reader is referred to the Study Limitations, which follows the text and forms an integral part of this memorandum.

We trust this memorandum addresses your current needs for a Pit Slope Monitoring Plan and Trigger Action Response Plan at the Faro Mine Remediation Project. Please do not hesitate to contact us if you have any questions or comments.

**GOLDER ASSOCIATES LTD.**

PROFESSIONAL ENGINEER YUKON TERRITORY Jan 6/2017

Ryan Preston, MSc, PEng (BC)
Geological Engineer

Al Chance, PEng
Principal, Mining Geotechnical Engineer

RP/AVC/it/cmm/rs/ah/itcmm

Attachments: Study Limitations
Figures 1 to 10

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## REFERENCES

Golder Associates Ltd (Golder). 2015. Study of Alternative Slope Monitoring Methods for Faro and Grum Pits. Submitted to Faro Mine Remediation Project Assessment and Abandoned Mines, Whitehorse, YT, Canada. Golder Doc. No. 1410944-004-TM-Rev0-7000. 14 January 2015.

Golder 2016a. 2015 Pit Slope Stability Review. Submitted to Faro Mine Remediation Project Assessment and Abandoned Mines, Whitehorse, YT, Canada. Golder Doc. No. 1410944-007-R-Rev0-2015. 16 February 2016.

Golder 2016b. Faro Mine Remediation Project September 2016 Site Visit. Submitted to Faro Mine Remediation Project, Whitehorse, YT, Canada. Golder Doc. No. 1410944-011-TM-RevB-2016. 7 October 2016.

Golder 2016c. Pit Slope Photogrammetry Monitoring Network Training Manual. Submitted to Faro Mine Remediation Project, Whitehorse, YT, Canada. Golder Doc. No. 1410944-012-TM-RevB-2016. 7 October 2016.

## 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.

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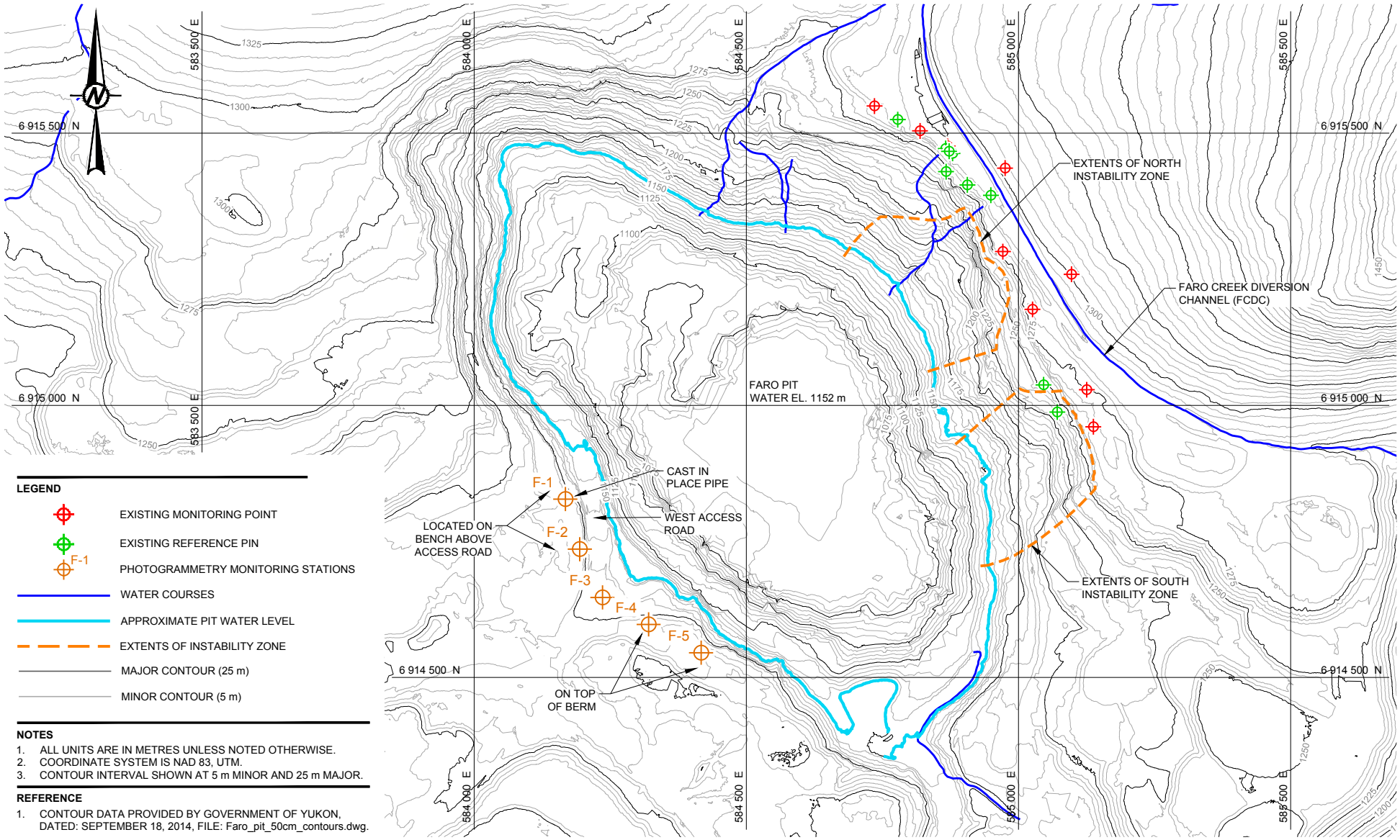


**LEGEND**

- EXISTING MONITORING POINT
- EXISTING REFERENCE PIN
- F-1 PHOTOGRAMMETRY MONITORING STATIONS
- WATER COURSES
- APPROXIMATE PIT WATER LEVEL
- EXTENTS OF INSTABILITY ZONE
- MAJOR CONTOUR (25 m)
- MINOR CONTOUR (5 m)

**NOTES**

1. ALL UNITS ARE IN METRES UNLESS NOTED OTHERWISE.
2. COORDINATE SYSTEM IS NAD 83, UTM.
3. CONTOUR INTERVAL SHOWN AT 5 m MINOR AND 25 m MAJOR.

**REFERENCE**

1. CONTOUR DATA PROVIDED BY GOVERNMENT OF YUKON, DATED: SEPTEMBER 18, 2014, FILE: Faro_pit_50cm_contours.dwg.

NOT FOR CONSTRUCTION

0 250 500
1:10,000 METRES

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YUKON GOVERNMENT

CONSULTANT
Golder Associates

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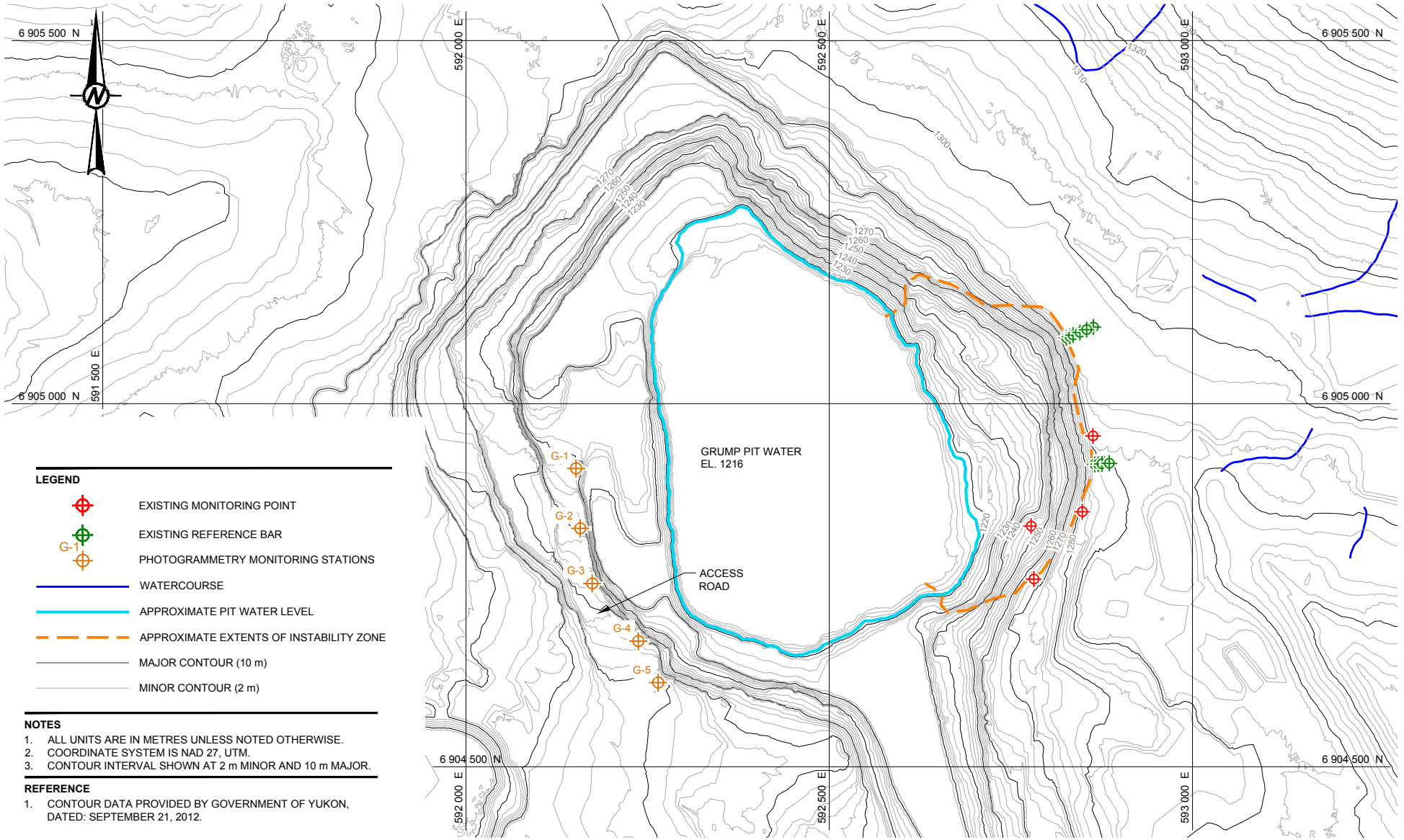
| YYYY-MM-DD | 2016-12-07 |
| DESIGNED | RP |
| PREPARED | RM |
| REVIEWED | RP |
| APPROVED | AC |

PROJECT
FARO MINE REMEDIATION PROJECT
FARO, YT

TITLE
**INSTALLED LOCATIONS OF FARO PIT MONITORING STATIONS**

| PROJECT NO. | PHASE | REV. | FIGURE |
|---|---|---|---|
| 1410944 | 2016 | 0 | 1 |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
0 25 mm




**LEGEND**

- EXISTING MONITORING POINT
- EXISTING REFERENCE BAR
- G-1 PHOTOGRAMMETRY MONITORING STATIONS
- WATERCOURSE
- APPROXIMATE PIT WATER LEVEL
- APPROXIMATE EXTENTS OF INSTABILITY ZONE
- MAJOR CONTOUR (10 m)
- MINOR CONTOUR (2 m)

**NOTES**

1. ALL UNITS ARE IN METRES UNLESS NOTED OTHERWISE.
2. COORDINATE SYSTEM IS NAD 27, UTM.
3. CONTOUR INTERVAL SHOWN AT 2 m MINOR AND 10 m MAJOR.

**REFERENCE**

1. CONTOUR DATA PROVIDED BY GOVERNMENT OF YUKON, DATED: SEPTEMBER 21, 2012.

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| REVIEWED | RP |
| APPROVED | AC |

PROJECT
FARO MINE REMEDIATION PROJECT
FARO, YT

TITLE
**INSTALLED LOCATIONS OF GRUM PIT PHOTOGRAMMETRY MONITORING STATIONS**

| PROJECT NO. | PHASE | REV. | FIGURE |
|---|---|---|---|
| 1410944 | 2016 | 0 | 2 |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

0 25 mm

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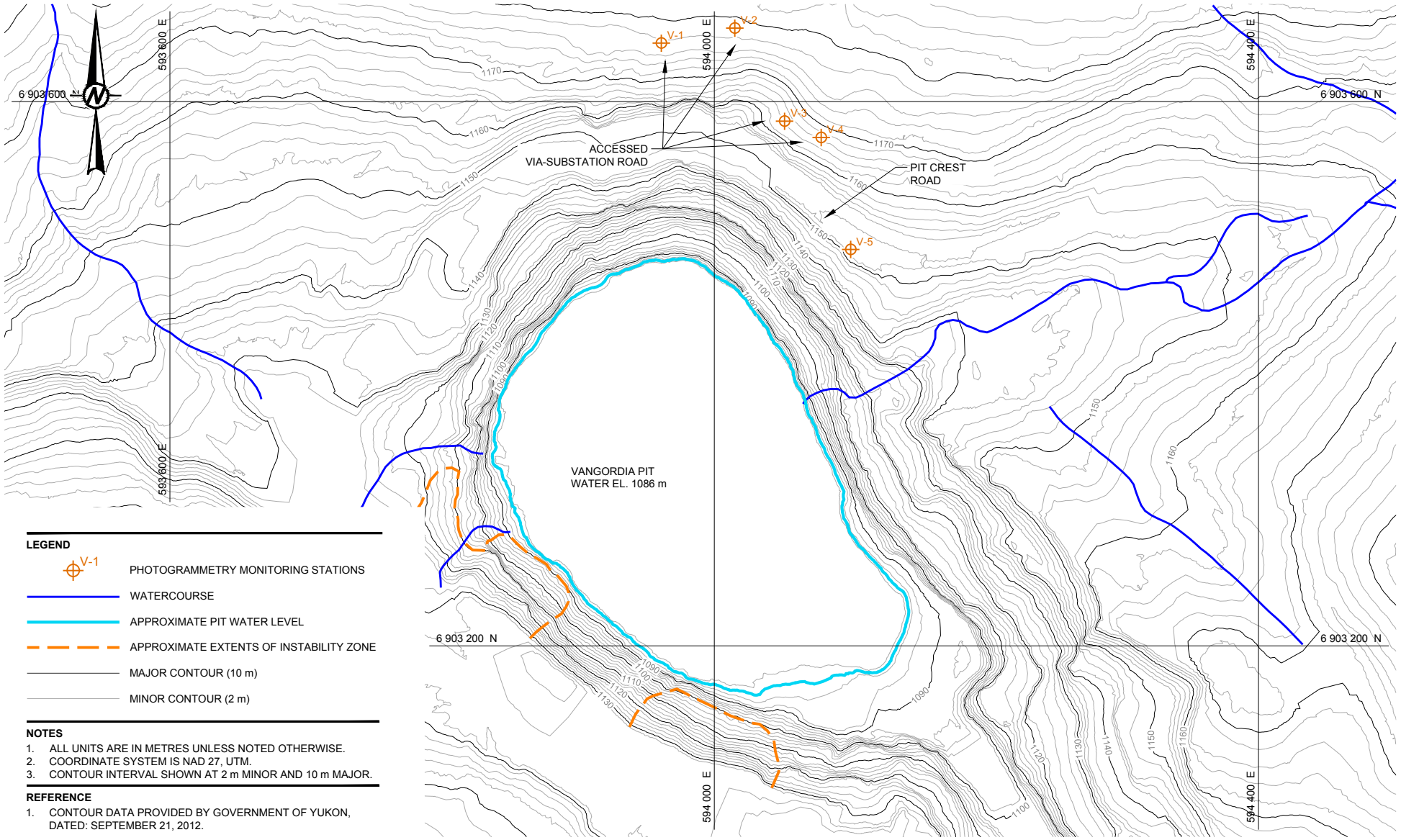


**LEGEND**

- V-1 — PHOTOGRAMMETRY MONITORING STATIONS
- WATERCOURSE
- APPROXIMATE PIT WATER LEVEL
- APPROXIMATE EXTENTS OF INSTABILITY ZONE
- MAJOR CONTOUR (10 m)
- MINOR CONTOUR (2 m)

**NOTES**

1. ALL UNITS ARE IN METRES UNLESS NOTED OTHERWISE.
2. COORDINATE SYSTEM IS NAD 27, UTM.
3. CONTOUR INTERVAL SHOWN AT 2 m MINOR AND 10 m MAJOR.

**REFERENCE**

1. CONTOUR DATA PROVIDED BY GOVERNMENT OF YUKON, DATED: SEPTEMBER 21, 2012.

NOT FOR CONSTRUCTION

0 100 200
1:4,000 METRES

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YUKON GOVERNMENT

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| PREPARED | RP/RM |
| REVIEWED | RP |
| APPROVED | AC |

PROJECT
FARO MINE REMEDIATION PROJECT
FARO, YT

TITLE
**INSTALLED LOCATIONS OF VANAGORDA PIT MONITORING STATIONS**

| PROJECT NO. | PHASE | REV. | FIGURE |
|---|---|---|---|
| 1410944 | 2016 | 0 | 3 |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

0 25 mm


| REV | DATE | DESCRIPTION | DRW | DES | CHK | RVW |
|---|---|---|---|---|---|---|
| B | 26/SEP/16 | FIGURE | RP | RP | AVC | AVC |

CLIENT
YUKON GOVERNMENT

CONSULTANT
Golder Associates

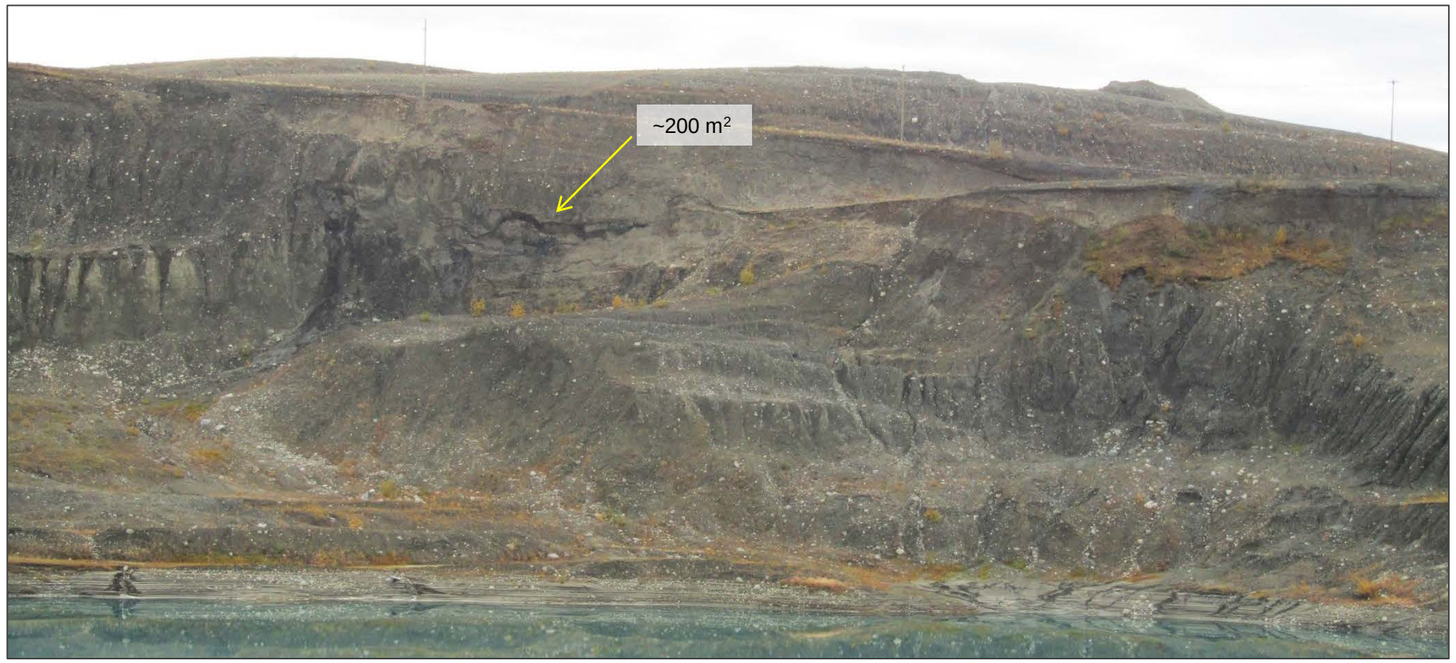
PROJECT
1410944/2015
FARO MINE REMEDIATION PROJECT
FARO, YT
PIT SLOPE MONITORING PLAN

TITLE
CRITICAL CREST REGRESSION AREA WITH SCHEMATIC LAYOUT FOR TELEPHONE POLE

FIGURE No.
4

O:\Active_2014\1426\1410944 YG 2014 Faro Pit Slopes\2016\01 Deliverables\1410944-013-TM-RevB-Pit Slope Monitoring Plan

2014 PHOTOGRAPH OF INSTABILITY ZONE, VIEW LOOKING EAST




2015 PHOTOGRAPH OF INSTABILITY ZONE, VIEW LOOKING EAST

| REV | DATE | DESCRIPTION | DRW | DES | CHK | RVW |
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| B | 26/SEP/16 | FIGURE | RP | RP | AVC | AVC |

CLIENT: YUKON GOVERNMENT

PROJECT: 1410944/2015
FARO MINE REMEDIATION PROJECT
FARO, YT
PIT SLOPE MONITORING PLAN

CONSULTANT: Golder Associates

TITLE: EXAMPLE OF SLOUGHING – GRUM PIT

FIGURE No. 5

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2014 PHOTOGRAPH OF CREST OF EAST WALL, BACKSCARP OF INSTABILITY ZONE, VIEW LOOKING EAST

2015 PHOTOGRAPH OF CREST OF EAST WALL, BACKSCARP OF INSTABILITY ZONE, VIEW LOOKING EAST

| REV | DATE | DESCRIPTION | DRW | DES | CHK | RVW |
|---|---|---|---|---|---|---|
| B | 26/SEP/16 | FIGURE | RP | RP | AVC | AVC |

CLIENT: YUKON GOVERNMENT

CONSULTANT: Golder Associates

PROJECT: 1410944/2015
FARO MINE REMEDIATION PROJECT
FARO, YT
PIT SLOPE MONITORING PLAN

TITLE: EXAMPLE OF SLUMPING – GRUM PIT

FIGURE No. 6

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2014 - SOUTH SIDE OF UPPER WEST WALL, VIEW LOOKING WEST

2015 - SOUTH SIDE OF UPPER WEST WALL, VIEW LOOKING WEST
YELLOW ARROWS SLUMPED AREAS

| REV | DATE | DESCRIPTION | DRW | DES | CHK | RVW |
|---|---|---|---|---|---|---|
| B | 26/SEP/16 | FIGURE | RP | RP | AVC | AVC |

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PROJECT
1410944/2015
FARO MINE REMEDIATION PROJECT
FARO, YT
PIT SLOPE MONITORING PLAN

TITLE
SEEPAGE INDUCED SLOUGHING IN UPPER PART OF VANGORDA WEST WALL

FIGURE No.
7

O:\Active_2014\1426\1410944 YG 2014 Faro Pit Slopes\2016\01 Deliverables\1410944-013-TM-RevB-Pit Slope Monitoring Plan

NORTH SIDE OF WEST WALL, VIEW LOOKING WEST
ARROWS INDICATE RECENTLY SLUMPED AREAS


NORTH SIDE OF WEST WALL, VIEW LOOKING SOUTH FROM CREST
ARROWS INDICATE CRACKS

| REV | DATE | DESCRIPTION | DRW | DES | CHK | RVW |
|---|---|---|---|---|---|---|
| B | 26/SEP/16 | FIGURE | RP | RP | AVC | AVC |

CLIENT: YUKON GOVERNMENT

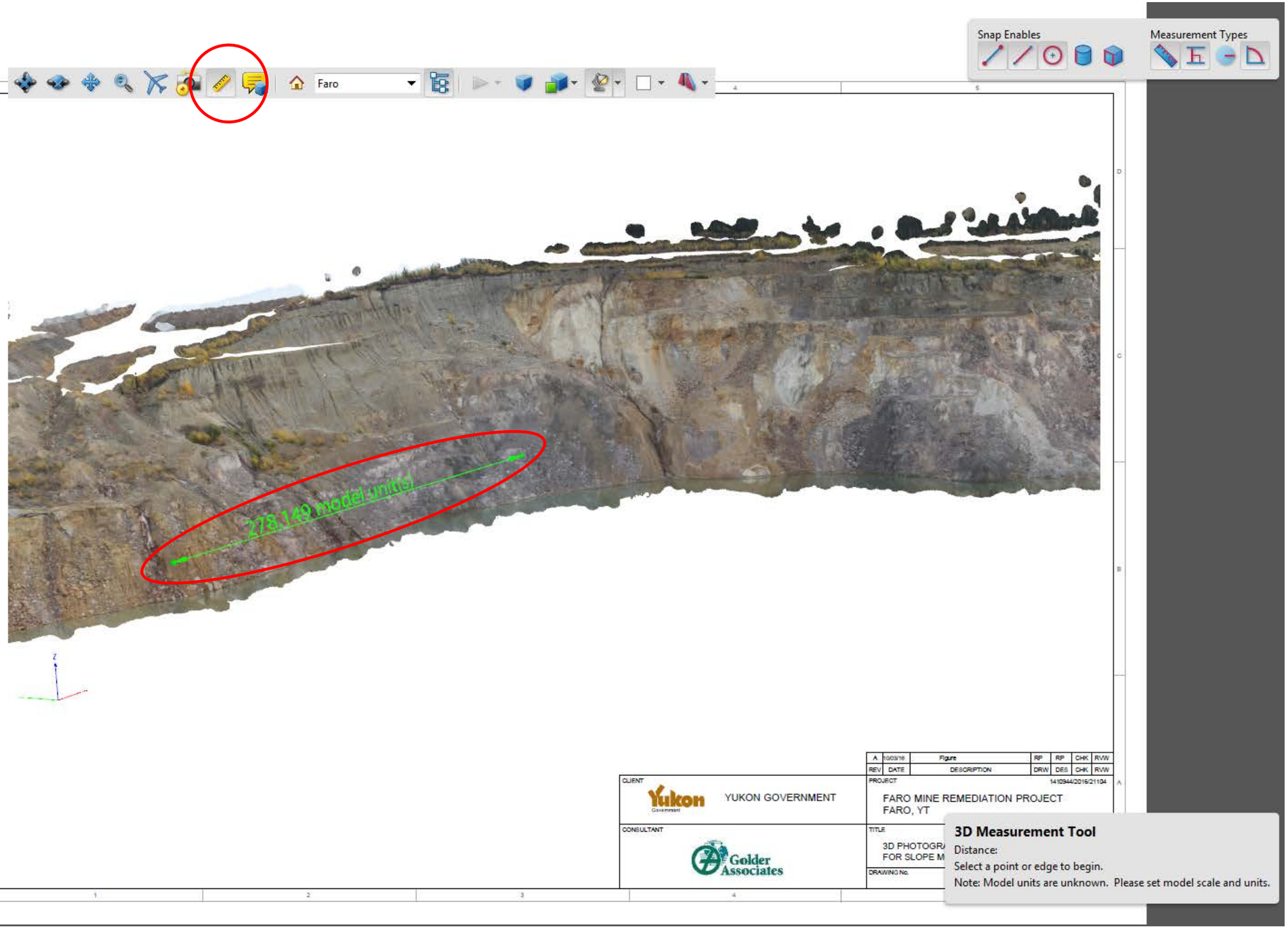
CONSULTANT: Golder Associates

PROJECT: 1410944/2015
FARO MINE REMEDIATION PROJECT
FARO, YT
PIT SLOPE MONITORING PLAN

TITLE: CRACKS AND SLOUGHING IN UPPER PART OF VANGORDA WEST WALL – NORTH SIDE

FIGURE No. 8

O:\Active_2014\1426\1410944 YG 2014 Faro Pit Slopes\2016\01 Deliverables\1410944-013-TM-RevB-Pit Slope Monitoring Plan




| REV | DATE | DESCRIPTION | DRW | DES | CHK | RVW |
|---|---|---|---|---|---|---|
| A | 10/03/16 | Figure | RP | RP | CHK | RVW |

CLIENT: YUKON GOVERNMENT

CONSULTANT: Golder Associates

PROJECT: 1410944/2016/21104
FARO MINE REMEDIATION PROJECT
FARO, YT

TITLE: 3D PHOTOGRA
FOR SLOPE M

DRAWING No.

NOTE: MODELS ARE ALL SCALED IN METERS

| REV | DATE | DESCRIPTION | DRW | DES | CHK | RVW |
|---|---|---|---|---|---|---|
| B | 26/SEP/16 | FIGURE | RP | RP | AVC | AVC |

CLIENT: YUKON GOVERNMENT

CONSULTANT: Golder Associates

PROJECT: 1410944/2015
FARO MINE REMEDIATION PROJECT
FARO, YT
PIT SLOPE MONITORING PLAN

TITLE: MEASURING DIMENSIONS FROM 3D PDF MODEL

FIGURE No. 9

O:\Active_2014\1426\1410944 YG 2014 Faro Pit Slopes\2016\01 Deliverables\1410944-013-TM-RevB-Pit Slope Monitoring Plan





CRACKS CONTINUE TO THE NORTH OF NORTH ARRAY,
BEHIND THE CREST OF THE EAST WALL

| REV | DATE | DESCRIPTION | DRW | DES | CHK | RVW |
|---|---|---|---|---|---|---|
| B | 26/SEP/16 | FIGURE | RP | RP | AVC | AVC |

CLIENT: YUKON GOVERNMENT

CONSULTANT: Golder Associates

PROJECT: 1410944/2015
FARO MINE REMEDIATION PROJECT
FARO, YT
PIT SLOPE MONITORING PLAN

TITLE: CRACKS IN TILL BEHIND CREST OF EAST WALL – GRUM PIT

FIGURE No. 10

O:\Active_2014\1426\1410944 YG 2014 Faro Pit Slopes\2016\01 Deliverables\1410944-013-TM-RevB-Pit Slope Monitoring Plan