TECHNICAL MEMORANDUM

DATE 16 January 2017 **REFERENCE No.** 1410944-015-TM-Rev1-2016

TO Ms. Carrie Gillis
Faro Mine Remediation Project

FROM Aaron Brisbin and Paolo Chiaramello **EMAIL** Aaron_Brisbin@golder.com; Paolo_Chiaramello@golder.com

FARO – MINING SUPPORT SERVICES: FCO SUMP FLOW PATH ASSESSMENT

1.0 INTRODUCTION

The Faro Mine Complex (FMC) is located approximately 350 kilometres northeast of Whitehorse, Yukon. The Faro Creek Overflow Sump (Sump) at the FMC is located north of the Faro Pit. The Faro Waste Rock Dump (WRD) separates the Sump from the Faro Pit and acts as the southern containment for the Sump. The remainder of the Sump containment is formed by the natural valley of the Faro Creek, downstream of the Faro Creek Diversion Channel (FCDC).

The FCDC diverts runoff from an approximately 16 km² portion of the natural Faro Creek catchment and directs it east around the Faro Pit for discharge to the natural environment through the Rose Creek Diversion. The small direct catchment to the Sump is the area downstream of the FCDC that drains to the sump and is delineated by the FCDC on the northern, eastern and western sides, and by the WRD on the southern side.

Golder understands that if the FCDC were to overflow and/or require diversion (e.g., due to downstream failure), the Faro Mine Remediation Project (FMRP) consider diverting the flow in the FCDC towards the Sump to prevent it from entering the Faro Pit. Under this circumstance the Sump may overflow. Any overflow from the Sump would initially flood the platform between the Sump and the WRD, and then drain to the Faro Pit through existing ditches and incisions.

The purposes of this assessment are to estimate the likelihood of the Sump overflowing, to identify the flow path from the Sump to the Faro Pit if overflow does occur, and to recommend erosion protection upgrades along the flow path, especially along the portion of the flow path located along the FCDC road.

2.0 BACKGROUND

2.1 Previous Studies

A number of hydrology studies have been completed to estimate instantaneous peak flows for catchments around the FMC. Key results of these studies are included in the report "Faro Mine Complex Design Flood Manual", by CH2M Hill Canada Limited (2015). These studies were completed using data available from local and regional hydrometric stations. Maximum flows were found to typically occur during the freshet season, therefore the peak flows reported in CH2M Hill (2015) are likely to represent rain-on-snow events.

Two studies dealt particularly with Faro Creek catchment; Northwest Hydraulics Consultants (NHC, 2001) and NHC/BGC Engineering (NHC and BGC, 2004) estimated instantaneous discharge rates for this catchment for a range of return periods.

2.2 Methodology

For the purpose of assessing the overflow from the Sump, the runoff hydrograph is required for estimating the runoff volume reporting to the Sump and for routing peak flows through the Sump. The inflow hydrograph to the Sump (Figure 2) was developed using the rainfall-runoff software by the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) (USACE, 2016). Climate inputs to the hydrograph development were estimated based on climate data from regional stations near the FMC; catchment parameters were estimated based on Golder's experience on similar projects.

Once validated using instantaneous peak flows from previous studies, the HEC-HMS model was then used to route runoff generated from the catchment area reporting to the Sump (approximately 16 km^2) during storm events with various return periods. The model was run considering a catchment area reporting to the Sump of approximately 16 km^2 (FCDC is diverted to the Sump). The model allows simulating the filling of the Sump and, in the case of the larger storm events, estimating the overflow discharge rate from the Sump. Seepage discharge from the Sump through the WRD was not considered as it was assumed to be negligible in comparison with inflow runoff volumes and flows.

Each storm event modeled is associated to a return period which is a representation of the likelihood of occurrence of the event. Runoff volumes reporting to the Sump during storm events with different return periods were compared to the storage capacity of the Sump, to support the assessment of the likelihood of the Sump overflowing (different initial water levels in the Sump were also considered for this assessment).

3.0 CLIMATE AND HYDROLOGY

3.1 Climate

The magnitudes of 24-hour storms for various return periods were estimated using daily rainfall data available at the Environment Canada Anvil Climate Station (EC 2100120), which is located within 1 km of the Faro Creek catchment and has a daily record period from 1967 to 1991. The annual maximum daily precipitation data for the entire record were processed, and years with significant gaps were removed. The daily maximums were then multiplied by 1.13 to convert to the equivalent 24 hour precipitation (WMO 1986). The resulting data set was fit to an Extreme Value distribution to obtain estimates of storm depths for various return periods (Table 1). The same data set was used to estimate a Probable Maximum Precipitation (PMP) using the Herschfield Method (WMO 1986).

The 24-hour rainfall estimates are considered preliminary and are developed for the purpose of this assessment only; confirmatory assessments would be required if these estimates are to be used for other purposes.

Table 1: 24-hour Rainfall

Return Period (years)	24 Hr Rainfall (mm)
100	54
200	61
500	71
PMP[(a)]	201

a) PMP does not have an associated return period, it is the theoretical maximum precipitation that can occur in an area.

3.2 Hydrology

Hyetograph and catchment runoff characteristics were obtained based on available topographic information and Golder's experience on similar projects, and are presented in Table 2.

Table 2: Hyetograph and Catchment Runoff Characteristics

Parameter	Value	Unit	Reference
Hyetograph	SCS Storm Type 1[(a)]	no unit	Chow (1988)
SCS CN[(b)]	77 (100-year, 200-year and 500-year Return Period), 88.5 (PMP)	no unit	USDA TR-55
Lag Time	55	minutes	USDA TR-55
Catchment Area	16	Km^2	CH2M Hill (2015)

a) US Soil Conservation Service storm type for Alaska is appropriate for the FMC location.

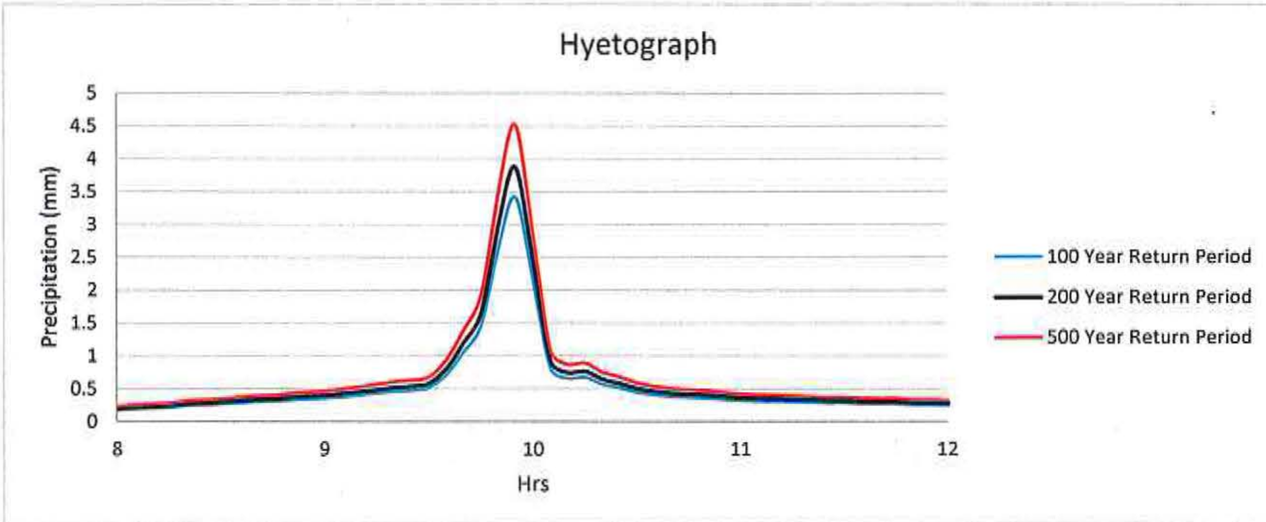
b) US Soil Conservation Service Curve Number for average antecedent moisture condition (AMC II) was considered for events up to the 500 year event; wet antecedent moisture condition (AMC III) was considered for the PMP.

The following hydrological components were not considered in the HEC-HMS model:

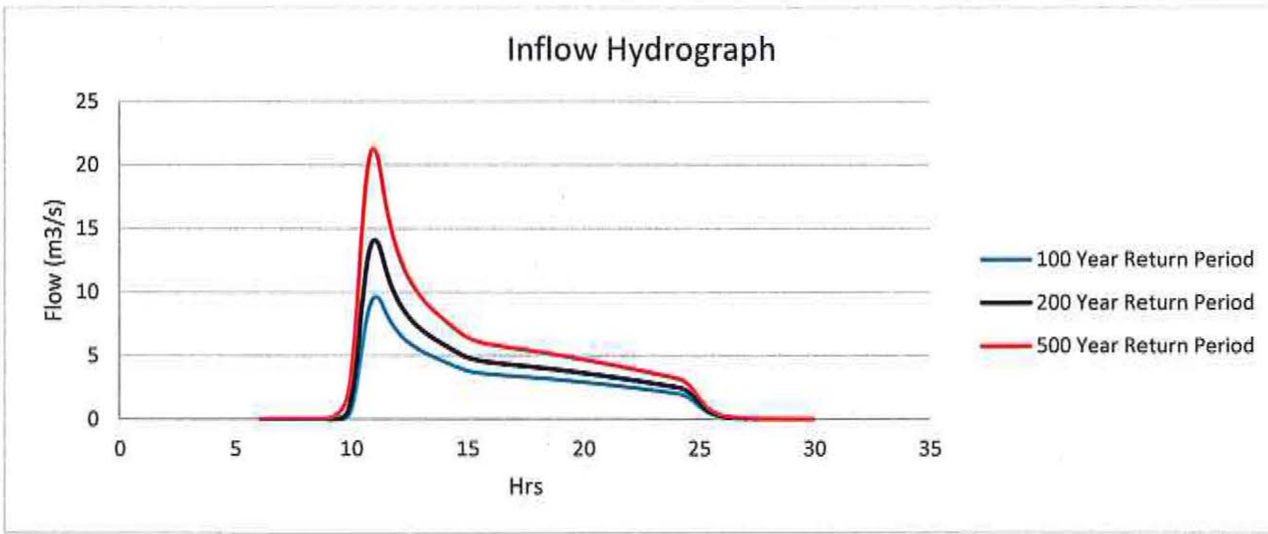
- snowmelt contribution (see Section 3.3)
- attenuation that may be naturally provided by lakes within the catchment reporting to the Sump
- Seepage from the Sump through the WRD.

3.3 Peak Flow Consistency Verification

The hyetographs for the 100-year, 200-year and 500-year 24-hour events, generated based on the assumptions listed in the previous sections, are provided in Graph 1. HEC-HMS uses these hyetographs and the SCS CN values to calculate the portion of the precipitation that contributes to runoff for the catchment, and produces a hydrograph based on these runoff depth and the time of concentration for the catchment area. The inflow hydrographs to the Sump for the 100-year, 200-year, and 500-year 24-hour events are shown in Graph 2.



Graph 1: 100-year, 200-year and 500-year 24-hour Events Hyetographs



Graph 2: 100-year, 200-year and 500-year 24-hour Events Sump Inflows Hydrographs

The estimated instantaneous peak flows obtained with the HEC-HMS model for different storm events are within the ranges provided by previous studies presented in the Faro Mine Complex Design Flood Manual (CH2M), as shown in Table 3. The HEC-HMS model developed is considered suitable to support the preliminary assessment presented in this document; all flows and volumes presented in Section 4.0 are obtained from the HEC-HMS model developed as part of this study.

It is noted that the peak flows in NHC (2001) and NHC and BGC (2004) may include snowmelt contribution, which is not considered in the HEC-HMS model developed for this study. The HEC-HMS model is considered suitable for this preliminary assessment; a model upgrade to include snowmelt contribution is recommended if the model is to be used for further assessments of Sump overflow and erosion along the overflow path.

Table 3: Peak Flow Consistency Verification

Study	Area (km^2)	1-in-100 Year Peak (m^3/s)	1-in-200 Year Peak (m^3/s)	1-in-500 Year Peak (m^3/s)
NHC, 2001	16	14	18	24
NHC and BGC, 2004	16	9.4	11	14
Current Study	**16**	**9.6**	**14.1**	**21.3**

4.0 SUMP OVERFLOW ASSESSMENT AND EROSION PROTECTION FEATURES

4.1 Flow Path Description

Based on the available topographic information, any overflow from the Sump will first flood the platform between the Sump and the WRD, then enter an existing drainage ditch starting at the northeast toe of the WRD and extending along the FCDC road. The ditch crosses the southern WRD access road and connects to a ditch ultimately reporting to the Faro Pit. The complete flow path from the Sump to the Faro Pit is shown on Figure 1, attached. The flow path does not appear to be engineered; erosion may occur along portions of the flow path depending on the magnitude of flow being conveyed.

4.2 Sump Overflow Likelihood Assessment

A reservoir component was included in the HEC-HMS model to simulate Sump filling and overflowing in the flow path. The following elements were included in the model to simulate the Sump:

- an elevation-storage curve (Graph 3), developed based on available topographic information provided by FMRP
- different water levels in the Sump at the beginning of the storm event were considered to account for:
  - active pumping which Golder understand is considered as a potential mitigation measure to maintain low water levels in the sump
  - precipitation that may have occur prior to the modeled event
- no seepage and/or pumping from the Sump during the storm events was considered since these discharges are assumed to be negligible compared to the inflow during the storm
- a catchment area of 16 km^2 was confirmed as total catchment draining to the Sump in the case of the FCDC being diverted to the Sump

The ability of the Sump to contain the runoff inflow generated by a storm event is dependent on the initial water elevation in the sump. Active pumping may allow maintaining a low normal water elevation in the Sump; rainfall events in sequence and snowmelt may temporarily raise the water elevation in the Sump. The HEC-HMS model was run for the 100-year, 200-year, and the 500-year 24-hour events considering various initial water elevations in the Sump, to estimate what storm event will trigger overflow for various initial water elevations. The results of the Sump overflow likelihood assessment are presented in Table 4, and Graph 3.

As shown in Table 4, if the water elevation in the Sump at the beginning of the storm is equal or lower than 1292.0 metres above sea level (masl), the Sump will be able to contain the entire runoff volume generated from the reporting catchment (including FCDC catchment) during storm events up to and including the 500-year, 24-hour event. If the water elevation in the Sump is higher than 1295.0 masl (e.g. due to previous rainfall events, or failure of active pumping) overflow will occur for storm events greater than the 100-year, 24-hour event.

The runoff volume generated from the catchment reporting to the Sump during the PMP, 24-hour event (approximately 3 million m^3) is greater than the total capacity of the Sump; overflow from the Sump will occur during the PMP, 24-hour event.

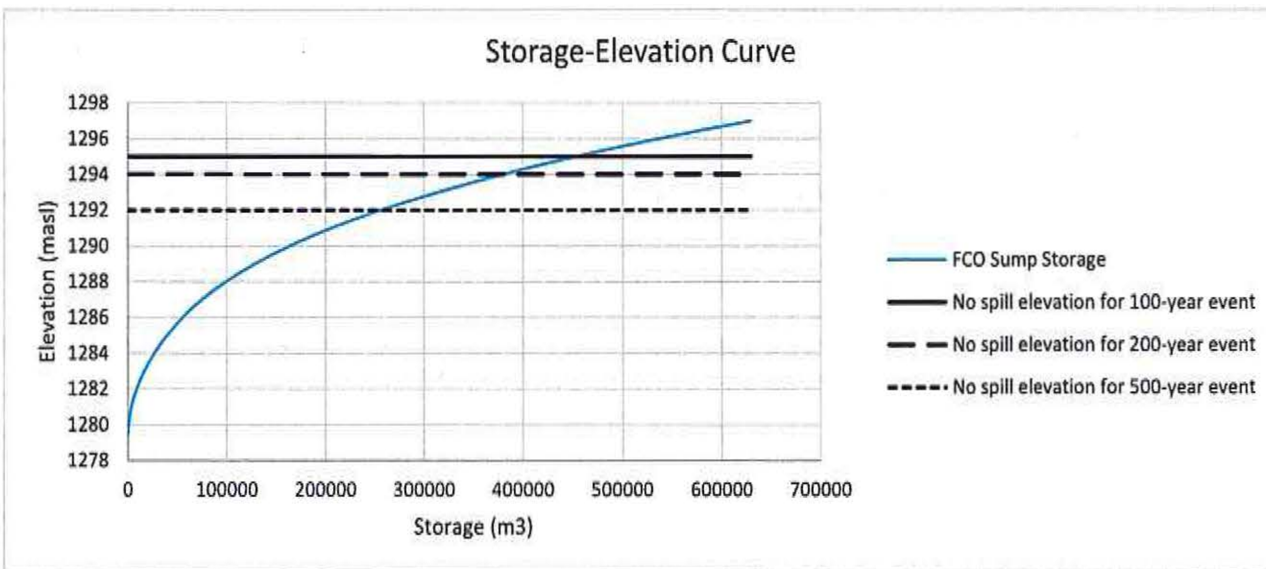
Table 4: Sump Overflow Likelihood Assessment

Initial Water El. (masl)	Initial % of Total Sump Volume	100-year, 24-hour Water El. (masl)	200-year, 24-hour Water El. (masl)	500-year, 24-hour Water El. (masl)
1,292.0	39	1295.5	1296.0	1297.0
1,294.0	56	1296.5	1297.0	Overflow
1,295.0	67	1297.0	Overflow	Overflow
>1295.0	>67	Overflow	Overflow	Overflow

El.: Elevation

The sump will start discharging at elevations greater than 1297.2 masl

masl: metres above sea level



Graph 3: FCO Sump Elevation-Storage Curve and Initial Water Elevations to Avoid Spilling During the 100-year, 200-year and 500-year, 24-hour Storm Events

4.3 Erosion Protection Features

For storm events that generate overflow from the Sump, routed instantaneous peak overflows were estimated and an erosion potential assessment was conducted to identify and preliminarily size erosion protection features along the flow path. To estimate the routed instantaneous peak overflow, an elevation-discharge curve for the Sump overflow was included in the HEC-HMS model. The elevation-discharge curve was obtained using the broad crested weir equation based on the following assumptions:

- a spillway structure with a defined invert shape will be constructed to control overflow
- a discharge coefficient of 1.6 was used to estimate the discharge capacity of the invert of the spillway

Based on the understanding of the existing flow path, two options were investigated for allowing a controlled discharge of the Sump overflow:

- Option 1 – Flooding of the platform between the Sump and the WRD:
  - the overflow from the Sump will be allow to flood the platform and naturally spill into the ditch along the FCDC road
  - the beginning of the ditch located at the northeastern corner of the WRD toe represents the invert of the spillway for this option
  - the approximate dimensions of the invert of the spillway were defined based on available topographic information as 2 m base width and 1 m depth, with 2H:1V side slopes
- Option 2 – No flooding of platform and FCDC road:
  - the overflow from the Sump will enter a spillway channel located on the platform along the toe of the WRD
  - the spillway channel will connect to the existing ditch along the FCDC
  - the beginning of the spillway channel is the invert of the spillway

The overflow assessment was completed considering the 500-year, 24-hour event occurring when the Sump is at approximately 50% of its capacity (initial water elevation of 1292.5 masl).

For Option 1 discharge to the existing flow path from the flooded platform will commence when the flooding on the platform between the Sump and the WRD has reached an elevation of 1297.2 masl. During the 500-year, 24-hour event, the flooding on the platform will reach an elevation of 1,297.4 masl with a peak overflow discharge in the flow path of about 0.2 m^3/s (Table 5). At an elevation of 1,297.4 masl, the flooding on the platform will extend onto the FCDC road fill, and in localized areas road flooding may occur. A small berm or sand bags along the FCDC road in the area near the entrance of the existing ditch along the road (where water will enter the ditch) would reduce the risk of flooding the FCDC road. The estimated peak overflow will be conveyed in the existing flow path with potential risk of erosion/flooding along the flow path only at the start of the flow path and where the flow path crosses the southern access to the WRD. The following erosion/flooding protection features are recommended for option 1:

- A riprap protection pad (approximately 5×5 m) at the upstream end of the existing ditch along the FCDC road to prevent potential erosion generated by overflow entering the ditch from the platform. This riprap pad should have a D_{50} diameter of 150 mm and be a minimum of 300 mm thick.

- A small drive-through swale across the southern access to the waste dump to concentrate flow and limit road flooding. Swale could be excavated across the access road, with a base width of 3 m, a depth of 0.5m and 7H:1V side slopes.

For Option 2, discharge from the Sump will commence at the elevation selected for the invert of the spillway channel, which will be slightly below the elevation of the platform between the Sump and the WRD (at approximately 1296.5 masl). A spillway invert elevation of 1,296.0 masl was selected, approximately 0.5 m below the elevation of the platform. Water that will enter the invert of the spillway will be conveyed by an approximately 70 m long spillway channel located along the northern toe of the WRD. The spillway channel would have a base width of 2 m and would need to be lined with riprap. The spillway channel will discharge to the existing flow path along the FCDC road. For Option 2 flooding will be contained in the spillway channel preventing widespread flooding of the platform between the Sump and the WRD, with a peak discharge overflow rate during the 500-year event of about 3.3 m^3/s (Table 5).

The following erosion/flooding protection features are recommended for option 2:

- An approximately 70 m long spillway channel along the toe of the waste dump; the channel shall have a base width of 2 m and shall be lined with riprap with a minimum D_{50} diameter of 100 mm Riprap protection within the entire length of the ditch along the FCDC road to a minimum depth of to prevent erosion in the ditch. This riprap shall have a D_{50} diameter of 100 mm.
- A small drive-through swale across the southern access to the waste dump to concentrate flow and limit road flooding. Swale could be excavated across the access road, with a base width of 3 m, a depth of 0.5m and 7H:1V side slopes.

The flooding extent and the location of the erosion protection features for the two options are presented in Figure 2.

The overflow assessment was also completed for the PMP, 24-hour event. As expected, the Sump overflow during this event would be substantial. A significant expansion of the existing flow path would be required to convey the peak overflow rate generated during this event.

Table 5: Overflow Assessment Results

Option	Return Period	Peak Sump Overflow (m^3/s)	Overflow Volume (m^3)	Peak Water Elevation (masl)
Option 1 (Platform flooding)*	500	0.2	11,200	1297.4
Option 2 (No platform flooding)**	500	3.3	120,000	1296.7

* Discharge occurs at 1297.2 masl.

**Discharge occurs at 1296.0 masl.

5.0 CONSTRUCTION MATERIAL QUANTITIES AND COST

An estimate of construction material quantities and cost for the erosion protection features described above is presented in Table 6. Cost estimate is based on the assumption that riprap material will be sourced at site and that construction activities will be completed using equipment available at site. Material quantities in Table 6 include a 25% contingency.

Table 6: Construction Material Quantities and Cost Estimate

Scenario	Measure	Riprap Volume (m^3)	Riprap Cost ($)	Cut Volume (m^3)	Cut Cost ($)	Total Cost ($)
Option 1	Existing Ditch (Pad)	14	1,800	14	700	2,500
	Swale	n/a	n/a	122	6,100	6,100
	Total	**14**	**1,800**	**136**	**6,800**	**8,600**
Option 2	Existing Ditch	153	19,800	189	9,500	29,300
	Swale	n/a	n/a	122	6,100	6,100
	Spillway	113	14,700	463	23,200	37,900
	Total	**266**	**34,500**	**774**	**38,800**	**73,300**

6.0 CONCLUSIONS

The assessment indicates that:

- Sump capacity to contain runoff volumes from reporting catchment during storm events would depend on the water elevation in the Sump at the beginning of the storm event. Active pumping from the Sump would allow to keep low water elevations in the Sump.
- The Sump has a storage capacity sufficient to contain runoff from reporting catchment for events up to and including the 500-year event if the Sump water elevation is maintained at or below elevation 1292.0 masl. If water elevation in the Sump is allowed to raise to1295.0 masl, overflow from the Sump may occur for smaller storm events such as the 100-year, 24-hour event.
- During the 500-year event with the Sump at 50% capacity at the beginning of the storm, the Sump will overflow. The existing flow path would handle the estimated Sump overflow peak discharge, with minimal erosion protection features required (estimated cost of approximately $8,600). However the entire platform between the Sump and the WRD will be flooded. Flooding may also extent to the FCDC road fill and surface possibly resulting in eroding portions of the roads.
- Flooding of the platform and FCDC road can be prevented by concentrating the Sump overflow in a spillway channel located on the platform and along the toe of the WRD. The spillway channel will need to be lined with riprap; the ditch along the FCDC road will also need to be lined with riprap to prevent erosion in the ditch (total cost for erosion protection is estimated to be approximately $73,300).

7.0 RECOMMENDATIONS

Based on the considerations above, and assuming that pumping from the Sump will be implemented as a mitigation strategy to reduce risk of Sump overflow, the following recommendations are made:

- No major erosion protection features are considered required along the flow path.
- Monitoring of the water level in the Sump together with active pumping from the Sump should be implemented to maintain normal water levels below elevation 1292.0 masl, to the practical extent.

The construction of a small riprap pad at the entrance of the ditch along the FCDC road and a small swale across the southern access to the WRD could be considered as additional mitigation measures if desired, and/or in the case the findings of the monitoring in the Sump may suggest an increase in the risk of Sump overflow.

8.0 CLOSURE

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

We trust that the information provided in this technical memorandum meets your present needs. Should you have any questions or require additional information, please feel free to contact the undersigned.

GOLDER ASSOCIATES LTD.

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Associate, Senior Water Resources Engineer

APB/PC/it/kp/cmm/ls

Attachments: Study Limitations
Figures 1 and 2

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STUDY LIMITATIONS

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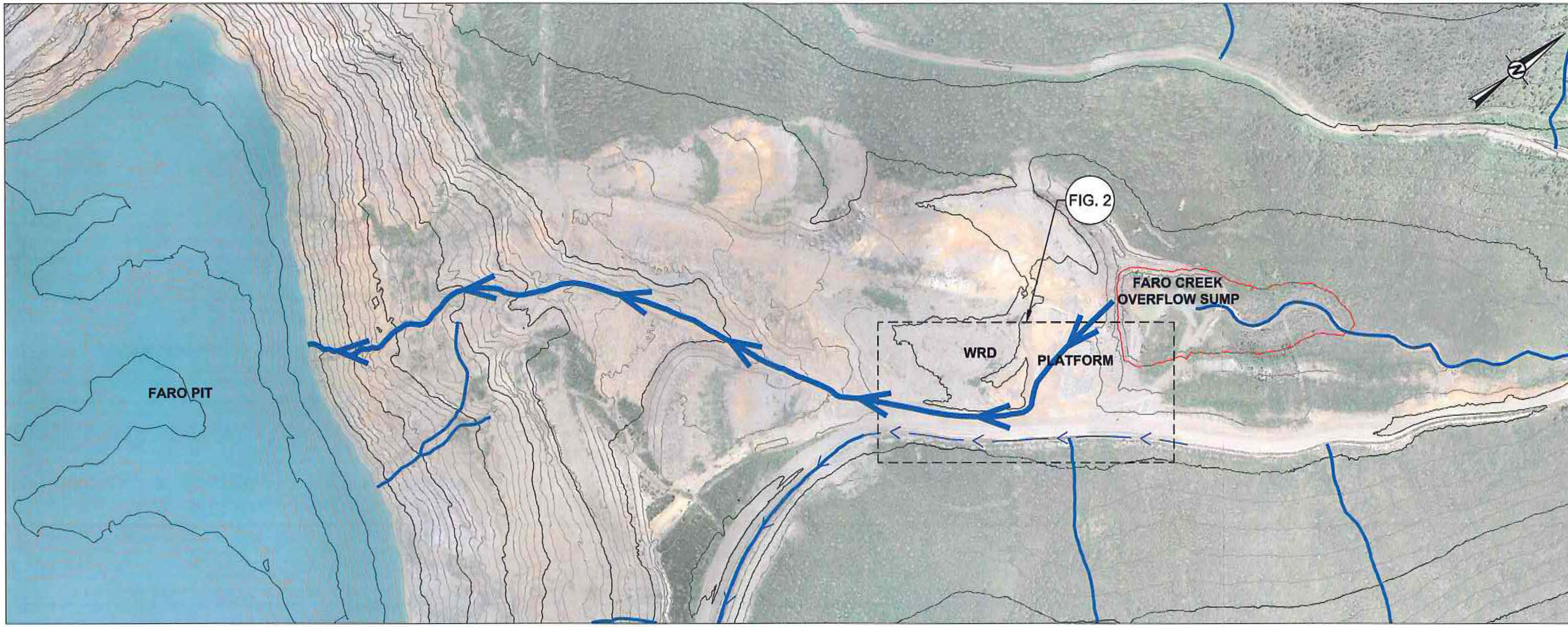


LEGEND

ESTIMATED FLOW PATH

NOT FOR CONSTRUCTION

DRAFT

0 100 200

1:4,000 METRES

NOTES

1. ALL UNITS ARE IN METRES UNLESS NOTED OTHERWISE.
2. COORDINATE SYSTEM IS NAD 83, UTM.

REFERENCES

1. CONTOUR DATA PROVIDED BY GOVERNMENT OF YUKON, DATED: AUGUST 30, 2016, FILE: Faro_pit_50cm_contours.dwg.
2. FLOOD AREA CONTOUR DATA ACQUIRED VIA UNMANNED AERIAL VEHICLE (UAV) SURVEY (GOLDER 2016).
3. 2012 AIRPHOTO PROVIDED BY THE CLIENT.

CLIENT

Yukon Government

YUKON GOVERNMENT
FARO MINE REMEDIATION PROJECT

CONSULTANT

Golder Associates

YYYY-MM-DD	2016-12-12
PREPARED	RM
DESIGN	APB
REVIEW	PC
APPROVED	PC

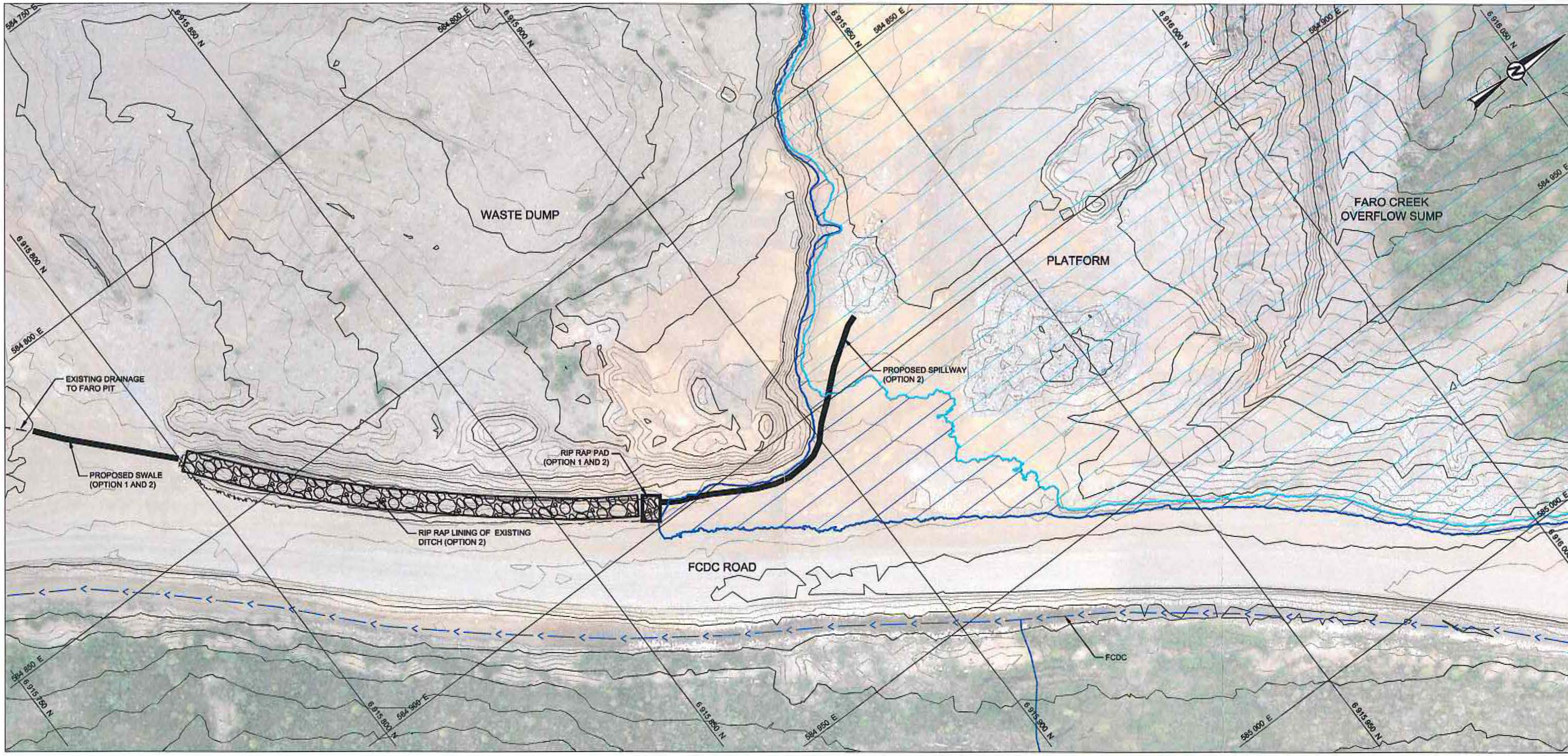
PROJECT
YG FARO MINE COMPLEX
FARO - MINING SUPPORT SERVICES

TITLE
FARO CREEK OVERFLOW SUMP
OVERFLOW PATH

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 B

25mm



LEGEND

- NO SPILLWAY (SCENARIO 1) FLOOD EXTENT (500 - YEAR EVENT)
- SPILLWAY AT 1296 masl (SCENARIO 2) FLOOD EXTENT (500 - YEAR EVENT)
- PROPOSED CHANNEL/SWALE
- RIP RAP LINNING
- FCDC

NOT FOR CONSTRUCTION

DRAFT

0 12.5 25

1:750 METRES

NOTES

1. ALL UNITS ARE IN METRES UNLESS NOTED OTHERWISE.
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3. 2012 AIRPHOTO PROVIDED BY THE CLIENT.

CLIENT

YUKON GOVERNMENT
FARO MINE REMEDIATION PROJECT

PROJECT

YG FARO MINE COMPLEX
FARO - MINING SUPPORT SERVICES

CONSULTANT

Golder Associates

YYYY-MM-DD	2016-12-12
PREPARED	RM
DESIGN	APB
REVIEW	PC
APPROVED	PC

TITLE

FARO CREEK OVERFLOW SUMP
GENERAL LAYOUT AND FLOODING EXTENTS

PROJECT No.	PHASE	Rev.	FIGURE
1410944	2015	0	2

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