DELOITTE & TOUCHE INC.

QUALITATIVE RISK ASSESSMENT OF

DOWN VALLEY TAILINGS AREA

FARO MINE, YUKON

FINAL

Project No: 0257-004-01
Date: November 2001

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Project No. 0257-004
November 8, 2001

Ms. Shannon Glenn
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Final Report on Qualitative Risk Assessment of Down Valley Tailings Area, Faro Mine, Yukon

Dear Ms. Glenn:

Please find attached the final report on the above captioned project. This report incorporates the discussions and comments made during the risk assessment meeting held from May 8 to 10, 2001. The final report incorporates review comments from Deloitte that were dated June 19 and July 16, 2001. In addition, some minor changes have been made to reflect comments supplied by DIAND on the final draft version dated August 17, 2001.

Should any discussion or explanation be required with the various stakeholders, we remain at your service.

Please do not hesitate to call if you have any questions.

Yours truly,
BGC Engineering Inc.
per:

James W. Cassie, M.Sc., P.Eng.
Specialist Geotechnical Engineer

Attachment: Final Report

JWC/sf

EXECUTIVE SUMMARY

The following Executive Summary is provided as a synopsis of the attached report for the convenience of the reader. It should only be read in conjunction with the attached report, which should be read in its entirety. BGC Engineering Inc. cannot be held liable for any errors or omissions resulting from reading only this Executive Summary.

Deloitte and Touche Inc., in their role as Receiver for Anvil Range Mining Corporation, is managing the currently shut-down Faro Mine. As part of their overall site planning process, and in response to potential dam stability concerns raised by Indian and Northern Affairs Canada, BGC Engineering Inc. (BGC) undertook a qualitative risk assessment study for the Fresh Water Supply Dam and the other mine waste containment and water retaining and diverting structures within the Down Valley tailings area. A Failure Mode and Effects Analysis (FMEA) type of risk assessment was undertaken for the existing structures within the Down Valley.

The primary objective of this study is to identify potential failure modes, firstly with the Fresh Water Supply Dam and secondly, with the other various dams, diversion canals and associated structures (within the Down Valley tailings area only) and to estimate the probability of these failures occurring, in order to assess the risks. The secondary objective of this study is to communicate both the risk assessment process and the potential risks to interested stakeholders. The risk assessment exercise is intended to provide a level of understanding and enhanced awareness of the potential hazards, both with individual structures, such as the Fresh Water Supply Dam, and with the overall containment system, associated with the Down Valley tailings area.

In an FMEA, the effects or consequences of individual component failure modes are systematically identified. The FMEA is intended to be a formalized method of project review or engineering reliability technique that will identify risks and allow the characterization and qualitative ranking of risks. The FMEA process does not in itself reduce risks. The four following personnel attended the FMEA meeting in Calgary on May 8 to 10, 2001:

1. Dr. Iain Bruce, P.Eng. (BGC) – Facilitator and Principal Geotechnical Engineer.
2. Mr. Eric Denholm (Gartner Lee Limited) – Formerly Senior Environmental Engineer at Faro Mine and now and Environmental Consultant to D&T on Faro issues.
3. Mr. Jim Cassie, P.Eng. (BGC) – Geotechnical Consultant to D&T on Faro issues.
4. Mr. Glen Gilchrist, P. Eng., (Golder Associates Ltd.) – Formerly, Geotechnical Consultant to both Curragh Resources and Anvil Range Mining Corp. on Faro tailings issues.

The team members worked together to review potential failure modes, assign probabilities of failure occurrence and assess the consequences of failures. Lists of elemental failure modes for dams, waste dumps and diversion channels were developed, based on external statistical work and from internal experience within the review team.

The systems bounds, including the major elements (such as a dam) and links (such as a spillway), within the Down Valley tailings system were outlined. A summary of the physical conditions, major components and structures and water handling processes within the Down Valley was provided.

For the FMEA to be carried out, it is necessary to define appropriate categories for the likelihood of occurrence, the consequences of failure and the confidence limits for each of the two preceding categories. The category selection is necessary in order to calibrate the subjective rankings of the members of the review team. Following from the category definitions, four categories of risk were proposed for this project: High, Moderately High, Moderate and Low. The selected categories of risk are based on the combination of the likelihood of failure occurring, along with the consequences of failure. For each of the four categories proposed, recommendations for the timing of additional work to define and implement remedial action plans are provided.

Within the FMEA study undertaken, for the currently configured structures within the Down Valley tailings area, 127 risk rankings were obtained for various failure modes. Of these 127 risks, 1 was ranked as a High Risk and 34 were ranked as Moderately High for the current configuration of the system. The one High risk occurred with the Fresh Water Supply Dam, which is related to the piping potential of the low level pipe. High risks should have a defined remedial action plan within the next six months and Moderately-High risks should have a remedial action plan within the next six to twelve months.

Six cases, beyond the 127 cases noted above, were also considered with the potential removal of the Fresh Water Supply Dam from the system. In all six cases, the risk ranking appeared to increase with the removal of the Fresh Water Supply Dam. Given the demonstrated importance of the Fresh Water Supply Dam, and acknowledging the potential risks with this structure, it is recommended that the first priority for any additional work in the Down Valley be a hydrotechnical assessment and a Dam Safety Review, in compliance with Section 2.0 of the Canadian Dam Safety Guidelines. Inclusive within this overall safety review should be a piping assessment of the low level pipe. In addition, the physical stability assessment work pertaining to the dam, currently under preparation under separate cover would also form a portion of the Dam Safety Review.

Following from the Fresh Water Supply Dam safety review, next in importance are the potential risks related to seepage and piping potential and the liquefaction of the three major dams and their foundations. Last in priority are an assessment of the foundation conditions beneath the Intermediate Dam, an evaluation of the landsliding potential over top of the Cross Valley pond and reviews of both operational and maintenance protocols and emergency response plans.

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1.0 INTRODUCTION

Recent releases of tailing effluents and solids from containment facilities around the world have heightened awareness that risks associated with tailing containment must be fully addressed during all phases of a facility life. These life-cycle phases include design, construction, operation and closure of tailing impoundments. Several agencies around the world have adopted guidelines for design, construction, management and closure of tailing facilities. These guidelines, including the Mining Association of Canada (1998), generally recommend that a risk assessment be undertaken for each of the design, construction, operational and closure phases of an impoundment life.

Deloitte and Touche Inc. (D&T), in their role as Receiver for Anvil Range Mining Corporation, is managing the currently shut-down Faro Mine, located in the central Yukon. As part of their risk assessment and planning process, and in response to potential dam stability concerns raised by Indian and Northern Affairs Canada (DIAND), BGC Engineering Inc. (BGC) recommended that a third party review be undertaken, using a qualitative risk format. The purpose of undertaking of qualitative risk assessment, which is subjective in nature, is to provide a coarse-screening technique for the prioritization of potential risks with the currently configured structures noted later. This risk assessment study was undertaken for the mine waste containment and water retaining and diverting structures within the Down Valley tailings area.

As such, BGC provided a proposal (No. 01-131), dated April 12, 2001, to D&T. Further from this initial proposal, Mr. Milos Stepanek, P.Eng. of Geo-Engineering (M.S.T.) Ltd. provided some comments on the risk assessment work scope on behalf of DIAND. In addition, a conference call and a meeting were held on May 1 and 7, 2001 between BGC, DIAND, D&T and Geo-Engineering representatives to discuss the risk assessment workscope and to provide some suggested modifications. Written authorization to proceed with the work was provided by Mr. Doug Sedgwick of D&T on May 6, 2001. As such, a Failure Mode and Effects Analysis (FMEA) type of risk assessment for the existing structures within the Down Valley was undertaken.

This report is structured so that third-party personnel, who may not be familiar with risk assessments, can obtain an introduction to the methodology used. The project objectives and constraints are defined in Section 2. A brief history of dam incidents is provided in Section 3, which sets the scene for identifying potential hazards. Risk evaluation methods are provided in Section 4. A brief description of the Faro Mine and background and operations information on the Down Valley tailings impoundment is provided in Section 5. Section 6 provides a summary of FMEA risk assessment results while Section 7 provides suggested work plans for significant failure modes. Section 8 provides a summary of the significant conclusions of the study.

2.0 OBJECTIVES AND CONSTRAINTS

The primary objective of this study is to identify potential failure modes, firstly with the Fresh Water Supply Dam and secondly, with the other various dams, diversion canals and associated structures (within the Down Valley tailings area only) and to estimate the probability of these failures occurring, in order to assess the risks. Associated with this assessment of the potential failure modes of individual structures is an overall evaluation of the entire "system" (defined later in this section) of the structures within, and adjacent to, the Down Valley. The report is intended to be a working document for Faro Mine to allow for the ongoing assessment of risks associated with the Fresh Water Supply Dam in context with other potential risks currently within the Down Valley. Also, this report will help to identify potential limitations for future design and construction aspects proposed for the potential closure phase of this mine. The risk assessment exercise is intended to provide a level of understanding and enhanced awareness of the potential hazards, both with individual structures, such as the Fresh Water Supply Dam, and the overall containment system, associated with the Down Valley tailings area.

The secondary objective of this study is to communicate both the risk assessment process and the potential risks to interested stakeholders. As previously noted, a conference call and a meeting were held with DIAND and Geo-Engineering so that both the process and the proposed objectives were explained to them before undertaking the work. As such, the risk assessment process will be used by D&T to explain and plan the use of future funding for potential assessment, rehabilitation and closure planning work.

The scope of this project is primarily oriented to hazard identification and risk assessment. However, recommendations regarding further technical studies are included where they have been identified as preliminary steps toward the future implementation of risk management.

The FMEA process brings together a series of experts in a workshop format to qualitatively assess both the likelihood of failure occurring for various failure modes and the potential consequences. The study objectives for this FMEA were met by undertaking the tasks identified below:

1. Define the elements and the links within the system to be assessed.
2. Review the risk assessment categories and evaluation criteria for the system.
3. Identify potential failure modes that could lead to the physical release of tailings and/or pond supernatant water into the environment.
4. Qualitatively estimate the probability of failure associated with the failure modes identified.
5. Identify the receptors that would be impacted by any failure and wherever possible, estimate the impact in terms of the degree or the cost of consequences.
6. Provide a qualitative assessment of the risk associated with each occurrence obtained by graphically plotting the probability of occurrence versus the potential consequences.
7. Prepare a summary report outlining the risks evaluated and recommendations for risk mitigation.

The qualitative probabilities defined in this report should be considered “first estimates” based on judgmental assessment of information known by the Review Team members. To reiterate, the estimates provided herein are subjective and this limitation should be noted. As additional information is collected, incidents occur on-site or remedial works are undertaken in the future, these risks should be reassessed and modified.

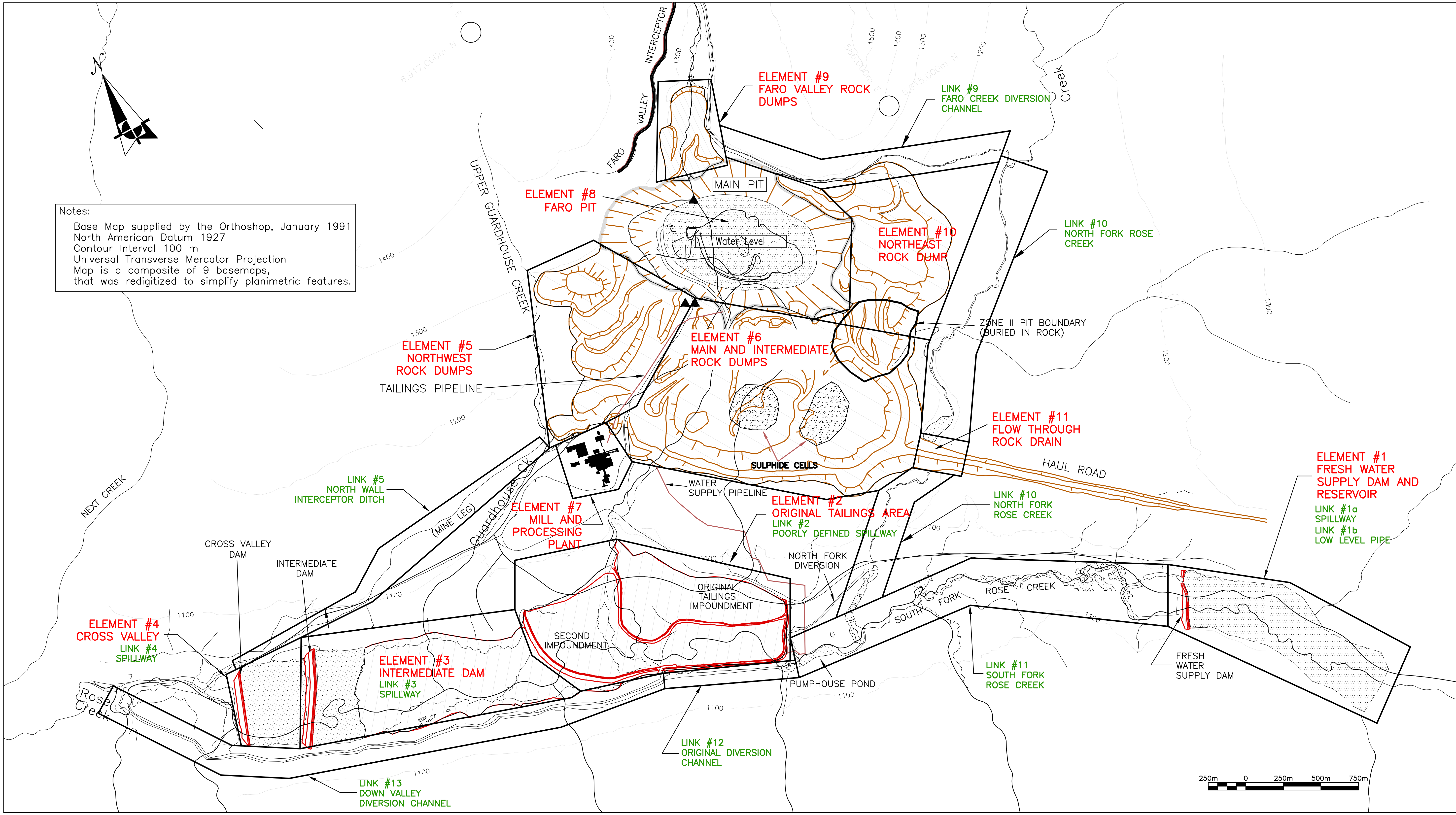
In order to properly assess the risks of a tailing containment area failure, the containment “system” has to be bounded. In this case, the “system” assessed is limited to the elements and links shown on Figure 1. As illustrated, the system contains the Fresh Water Supply Dam, the other major dams and diversion canals situated within the Down Valley. The bounded system also considers the potential impact of further a field components such as the flow-through causeway and the waste dumps surrounding the Faro Pit. Hence, for example, the impact of a failure of the flow-through causeway on the physical integrity of the Down Valley tailings area is assessed.

Within the risk assessment process undertaken, there are a number of constraints on the process that are outlined as follows:

1. The failure modes assessed for the Down Valley project are limited to the area as defined by the elements and links shown in Figure 1.
2. The assessment is limited to the current configuration of the structures and facilities within the Down Valley and on the current understanding of water conveying and procedural systems employed (as outlined in Section 4.4). As such, the analysis and results provided herein are considered appropriate for the period of the next several years, before any changes to the physical conditions are undertaken due to rehabilitation work and/or deterioration. Additional discussion on the relevance of the selected time period for the FMEA is provided in Section 4.5.1 as it pertains to the potential closure phase for this project.
3. This risk assessment examines geotechnical and physical stability issues that could lead to a deleterious affect on the environment (e.g. discharge of tailings outside of the containment area). This assessment, however, does not address potential deleterious impacts on the environment by chemical and geo-environmental issues such as acidic rock drainage (ARD) and/or aquifer contamination from impounded tailings water. These geo-environmental issues may be flagged as concerns in the following rating tables but their potential consequences are not considered within this risk assessment.
4. The assessment assumes that the current level of monitoring, inspection and maintenance will be on going and that both mobile equipment and required materials and personnel can be brought to site in a timely manner, should repairs be required.

In summary, this risk assessment report is meant as a dynamic document and should be revised as additional pertinent information becomes available.

Figure 1 Faro Mine Site Plan Elements and Links for FMEA



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PROJECT
DOWN VALLEY FMEA

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PROJECT No.	DWG. No.	REV.
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3.0 RISK ASSESSMENT DEFINITIONS AND BASIC CONCEPTS

3.1 Introduction

Management of natural hazards by natural resource and transportation industries has for many decades been, and in many cases still is, mainly reactive. However, over the last few years, some industries have become pro-active. Recently, there has been a renewed interest in risk analysis as a means for rationalizing decision-making in current times of financial constraints and limited budgetary resources. More importantly, rising public awareness of risk has led to the need for higher levels of regulatory scrutiny and for modern risk-based approaches to hazard management.

Risk management is an emerging discipline that integrates risk assessment and risk control measures. And, there is widespread acceptance of the merits of risk management. The high hazard chemical and nuclear industries are controlled by risk management procedures, resulting in rigid operating environments and processes that allow only very small deviations from standard procedures. However, risk management methods developed for industries such as these have only limited applications in civil (geotechnical) engineering settings, and even less so towards specific needs of the mining industry.

There is little in the way of published statistics for tailings impoundments so the notion of relative risks has been adopted for this report. Consequently, in this study, the term risk is defined as the combination (a multiplication) of the estimated qualitative likelihood of a specified hazard being realized and the estimated consequences (harm and/or damage) associated with that occurrence.

3.2 Risk Assessment Process

An effective risk assessment initially requires identification of hazards or potential failure modes. Many of the hazards related to tailings containment facilities (inclusive of dikes and dams) are unique to the mining industry. For example, mines, and in particular tailing containment systems, are constructed over long periods of time by a changing work force and usually under changing design criteria. Tailings systems are complex and include man-made components such as dams, pipelines and ponds interacting with natural components such as slopes, seismically active faults, precipitation and runoff. In addition, previous operations can have an impact on newly built components. Furthermore, tailing containment methods are process specific and therefore, can vary from mine to mine.

A comprehensive risk assessment system must account for all types of hazards and affected components existing at a specific site or location. To be effective, the risk assessment approach must be systematic, yet accommodate the varying spatial and temporal considerations of each mine site.

In order to assess as many failure modes as possible, and provide a template for comparison at each mine site, a series of potential failure modes were identified based on previous historical data published by United States Committee on Large Dams (USCOLD, 1994).

Failure modes, which are attributable directly to single external causes, are identified as "elemental failure modes". Elemental failure modes cannot be subdivided further. Examples of elemental failure modes are:

- a pipe bursting as a result of mechanical failure;
- a pipe bursting as a result of a traffic impact; or
- a pipe bursting as a result of over pressurizing due to freezing or sanding.

Several elemental failure modes could independently impact on a given element or link. Such elemental failure modes can be grouped together to create "compound failure modes". For example, a pipeline or siphon rupturing on top of the main dam could lead to a serious stability issue.

3.3 FMEA Technique

A variety of techniques are available for assessing "what can go wrong" and estimating its probability of occurrence. FMEA is a primarily qualitative technique that can be quantified to a degree. In an FMEA, the effects or consequences of individual component failure modes are systematically identified. The analysis is usually descriptive and is organized using a worksheet or table to display the information. FMEA relates component failures modes and their causative factors and effects on the system and presents them in a readable format. The major disadvantages to the FMEA are the difficulties in dealing with generalized risks and comparing these with other assessments to allow ranking of risks. Also, as previously noted, the rankings are subjective.

The FMEA is intended to be a formalized method of project review or engineering reliability technique, which will identify risks and allow the characterization and qualitative ranking of risks. The FMEA process does not in itself reduce risks. However, the systematic characterization it provides can be essential to designing risk management strategies that do.

The four following personnel attended the FMEA meeting on May 8 to 10, 2001:

5. Dr. Iain Bruce, P.Eng. (BGC) – Facilitator and Principal Geotechnical Engineer.
6. Mr. Eric Denholm (Gartner Lee) – Formerly Senior Environmental Engineer at Faro Mine and now and Environmental Consultant to D&T on Faro issues.
7. Mr. Jim Cassie, P.Eng. (BGC) – Geotechnical Consultant to D&T on Faro issues.
8. Mr. Glen Gilchrist, P. Eng., (Golder) – Formerly, Geotechnical Consultant to both Curragh Resources and Anvil Range Mining Corp. on Faro issues.

Three of the meeting attendees have extensive geotechnical and environmental experience specifically from Faro Mine and Dr. Bruce has worked previously on one assessment project related to Faro Mine. The team members worked together to review potential failure modes, assign probabilities of failure occurrence and assess the consequences of failures.

The probability of an event occurring has been estimated based on what has occurred at this mine in the past. As well, the probability was assessed by estimating the frequency of similar occurrences that has occurred at other mines in the area, combined with the professional judgement and opinion of the team members and/or the facilitators. Consequences of failure have been estimated based on local knowledge, an understanding of the ever increasing national and international environmental awareness and an understanding of environmental, regulatory, geotechnical and permafrost conditions at the site. The consequence magnitudes have been assessed in terms of direct cost of assessment and cleanup work, potential fines and impact to the environment.

An FMEA characterizes risks systematically but it does not identify every conceivable risk or failure mode. The FMEA reflects the information available as well as the judgement and professional opinion of the participants at the time it was performed. The factors may change with time, as does the assessment of risk.

The FMEA is qualitative and hence, likelihood and consequences are evaluated by using professional judgement and opinion. The likelihood, consequence and confidence categories used by the Review Team are described in Section 4.4.

4.0 RISK ASSESSMENT RESULTS

4.1 Failure Mode Identification Based on Past History

Based on past experience and with reference to published case histories, a preliminary list of elementary failure modes for tailings dams was prepared. The list was initially obtained by reviewing a report on tailing dam incidents and failures compiled by the United States Congress on Large Dams (USCOLD, 1994) and an update on tailing dam incidents from 1980-1996 prepared by the United Nations Environment Programme (UNEP, 1996). In addition, data from the past several years of undertaking risk assessments, gathered by BGC and their associates, Oboni Associates Ltd., has also been incorporated.

The published reports indicate that tailing dam failures can generally be categorized into the following groups:

- Dam Overtopping;
- Slope Instability;
- Earthquakes;
- Foundation;
- Seepage;
- Structural;
- Erosion;
- Mine Subsidence; and
- Unknown.

A summary of the number of failures and accidents for both active and inactive tailings dams, for each category listed above is presented in Table 1 below:

Table 1 Failure and Accident Causes For Tailings Dams

	Active Dams (Still receiving tailings)			**Inactive Dams** (No longer receiving tailings)		
Cause	**Failures**	**Accidents**	**Total**	**Failures**	**Accidents**	**Total**
Overtopping	13	3	16	4	0	4
Slope Instability	22	18	40	1	1	2
Earthquake	18	5	23	0	10	10
Foundation	8	10	18	1	0	1
Seepage	10	10	20	0	0	0
Structural	7	6	13	0	1	1
Erosion	0	2	2	0	0	0
Mine Subsidence	3	0	3	0	0	0
Unknown	16	0	16	3	0	3
TOTALS	**97**	**54**	**151**	**9**	**12**	**21**

Failures are defined by USCOLD as a dam breach leading to release of impounded tailings. An accident is defined as an event that causes physical damage to the embankment such as cracking or slope movement that does not result in the release of tailings but requires some sort of remedial action. The summary shows that slope instability is the leading cause of both failures and accidents in active tailings dams. This is closely followed by earthquakes. Overtopping, foundation and seepage have all occurred with similar frequencies of failures and accidents, while erosion and mine subsidence account for only a minor proportion. However, overtopping is the principle cause of failures of inactive impoundments.

It was concluded by BGC that the level of detail provided in the USCOLD summary table was insufficient for the level of study required by Faro Mine. Consequently, BGC reviewed all the incident descriptions presented in the USCOLD tailing dam document and identified a more detailed set of potential failure modes for dams, which are summarized in Table 2. The failure modes identified were all considered to be simple events and hence, have been classified as elemental failure modes. Each elemental mode could act independently or in conjunction with others to lead to a tailing dam incident.

Table 2 Generic List of Elemental Failure Modes for Dams

Reservoir (overtopping)

1	Landslide into reservoir generates a wave which overtops the dam
2	Reclaim system fails due to mechanical failure, power outage, sinking of barge or pipeline rupture
3	Perimeter bypass system fails and water enters reservoir exceeding capacity of spillway or storage or an external creek diversion fails and water enters reservoir, (Beavers)
4	Pond allowed to reach crest of dam due to poor operations, wave action overtops dam.
5	Pond allowed to reach dam by design (discharge from top end of pond to save dam height)
6	Excessive precipitation exceeds storage capacity
7	Water balance not maintained (human error)
Dam (upstream or downstream instability)	
8	Seepage causes piping and removes dam material (i.e. filter fails)
9	Seepage raises pore pressures and causes shallow instability
10	Seepage raises pore pressures and causes deep instability
11	Seismic liquefaction of dams
12	Seismic deformation of dams
13	Seismic liquefaction of tailings causes wave
14	Liquefaction of tails applies horizontal thrust to dam
15	Non Seismic liquefaction of dam due to straining or increased pore pressures
16	Seepage failure raises pore pressures and triggers a slide
17	Construction pore pressures rise and slope moves
18	Saturation of uncompacted fill either by first fill or rain or snow encapsulated in dam fill melts, dam settles, overtops
19	Uncontrolled toe erosion at the dam base retrogresses up the slope and through crest
20	Dam face erodes due to uncontrolled precipitation or snow melt runoff
Foundation	
21	Karst collapses beneath dam
22	Collapse due to mine subsidence allows tails to escape into mine or void
23	Sliding block on a weak plane of soil or liner interface
24	Compression of weak soils leads to cracking of dam
25	Permafrost degrades
26	Construction pore pressures rise and foundations move
27	Seepage through a poor membrane or pervious soils into ground water system, bypassing seepage recovery systems
28	Seismic liquefaction of foundations
29	Seismic deformation of foundations
30	Non Seismic liquefaction of foundations
Structural	
31	Piping around a culvert or decant pipe
32	Reclaim tower fails
33	Decant plugs
34	Pumps fail due to loss of power
35	Conduit fails
36	Blocked spillway, landslide, beavers, ice
37	Barge sinks
Tailings Delivery Lines	
38	Lines freeze and burst
39	Lines sand and burst
40	Joints rupture
41	Pipe hit by vehicle or snow removal equipment
42	Corrosion or abrasion wear on pipe
43	Operator error leads to an override of an auto system or operator hits line
44	Culvert capacity overloaded or ditch diversion fails and washes out line
45	Landslide occurs onto or below line
46	Rock falls on line from tunnel, slope or portal
47	Fire hazard Caused by internal electrical fault or external forest fire
48	Bridge or support structure fails

The elemental failure modes noted in Table 2 above were used as an initial checklist to determine if any potential hazards could be identified with the structures within the Down Valley. In addition, an attempt was made to identify and add new hazards and/or failure modes to the list, where appropriate. In several cases during the FMEA, additional site-specific modes were identified and are summarized on the attached rating tables.

In addition to potential failure modes for the dams, it was also necessary to formulate elemental failure modes for waste dumps, which were conceived by the members of the Review Team as outlined in Table 3:

Table 3 Elemental Failure Modes for Waste Dumps

Mode Number	Failure Mode Description
1a	Ponding on upper surface of dumps leads to surficial erosion of the dump face
1b	Ponding on upper surface of dumps leads to shallow sloughing of the dump face
1c	Ponding on upper surface of dumps leads to slightly deeper sloughing to instability of the dump face
2	Poor or weak material (e.g. snow) incorporated into the dump construction leading to slope failure
3a	Pore pressures rise in the foundation materials leading to significant dump instability
3b	Pore pressures rise in the foundation materials leading to major dump run out
4a	Permafrost, with ground ice content, melts within the foundation zone of the dump, leading to dump failure
4b	Permafrost, with ground ice content, melts within the foundation zone of the dump, leading to major dump run out
5a	Seismic related instability leads to surface sloughing to minor surface failure
5b	Seismic related instability leads to deeper failure of the dump
5c	Seismic related instability leads to major run out of the dump
6	Seismic related liquefaction of the dump foundation materials
7	Adjacent diversion channel plugs leading to erosion of the downstream dump faces
8	Seepage collection system fails
9	Dump fails due to overbuilding
10	Unknown weak materials in the dump foundation
11	Others

In addition to the failure modes for waste dumps, it was also necessary to formulate a list of failure modes for the various diversion channels and ditches, as shown in Table 4:

Table 4 Elemental Failure Modes for Channel Sections

Mode Number	Failure Mode Description
1	Slide fills the ditch/canal due to pore pressure rise.
2	Slide fills the ditch/canal due to seismic instability.
3	Slide fills the ditch/canal due to seepage flow.
4a	Flood equals design capacity of the ditch/canal.
4b	Flood greater than design but less than full capacity of 1:500 year event.
4c	Extreme flood greater than 1:500 year value.
5	Extreme flood volume causes erosion of adjacent materials.
6	Ice blockage.
7	Debris flowing into ditch/canal (from side creeks) blocks the channel section.
8	Inadequate maintenance (human error).
9	Sedimentation build up in the channel section.
10	Seepage out of the ditch exceed pond capacity.

The two lists summarized as Tables 3 and 4, in association with Table 2, were used to guide the failure mode discussions.

It should be noted that the Rose Creek Diversion Channel is designed to pass the 1 in 50 year flood discharge with freeboard left in the channel section. It is also designed to pass the 1 in 500 year event, but with no freeboard allowance. This information therefore explains the relevance of the return period values quoted in Table 4.

4.2 Down Valley Physical Conditions

An extensive amount of background and historical information on the entire Anvil Range Mining Complex has been previously complied in Robertson (1996), which is referred to as the Integrated Comprehensive Abandonment Plan (ICAP) for the site. Much of the background information provided in the following sections has been extracted from this reference.

4.2.1 Location and Physiography

Faro Mine, previously operated by numerous owners including Anvil Range Mining Corporation, is located in the central Yukon, approximately 200 km north-northeast of Whitehorse. The mine consists of a number of components including the Faro Pit and waste dumps, the mill facilities, the tailings impoundment area within the Down Valley and both the Grum and the Vangorda pits and dumps located up on the Vangorda Plateau. The Faro mine and pit site are situated approximately 15 km north of the Town of Faro while the Vangorda Plateau mine site is approximately 9 km northeast of the town site.

The physiography of the area is dominated by the northwest trending Tintina Valley, a structural trench, in which flows the Pelly River. At an intermediate elevation between this valley and the higher grantitic highlands is a tableland referred to locally as the Vangorda Plateau. Vangorda Creek is the most significant watercourse that flows to the southwest off the Plateau. To the northwest of this plateau is a narrow valley in which Rose Creek flows, directly adjacent to the dumps and the pit of the Faro deposit. Rose Creek is a tributary of Anvil Creek and both Anvil and Vangorda Creeks are tributaries of the Pelly River.

4.2.2 Geology

Faro Mine is situated within the Anvil Range lead-zinc-silver district, lying just immediately north of the Cretaceous-Tertiary Tintina Fault, a major, dextural strike-slip fault. Regionally, the Anvil Range district is underlain by Paleozoic meta-sedimentary and lesser meta-volcanic strata. A northwest trending Cretaceous granitic body, the Anvil Batholith, then intruded into the metamorphic sequence. The metamorphic units dip northeast and southwest, away from the batholith. Massive sulphide bodies occur within the Cambrian phyllites and schists. Jennings and Jilson (1986) summarizes the regional stratigraphic sequence within the area of Faro Mine.

Robertson (1996) provides a compilation of the geology, landforms and soils of the Anvil Range district. All of the area, except for the highest peaks, was covered by ice during the last glaciation. As such, discontinuous deposits of glacial till and glacio-fluvial deposits are common throughout the area. These deposits are generally not thick. Thick till and fluvial deposits are known to occur in Rose Creek.

4.2.3 Seismicity

Klohn Leonoff (1981) provided estimates of peak ground accelerations (PGA’s) for the Faro site as outlined below:

- 475 year return period - 0.07g
- 950 year return period - 0.10g
- 10,000 year return period - 0.32g

Section 3.2.2 of Robertson (1996) provides a seismic risk hazard as prepared by Dr. Scott Dunbar. Based on that assessment, the following PGA’s have been estimated for rock sites in the Faro Mine area:

- 475 Year Return Period – 0.05g.
- 10,000 Year Return Period – 0.13g.

Within that seismic review, it is also noted that the nearby Tintina fault is considered inactive and no maximum magnitude event has been defined for this fault.

The Pacific Geoscience Centre (part of the Geological Survey of Canada) provided the following PGA values for the Faro site:

- 475 year return period - 0.063g
- 1,000 year return period - 0.080g

No values for extreme events were provided by PGC.

The three different sources provide three different sets of PGA's. Generally, the assessment by Klohn Leonoff (1981) provides the highest values as compared to the other two sources.

4.2.4 Climate

Climatic data has been collected by Atmospheric Environmental Services (AES) of Canada since 1951 at the Faro Airport, which is located approximately 12 km south of the mine and approximately 450 m lower. A weather station, known as Anvil, was also established in 1967 at the mine site itself. Following is a summary of the main climatic parameters, as outlined in Section 3.6 of Robertson (1996):

- The mean annual air temperature is equal to –3.4 ^{o}C.
- Extreme air temperatures of 29.4^{o} and –46.1^{o}C have been recorded.
- The mean annual precipitation for Anvil totals 368 mm with roughly equal proportions of rainfall and snowfall as water equivalent. The greatest 24-hour rainfall recorded at Anvil station was 36.8 mm. The driest month is typically April and the wettest is typically July.
- The 100-year high annual precipitation value is estimated to be 550 mm. The 25-year high is estimated to be 500 mm.
- The mean annual lake evaporation value amounts to approximately 490 mm.

4.2.5 Permafrost Conditions

Permafrost is defined as ground, both soil and rock, that remains below 0^{o}C for more than two years. IPA (1997) notes that the Faro Mine site is situated near the boundary of the sporadic (10 to 50% of aerial extent) and the discontinuous (50 to 90% of aerial extent) permafrost zones. The zones are further classified as having a low content (0 to 10%) of ground ice.

4.3 Tailings System Boundaries

As noted in Section 2.0, the tailings containment system needs to be properly bounded for the risk assessment to proceed. This containment system is defined by firstly, the location of the contained tailings solids (upstream from the Intermediate Dam) and secondly, by the retained reservoir and surface water flow of Rose Creek, which flows through the Down Valley. Hence, all the components (reviewed in the next section) that contain and/or divert tailings solids, supernatant water and fresh water proximal to the Down Valley are considered within the system. In addition, a number of structures and watercourses not directly proximal to the Down Valley could also have an impact on the tailings area if a failure were to occur. These distant components are important because they are located higher in elevation than the Down Valley and the North Fork Rose Creek drains into the system downstream from the FWS dam. Therefore, failure or extreme events occurring with these distant components has a potential direct impact on the Down Valley components.

Section 4.3.1 provides a summary of the major structures within the Down Valley and Section 4.3.2 provides a summary discussion of the surface water flow across the Faro site. This information provides the context for the selection of the important components to be considered, as shown in Figure 1.

4.3.1 Down Valley Tailings Area Components

The major structures within the Down Valley consist of the following major components, moving downstream through the overall system:

1. Fresh Water Supply Dam, Spillway and Low Level Pipe – This dam impounds a fresh water reservoir based on the in flow of three creeks into it. The purpose of the dam was to store fresh water for processing but this role is now redundant, based on the mine’s ability to draw process water from Faro pit.
2. Original and Second Impoundment Tailings Area. – Two solids retention dikes retain tailings at the upstream end of the Down Valley area. No long-term storage of water occurs within this area.
3. Original Diversion Channel – This is the upper section of the Rose Creek Diversion Channel that bypasses Rose Creek around the tailings stored in the Original and Second Impoundment area.
4. Intermediate Dam and Emergency Spillway – This dam impounds both tailings solids and supernatant water. Excess water is typically treated as it is conveyed into the polishing pond behind Cross Valley Dam.
5. Cross Valley Dam and Emergency Spillway – This dam impounds the polishing pond water before it is discharged to the environment, generally using a decant siphon pipe.
6. Down Valley Diversion Channel – This is the lower section of the Rose Creek Diversion Channel and includes a weir section where Rose Creek connects back in to its original channel.
7. North Valley Interceptor Ditch – This ditch collects and directs fresh water runoff from the north side of the valley wall and discharges it just adjacent to the north abutment of the Cross Valley Dam.

4.3.2 Surface Water Handling Description

This section provides a description of the surface water flow and the function of the various elements within, and external to, the Down Valley tailings area.

<u>North Fork of Rose Creek</u>

The North Fork of Rose Creek originates above and to the northeast the Faro pit area and flows in a generally southwesterly direction.

The Faro Creek Diversion Channel collects water from the original Faro Creek channel upstream of the Faro pit area and diverts this water around the northeast side of the Faro Main pit and into the North Fork of Rose Creek. The original Faro Creek flowed directly through the area now occupied by the Faro Main pit. Some water that cannot be collected by gravity into the Faro Creek Diversion continues to flow directly into the Faro Main pit. The Faro Creek Diversion is observed to leak some water into the Faro Main pit along the northeast wall of the pit. The Diversion enters the North Fork of Rose Creek below and upstream of the Northeast Rock Dumps.

The North Fork of Rose Creek passes approximately 400 to 500 metres below the toe of the Northeast rock dump. This location is approximately 200 metres below the toe of the Zone II Rock Dumps and approximately 200 metres below the southeast toe of the Main Rock Dump, prior to entering a small pond at the upstream side of the Vangorda haul road rock drain.

The North Fork of Rose Creek passes through a rock drain constructed (of large sized rock fragments) in the Vangorda haul road. A head pond is present on the upstream side. Downstream of the rock drain, the North Fork of Rose Creek flows under the mine access road via two metal culverts.

The North Fork channel is divided immediately downstream of the access road crossing, as reviewed below:

1. The primary flow channel follows (approximately) the original stream route through a series of small, constructed ponds prior to joining with the South Fork of Rose Creek immediately upstream of the pumphouse pond. The small ponds are intended to allow surface water to recharge the groundwater system through the sand/gravel surface soils. This was an operating concern for the mine because groundwater wells local for that area were utilized during the winter season to augment the supply of water for processing (prior to 1997).
2. A secondary channel passes high water levels around the groundwater recharge ponds and into the South Fork of Rose Creek immediately downstream of the pumphouse pond. This channel was constructed in response to previous mine operating concerns regarding excess sediment entering the pumphouse pond during freshet. A common operating practice (prior to 1997) was to open up this secondary channel in spring to avoid sedimentation and to close this secondary channel in fall in order to maximize the water supply to the pumphouse pond through winter. There have not been any recent alterations to the channel configuration.

South Fork Of Rose Creek

The South Fork of Rose Creek originates south and east of the Faro Mine site. The creek initially flowed in a southwesterly direction parallel to the North Fork. The South Fork of Rose Creek crosses the Vangorda haul road and the mine access road via metal culverts. The mine access road crossing is immediately north of the turnoff to the Grum office.

The South Fork of Rose Creek crosses the mine access road and then enters the Freshwater Reservoir, formed by the Fresh Water Supply Dam. This reservoir was created to provide storage of water for winter use for processing. Water is released from the reservoir in two ways: an overflow spillway at the north abutment and a low-level pipe that is buried in the base of the dam near the south abutment. A common operating practice (prior to 1997) was to place stop logs in the overflow spillway in fall in order to maximize the water stored and to release water through the winter via the low-level pipe. In this practice, the reservoir level would be low in spring and the initial freshet flood flows would be contained within the reservoir until the water level had reached the overflow spillway. The stop log guides were removed in 2000 in order to prevent future overfilling of the reservoir.

Since 1998, water has continued to be released from the reservoir through the winter via the low level pipe at a reduced flow rate (as compared to the preceding period of mine operations). This has resulted in a small annual drawdown of the reservoir water level. This winter water is released for two reasons: to meet the minimum flow requirement in Rose Creek as per the Water Licence and to maintain an open flow channel beneath the ice in the Rose Creek Diversion Canal.

There are two primary tributaries into the Freshwater Reservoir in addition to the South Fork of Rose Creek. One tributary enters from the northeast along the northeast side of the reservoir and one tributary enters the south (upstream) end near to where the South Fork of Rose Creek enters.

The South Fork of Rose Creek passes in its natural channel from the Freshwater Reservoir into the pumphouse pond. The natural channel in this area is meandering and the valley floor is relatively flat.

The pumphouse pond was constructed to create a pumping station to lift water to the mill for processing (prior to 1997). A dyke at the outlet of the pumphouse pond contains a concrete spillway that is currently bypassed by a breach of a soil bank near the north side of the dyke.

Rose Creek Diversion Channel (Original and Down Valley Sections)

The Rose Creek Diversion Channel was constructed to bypass Rose Creek water around the tailings impoundments. Water exiting the pumphouse pond plus water flowing through the North Fork secondary channel (described above) enters the upper section of the Rose Creek Diversion Channel. The upper section is a predominantly straight channel that is constrained by natural slopes on the south side and by a constructed dyke augmented by tailings on the north side.

An emergency overflow was incorporated into the containment dyke at the interface between the upper and lower sections of the diversion canal. This overflow is intended to allow high flow events to overflow the containment dyke in a controlled manner and, thereby, relieve some flood risk from the lower section of the Rose Creek Diversion Canal.

The lower section passes water along the south side of the Intermediate Impoundment and returns flow into the natural Rose Creek Channel downstream of the Cross Valley pond. The lower section includes a series of boulder-lined drop structures and a sharp corner at the downstream end. The lower section is constrained by natural slopes on the south side and by a constructed till dyke on the north side. The water level in the lower section of the diversion canal is higher than the water level in the Intermediate and Cross Valley Ponds. Water is routinely observed to seep through and/or under the containment dyke into the ponds in two locations.

There is one primary tributary that enters the upper section from the south side just downstream of the pumphouse pond. One primary tributary enters the lower section from the south side near the downstream end.

Faro Main And Zone II Pits

The Zone II pit is a relatively small satellite to the Main pit that was filled with waste rock following completion of mining. The pit acts as a collection point for some rock dump seepage water and is dewatered on an as-required basis into the Main pit. Dewatering is required because the water that accumulates in the Zone II pit is contaminated with zinc and other metals and, therefore, cannot be allowed to fill to overflow elevation. The overflow elevation is on the south side of the pit and water would flow directly into the North Fork of Rose Creek.

Water enters the Faro Main pit from groundwater inflows (assumed), precipitation, local area runoff including the old Faro Creek channel, water pumped from the Zone II pit, and leakage from the Faro Creek diversion. The current management plan for the Faro Main pit is a summer season pumping and treatment program that removes approximately 1.5 million m^3 of water annually from the pit. Water is pumped via the recycle water system that was installed in 1997.

Prior to 1997, all water required for processing (approximately 7,000 US gpm) was pumped from the pumphouse pond in Rose Creek. Beginning in 1997, the recycle water system provided over 95% of the water required for processing from the Faro Main pit. Since mine shut down in 1998, the recycle water system has been used for the summer season pumping program. The use of the recycle water system beginning in 1997 eliminated the need for winter storage and drawdown in the Freshwater Reservoir.

The current method of treating and releasing water from the Faro Main pit is to pass the water through the Intermediate and Cross Valley ponds prior to discharge. The typical flow rate is approximately 4,000 US gpm. A new treatment system is under construction in 2001 that is intended to enable Faro pit water to bypass the Intermediate pond.

The currently utilized maximum recommended water level for the Faro Main pit is approximately 15 metres below the overflow elevation. This freeboard is intended to provide some short-term storage capacity for unforeseen emergency events such as a breach of the Faro Creek Diversion. The overflow elevation from the Faro main pit is on the south side near the Zone II pit such that an overflow from the Main pit would enter the Zone II pit and, thereby, enter the North Fork of Rose Creek.

Intermediate and Cross Valley Ponds

Water enters the Intermediate and Cross Valley Ponds from precipitation, local area runoff, seepage from the toe of the Main Rock dump, flow from Guardhouse Creek and (until operation of the new treatment system is implemented in 2001) water pumped from the Faro Main pit. Seepage flow from the toe of the Main Rock Dump is relatively consistent at 2 to 3 l/s. Flow from Guardhouse Creek is highly variable and includes runoff from a portion of the plantsite.

Some clean runoff water is diverted around the Intermediate Impoundment via the North Wall Interceptor Ditch. This water enters the Cross Valley Dam spillway just below the dam.

The Intermediate Pond contains process tailings that were deposited from the upstream end of the impoundment and that extend to the dam. The pond water is approximately 7 to 8 metres deep near the dam. Water exits the Intermediate Pond via an overflow spillway at the north abutment. A spillway was previously located at the south abutment prior to raising of the dam.

The Cross Valley Pond does not contain tailings but does contain lime treatment sediments. These are largely beached at the bottom of the Intermediate Dam spillway. The depth of the Cross Valley Pond is variable and is approximately 14 metres at the deepest point. Water exits the Cross Valley Pond via two overflow spillways at the north abutment. A smaller spillway is approximately 0.3 metres lower than a larger spillway.

Syphon pipes are utilized on occasion to discharge water from the Intermediate and Cross Valley Ponds. Use of these pipes allows the pond water levels to be drawn down, on occasion, below the overflow elevations.

4.4 Definition of Evaluation Criteria

For the FMEA to be carried out, it is necessary to define the appropriate categories of the likelihood of occurrence, consequences of failure and confidence levels. The following three sections provides an explanation of each of these three categories.

4.4.1 Likelihood of Occurrence Categories

In order to assess and estimate the likelihood of an event, it is necessary to define a common base for personnel to estimate the probability of occurrence in terms of classes such as Negligible, Low, Moderate, High or Very High. A table summarizing descriptions and likelihood's of occurrence used for the Down Valley risk assessment is provided as Table 5:

Table 5 Summary of Likelihood of Occurrences Categories

Likelihood of Occurrence	Approximate Return Period	Example
Very High	Happens repeatedly; greater than or equal to 1 time/year	Power losses
High	Happens several times; approximately 1 time/year to 1 time/5 years	Tailing line valve breaks
Moderate	Happens once in a while; approximately 1 time/6 years to 1 time/20 years	Collapse of decant tower
Low	Rarely happens; less than 1 time/20 years	Traffic accident, vehicle hits pipeline
Negligible	Barely imaginable	Maximum Credible Earthquake or Probable Maximum Precipitation

The upper limit of the most likely event is Very High. A lower limit of Negligible likelihood events corresponds approximately to the annual probability of extreme events such as Probable Maximum Precipitation (PMP) or Maximum Credible Earthquake (MCE).

As previously noted in Section 2.0, the likelihood of occurrence is assessed for the current configuration of the structures for the time period of the next several years, which was nominally set at a length of five years. As such, the likelihood of failure occurring is estimated for this period, based on the occurrence categories provided in Table 5. For evaluation of a closed mine, the potential time period for assessing failure modes may be extended to 100 to 500 years and possibly longer. If a 500 year time period were to be used for evaluation of the likelihood of occurrence, then the category selected for each mode would be higher by at least one category. As further discussed in Section 4.5.3, the confidence category for this assessment would also decrease, due to issues such as required maintenance, monitoring and inspection. These aspects are difficult to estimate for the next 500 years.

4.4.2 Consequence Categories

In order to assess and estimate the consequences of an event, it is necessary to agree upon a description of the consequences in terms of classes such as Very Low, Low, Moderate, High and Very High. Descriptions which were agreed to prior to the start of the risk assessment are provided in Table 6.

Table 6 Summary of Consequences Categories

Consequence Categories	Descriptions
Very Low	Minor non-reportable release of sediment or contaminated water. Easy to control and stop continued losses. No injury and no significant damage to environment. Remediation cost of approximately less than $10,000 USD
Low	Minor release of sediment or contaminated water. Localized problems, controllable, no significant permanent damage to environment. Repair time < 1 day. Approximate remediation cost of $10,000 - $100,000 USD
Moderate	Release of fluids and sediment. Can be controlled and repaired but significant effort required. Possible repair work estimated to be 2-3 days. Approximate remediation cost $100,000 - $1 million USD. Local press exposure.
High	Significant release of solids and fluids affecting surface water. Damage can be repaired but some long lasting contaminant effect. Some fines for non-compliant discharge. Possible repair duration of up to 2 weeks. Approximate costs of $1 million – $10 Million USD. National Press Coverage
Very High	Major uncontrolled release. Major failure of dams, dumps, or tailing ponds. Surface water contaminated for long periods. Repair and clean-up duration in excess of two weeks. Major fines or clean up costs. Approximate remediation costs of $10 million to $100 Million USD. International press coverage, CNN.

If the time period for assessment of the failure modes were extended to 500 years, as used in Section 4.5.1, then no changes to the consequences estimated would be forecast.

4.4.3 Confidence Categories

Judgement on the likelihood of occurrence and consequences may vary substantially with their associated degree of confidence, depending on the amount of available information and the understanding of the project. A high degree of confidence in a category reflected the consensus that the group was secure in the level of exploration undertaken or the confidence in the modelling procedure. Confidence levels of low or medium indicated a lack of comfort and indicated that more work was required to raise the degree of confidence to high. The confidence categories that apply to both likelihood and consequence assessments are defined in Table 7.

Table 7 Confidence Limits Categories

Confidence Level	Description
Low	Do not have confidence in the estimate
Moderate	Have some confidence
High	Have lots of confidence in the estimate

In areas where the confidence is considered to be low, that is the group is not confident in the classifications of the probability of occurrence or the consequences as a result of lack of knowledge, the risk categories chosen are raised by one grouping in order to increase the risk levels and prompt action. For example if a "probability of occurrence" is deemed by the group to be low but the group has only a low confidence in their assessment, then the 'probability of occurrence' is elevated to a moderate probability for purposes of assessing the "risk". The risk is therefore higher than initially considered and action is prompted to gain knowledge to reduce the uncertainty and therefore, reduce the risk rating.

As initially noted in Section 4.5.1, the confidence limits estimated herein are for a nominal five year period. If the time period for consideration were extended to 500 years for example, then the confidence estimations would drop, and hence, the risk category would be raised by the protocol noted in the previous paragraph. As such, if low confidence limits were provided for all failure modes, the end ranking of the various risks would be lacking in definition.

4.5 Risk Assessment Categories

Four categories of risk, High, Moderately High, Moderate and Low, were formulated for this project. These risk categories are based on the combination of the likelihood of occurrence, coupled with the consequence of failure occurring. Further from this strict tabular definition, it is also important to note the perceived risk tolerance of the owner or manager of these risks needs to be reflected in the category selection. BGC has undertaken several of these assessments for mining companies directly and it is likely that their level of risk tolerance would be higher for a mining company than for a regulatory agency and/or a government department. As such, the generalized categories of risk in Table 8 were altered to reflect the perceived lower risk tolerance by such stakeholder parties:

Table 8 Generalized Risk Classifications

	LIKELIHOOD OF OCCURRENCE				
Consequences	Very High	High	Moderate	Low	Negligible
Very High	Highest Risk VH/VH	VH/H	VH/M	VH/L	VH/N
High	H/VH	**High Risk** H/H	H/M	H/L	H/N
Moderate	High Risk M/VH	M/H	**Moderately High Risk** M/M	**Moderate Risk** M/L	M/N
Low	L/VH	L/H	L/M	**Low Risk** L/L	L/N
Very Low	VL/VH	VL/H	VL/M	VL/L	**Lowest Risk** VL/N

Further context for these four major risk classification categories as provided as follows:

High Risk

Failure modes that were considered to have a High Risk classification were considered to have a major impact on the mine and required immediate attention. Additional work required, to be started immediately, to define the system, quantify elements and issues and implement a remedial action plan within the next 6 months.

Moderately High Risk

Failure modes that were identified as having a Moderately High Risk were considered to require additional work over the coming year. Additional work is required to define the system, quantify elements and issues and determine a remedial action and implement within the next 6 to 12 months.

Moderate Risk

Failure modes that were identified as Moderate Risks were considered to be reasonably well defined and understood. Action plan to be needed within 6 to 12 months, but risks are not a high priority.

Low Risk

Failure modes that were identified as having Low Risk were considered to have either a low likelihood of occurrence or a low consequence. No additional work was considered necessary at this time for these failure modes.

It should be again stated that these categories are subjective, but previously have been calibrated to industry tolerances.

4.6 FMEA Risk Analysis Results

As previously noted, a meeting was held on May 8 to 10, 2001 between Messrs. Eric Denholm, Glen Gilchrist, Jim Cassie, and Iain Bruce. At the meeting, a series of failure modes and effects were developed for each of the links and elements identified within the Down Valley tailings area, as shown on Figure 1.

For each failure mode identified, a consensus was reached for each category of likelihood of occurrence, impacts or consequences and a confidence limit on each. The categories estimated, the confidences agreed upon and the risk ranking for the various elements and links are summarized on Tables 9 to 15. The risk categories are defined using the methodology outlined in Section 4.0 and Table 8. For all categories that were identified as being known with a moderate or high confidence, the risks are determined directly. As previously noted, if the confidence limit was low, then the assessment of the "probability of occurrence" or "consequence" is raised one category. Within Tables 9 to 15, 133 risks were ranked for the various elements and links in the system.

It should be noted, that as stated previously, the risks assessed were for the current configuration of the tailings system. Where pertinent to the risk discussion, the risk assessment was also evaluated for six potential cases that included the removal of the Fresh Water Supply Dam. Some further elaboration on this topic is provided further on in this section of the report.

Based upon these 133 rankings of risk, one High and thirty-nine Moderately-High risks were identified. Broken down by major element, one High and eight Moderately-High risks applied to the Fresh Water Supply Dam, while twelve Moderately-High risks applied to the Intermediate Dam, eight to the Cross Valley Dam and an additional ten risks to the remainder of the system. Table 16 provides a summary of these High and Moderately-High rankings, based on component element rather than a prioritised list. Recommendations for assessing these risks are provided in Section 5.0.

Table 9 Element 1 et. al. Risk Rankings

Page 2 table 9

Table 10 Element 2 et. al. Risk Rankings

Page 2 table 10

Page 3 table 10

Table 11 Element 3 et. al. Risk Rankings

Page 2 table 11

Table 12 Element 4 et. al. Risk Rankings

Page 2 table 12

Table 13 Element 5 et. al. Risk Rankings

Page 2 table 13

Table 14 Various Channel Risk Rankings

Page 2 table 14

Table 15 Various Elements Risk Rankings

Table 16 Summary of High and Moderately High Risks

Mode Number	Failure Modes	Ranking
See Table 9	**Element 1 - Fresh Water Supply Dam, Link 1a spillway and Link 1b low level pipe**	
8	Seepage causes piping and removes dam material (i.e. filter fails) leading to general dam failure.	VH/N
10	Seepage raises pore pressures and causes deep instability	M/M
11	Seismic liquefaction of dams leading to general dam failure.	VH/L
12	Seismic deformation of dams	H/M
20b	Surface water infiltrates into surface crest cracks leading to core damage	L/H
28	Seismic liquefaction of foundations	VH/N
30	Non Seismic liquefaction of foundations	VH/N
31	Piping around a culvert or decant pipe (low level pipe)	VH/M
35	Conduit fails (deteriorating pipe conditions leading to possible collapse)	H/L
See Table 11	**Element 3 - Intermediate Dam and Emergency Pond/Spillway - Link 3**	
3a	Perimeter bypass system fails and water enters reservoir exceeding capacity of spillway or storage or an external creek diversion fails and water enters reservoir, (Beavers)	H/L
3b	As FM #3a, but without the existence of the FWS Dam.	H/M
8	Seepage causes piping and removes dam material (i.e. filter fails) leading to general dam failure	VH/N-L
9	Seepage raises pore pressures and causes shallow instability	M/M
10	Seepage raises pore pressures and causes deep instability	H/L
11	Seismic liquefaction of dams leading to general dam failure	VH/L
12	Seismic deformation of dams	H/L
15	Non Seismic liquefaction of dam due to straining or increased pore pressures leading to general dam failure	VH/N
23	Sliding block on a weak plane of soil or liner interface	VH/N
28	Seismic liquefaction of foundations leading to general dam failure	VH/L
29	Seismic deformation of foundations	H/L
30	Non Seismic liquefaction of foundations leading to general dam failure	VH/N
See Table 12	**Element 4 Cross Valley Dam & Emergency Spillway Link #4**	
1	Landslide into reservoir generates a wave which overtops the dam	H/L
3b	As FM #3a, but Link 13 fails with FWS Dam is operative	H/L
3c	As FM #3a, but Link 13 fails and FWS Dam has been removed	H/M

Table 16 Continued

Mode Number	Failure Modes	Ranking
8	Seepage causes piping and removes dam material (i.e. filter fails) leading to general dam failure	VH/N-L
11	Seismic liquefaction of dams leading to general dam failure	VH/N
12	Seismic deformation of dams	H/L
28	Seismic liquefaction of foundations leading to general dam failure	VH/L
29	Seismic deformation of foundations	H/L
30	Non Seismic liquefaction of foundations leading to general dam failure	VH/N
See Table 13	**Element 5 NW Dump, Element 6 Main Dump, Element 9 Faro Valley Dump and Element 10 NE Dump & Element 8 Faro Pit**	
12	Retrogression of Faro Pit wall leading to breaching of the Faro Creek Diversion Channel (leading to failure of the channel).	M/H
See Table 14	**Link 12 - Original Section of the Diversion Channel**	
9b	Sedimentation build up in the channel section - FWS Dam has been removed	L/VH
See Table 14	**Link 13 - Down Valley Diversion Canal**	
1	Slide fills the ditch/canal due to pore pressure rise (e.g. melting permafrost).	M/M
2	Slide fills the ditch/canal due to seismic instability.	H/L
3	Slide fills the ditch/canal due to seepage flow.	M-M
4a	Flood equals design capacity of the ditch/canal.	M/M
4b	Flood greater than design but less than full capacity of 1:500	H/L
4c	Extreme flood greater than 1:500 year value	VH/L
8	Inadequate maintenance (human error).	M/M
9b	Sedimentation build up in the channel section - without the FWS Dam	L/VH

Work programs were identified in the meeting to address the concerns raised from the risk rankings identified above. The assessment programs specifics are provided in Section 5.0

Numerous High and Moderately High risks have been identified with the Fresh Water Supply Dam. Acknowledging that fact, the presence of the Fresh Water Supply Dam has the potential to reduce the risks associated with various components of the Down Valley works. Table 17 summarizes the cases considered and the changes in the risk ranking after the postulated complete removal of this dam:

Table 17 Cases Considered Presuming FWS Dam is Removed

Element No.	Failure Mode Case	Risk Ranking Change	Category (Table 8) Change
#2 Second impoundment	19c to 19a	L/N to L/L	None
#3 Intermediate Dam	3a to 3b	H/L to H/M	None
#3 Intermediate Dam	36a to 36b	L/N to M/N	None
#4 Cross Valley Dam	3b to 3c	H/L to H/M	None
#12 Original Diversion Channel	9a to 9b	L/H to L/VH	Up to Moderately High
#13 Down Valley Diversion Canal	9a to 9b	L/H to L/VH	Up to Moderately High

As is demonstrated by the results, the removal of the Fresh Water Supply Dam has the potential to increase the risk ranking for all of the cases evaluated (the actual risk reduction role needs to be assessed within a recommended hydrotechnical assessment). In only two of the cases does the risk category actually increase, but in both cases, the category increases from Moderate to Moderately-High, which is a significant increase.

Further from the discussion of the potential complete removal of the Fresh Water Supply Dam, it is also possible that only a partial breach of this dam may be undertaken. The potential risks of the breach option were not formally reviewed during the FMEA workshop. In concept, the "protective" ability of the Fresh Water Supply Dam is derived from its flood routing capability (dependent upon the storage capacity curve of the reservoir and the spillway sizing) and its ability to trap sediment. If the flood routing capability of the breached dam was unchanged from the current dam configuration. then the associated downstream risks would not change. Alternatively though, a lower volume of retained water behind the dam would likely have a lower consequence of failure.

Within the discussion on the FMEA results, it is also important to note that six cases of significant environmental impacts were noted as a result of potential failure modes. As previously stated, environmentally related effects were not evaluated within this specific risk assessment, but the consequences noted in Tables 9 to 15 are important for the overall risk assessment of the site. Hence, for information, the following elements and failure modes indicate some significant environmental consequences that should be considered within the overall site context:

- Element #2 – Second impoundment; mode #27, seepage into the groundwater system.
- Element #3 – Intermediate dam; mode #27, seepage into the groundwater system.
- Element #4 – Cross Valley dam; mode #27, seepage into the groundwater system.
- Element #5 et. al. – mode #8, seepage collection system fails.

- Element #5 et. al. – mode #11, north wall of Faro Pit fails catastrophically.
- Element #5 et. al. – mode #12, retrogression of north wall of Faro Pit leading to failure of diversion channel.

Environmental risk assessment and contingency planning for the site may wish to consider these noted consequences.

5.0 RECOMMENDED WORK PLANS

5.1 Context For Proposed Workscope

One High risk and eight Moderately-High risks were identified for the Fresh Water Supply Dam. Following from the comments provided in Section 4.6, the Fresh Water Supply Dam appears to provides a risk reduction role for several of the structures and facilities located downstream. It does this by providing some flood routing capability (more significant when the reservoir level is initially below the spillway level) and by reducing sediment load in the downstream flows. This interim conclusion needs to be re-evaluated when a hydrotechnical assessment is completed for the dam. Additionally, the winter flow quantity discharged from the low level pipe is generally sufficient to prevent icings of the downstream channel. Ice blockage in the channel reduces its capacity and hence, increases the potential risk of flooding and breaching in the following spring.

Although not specifically assessed, the flow-through rock drain at the Vangorda causeway also appears to provide some flood routing and sediment trapping protection respecting flows in the North Fork Rose Creek.

At the current time, it is estimated that the Fresh Water Supply Dam spillway can discharge the 1 in 100 year flood quantity of 24 m^3/s (based on information provided in Klohn Leonoff's 1981 abandonment plan). Other design documentation indicates that the Original Diversion Channel (Link #12) is designed for a 1 in 50 year quantity of 48 m^3/s, while the downstream Down Valley Diversion Channel (Link #13) is designed for a 1 in 50 year event (with freeboard) of 88 m^3/s and a 1 in 500 year event of 160 m^3/s (with no freeboard). If the Fresh Water Supply Dam and spillway were removed, it is clear that the risk of failure occurring further downstream would be increased in the overall system because peak flows would be higher. As such, any anticipated changes to the water discharge volumes at the Fresh Water Supply Dam, in the short term, must be compatible with the design discharge of the current Rose Creek diversion channel.

Given the potential upstream protection role of both the flow-through causeway and the Fresh Water Supply Dam, it is recommended that these two structures remain in-place until either of the following work is undertaken;

- Firstly, an overall hydrotechnical assessment of the entire Down Valley system is undertaken, which demonstrates the level of flood protection capability of these two structures. If the hydrotechnical assessment demonstrates significant flood protection capability within the system, then the next proposed step should be the Dam Safety Review as noted in the next point. If little flood protection capability is demonstrated, and the downstream channel is appropriately sized for passage of flood events, then the Fresh Water Supply Dam could be breached, if an economic and risk analysis provides this to be a rationale decision.
- Secondly, a Dam Safety Review of the Fresh Water Supply Dam indicates that leaving the currently configured dam in-place presents an unacceptable risk.

As noted earlier, some potential risks are present because of the current condition of the Fresh Water Supply Dam. DIAND and their consultants have concerns with the dam relating to frost-action damage in the top 4m and some potential softening at the toe which may have occurred just after first filling. Hence, it is recommended that a Dam Safety Review, in compliance with the requirements provided in Section 2.0 of CDA (1999), be undertaken to further assess its condition. This review procedure basically compares the existing condition of the dam versus the designer's intention. It would include an assessment of the low level pipe piping potential, an assessment of the physical stability (report currently under preparation under a separate cover), a hydrological and hydrotechnical assessment (recommended in the first bullet above), in addition to several other aspects.

In the following two sections, assessment needs for the High and Moderately-High risks are provided.

5.2 Proposed Workscope for High Risks

Only one High risk was identified and this relates to potential seepage and piping that may occur around the low level pipe that goes through the Fresh Water Supply Dam. The pipe has been in service since the dam was constructed. Conduits through dams, when pressurized and leaky, can be a significant source of piping, which, in turn, can lead to catastrophic failure of a dam.

Between September 15 and 19, 2001, divers from Diving Dynamics entered the low level pipe. They undertook both a visual inspection and measurements of the steel pipe wall thickness. Although the inside of the pipe was coated with approximately 5 cm of build up, no signs of structural failure and/or cracking of the pipe were noted. The pipe wall measurements indicated that the original wall thickness of 0.375 inches was reduced in certain locations to less than 0.2 inches. In addition, a bend of approximately 1.5 meters was noted within the center portion of the dam. Diving Dynamics (2001) provides a complete summary of their observations.

Following on from this information, Mr. Jim Cassie of BGC was mobilized to site on October 4 and 5, 2001. During that time, no signs of settlement, cracking or increased seepage were noted in the expected crossing area of the low level pipe. A review of the diving survey data to an as-built drawing provided for the pipe indicates that the majority of the low-level pipe is installed in bedrock. Additionally, the as-built drawing indicated that concrete collars were placed at approximately 6 m intervals along the pipe. Therefore, no current signs of piping were observed and since the low level pipe is situated in bedrock, the likelihood of piping occurring is low. But there still remains the issue that the pipe wall thickness has decreased and has a remaining finite life.

Although it is likely that low level pipe was installed with the bend, there is the alternative possibility that the bend is due to some unexplained deformation and/or seepage related phenomena. As such it is prudent to lower the reservoir level and hence, lower the hydraulic gradient available to initiate piping.

In parallel with this recommended lowering, additional assessment of the piping potential of the low level pipe should be undertaken. Within that assessment, four potential options should be assessed:

1. Lowering of the reservoir level and flow through the current low level pipe.
2. Lowering of the reservoir, relining of the pipe with a plastic sleeve and grouting of the annulus space.
3. Lowering of the reservoir and grouting to completely block the pipe.
4. Complete extraction of the low level pipe and backfilling of the excavation.

Moderately-High risk #35 for the Fresh Water Supply Dam is also dependent upon the current condition of the low level pipe. Hence, this risk should also be assessed when the evaluation of the diving inspection information is completed.

5.3 Proposed Workscope for Moderately-High Risks

As noted previously, 39 Moderately-High risks were identified within the FMEA process, of which one has been addressed under the High risk workscope discussion in Section 5.2. Four further Moderately-High risks were due to the postulated removal of the Fresh Water Supply Dam. As such, there remain 34 Moderately-High risks that need to be assessed, evaluated and potential remediation plans formulated. Within these 34 individual risks, there are a number of consistent themes of risk that can be summarized in the following points:

- Numerous risks are related to the hydrological information and the hydraulic design parameters, as previously mentioned in Section 5.1. Further from this note is the concern that some of the previous hydrological forecasts were based on limited time data sets. For risk assessment, it is recommended that a hydrotechnical assessment of the current Down Valley system be undertaken evaluating the expected flood discharge quantities and existing capacities for various key points in the system, the flood retention and routing capacities of the current system, erosion potential of the channel sections and the sedimentation potential downstream from the Fresh water Supply Dam.

- An assessment of the seepage performance and piping potential of all three major dams (Fresh Water Supply Dam, Intermediate Dam and the Cross Valley Dam). This assessment should include an evaluation of the seepage performance (higher than expected levels, lower than expected, etc.), an evaluation of the toe seepage quantities (decreasing values, increasing values, etc.) and the filter criteria used for design, vetted against the potential seepage-deteriorating causes such as the formation of precipitates.
- An assessment of the seismic deformation and liquefaction potential of all three major dams and their foundations. This study should include an evaluation of the materials in the embankments sections and foundations, their in situ densities and phreatic surface conditions within each of these dams. Also, it will be necessary to undertake (or update) a seismic hazard assessment for the Faro Mine site to provide peak ground accelerations for various return periods of these events.
- An assessment of the non-seismic liquefaction potential of all three major dams and their foundations.
- An assessment of the foundation conditions and associated engineering properties beneath the Intermediate Dam. This assessment has linkages to the liquefaction assessment that has been mentioned earlier.
- An assessment of the engineering geology, terrain units and landslide potential in the slopes immediately overlooking the Cross Valley Dam and the associated polishing pond.
- Operational and maintenance protocols are required for the current system to ensure that human error and lack of required maintenance do not increase the potential risks within the system. For example, occasionally a temporary blockage is placed within the spillway of the Intermediate Dam to retain non-compliant water. If this temporary blockage were not properly removed, then the risk of additional problems occurring increases. As such, a protocol for the installation, removal and approval of same for such a blockage should be implemented, along with several other operational aspects.
- Emergency response plans need to reviewed and possibly expanded in terms of manpower, mobile equipment and materials on-site (or readily accessible) to ensure that damage from high likelihood events is not exacerbated, leading to unnecessary and costly consequences.

A number of these assessments can be undertaken on the basis of review of readily available information, although some effort will be required to locate, synthesize and interpret this information. In some cases, additional fieldwork, monitoring and/or modelling will be required to provide the required evaluation.

6.0 CONCLUSIONS

The FMEA study provided herein was planned as a screening tool to assist D&T with the prioritisation of future funding for engineering related issues within the Down Valley. A number of potential risks, or alternatively conceptualised as the lack of specific knowledge, have been identified. Suggested assessment plans, basically consisting of the compilation and interpretation of existing information, have been provided in terms of gaining further knowledge on these risks. As such, the next stage of assessment work will examine again the likelihood of occurrence and perhaps some additional information on the potential consequences.

Within the FMEA study undertaken for the Down Valley tailings system, as defined in Section 2.0, the following conclusions were reached:

1. For the currently configured elements and links with the Down Valley tailings area, 127 risk rankings were obtained for various failure modes.
2. Of these 127 risks, 1 was ranked as a High Risk and 34 were ranked as Moderately High for the current configuration of the system.
3. Six cases, beyond the 127 cases noted in Item #1, were also considered with the potential removal of the Fresh Water Supply Dam from the system. In all six cases, the risk ranking increased with the removal of the Fresh Water Supply Dam.
4. Given the demonstrated importance of the Fresh Water Supply Dam, and acknowledging the potential risks with this structure, it is recommended that the first priority for any additional work in the Down Valley be a hydrotechnical assessment and a Dam Safety Review (of which the proposed physical stability evaluation is one component) of this dam. Inclusive within this overall review should be a piping potential assessment of the low level pipe.
5. Next in importance is an assessment of the seepage and piping potential of the three major dams, with the FWS Dam having the highest priority.
6. Next in importance are the potential risks related to both seismic and non-seismic liquefaction of the three major dams and their foundations. As such, the first three assessments noted in Section 5.3 should be undertaken.
7. Last in priority are the four miscellaneous assessments noted at the end of the list in Section 5.3.

To reiterate the timing provided in Section 4.5 for these risks, High risks should have a defined remedial action plan within the next six months and Moderately-High risks should have a remedial action plan within the next six to twelve months.

It should again be noted that the risk categories provided in Table 8 are subjective, but are meant to be reflective of the owner's and stakeholders' level of risk tolerance. As such, these categories are open to discussion with these stakeholders. Additionally, as further information becomes available, and as changes are made to the Down Valley system, the risk assessment provided herein should be updated.

7.0 CLOSURE

We trust the above meets your present requirements and we thank D&T for the opportunity to again be of service to Faro Mine. If you have any questions or require additional details, please contact the undersigned.

Respectfully submitted,
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