Gartner Lee

DRAFT REPORT
Faro Fresh Water Supply Dam Evaluation of Reclamation Approaches

Prepared for

Deloitte and Touche Inc.

Consultants In The Environment

Gartner
Lee

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Faro Fresh Water Supply Dam
Evaluation of Reclamation Approaches

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Deloitte and Touche Inc.

Prepared by:

Gartner Lee Limited

GLL 20-933

November 2000

Distribution:

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Executive Summary

Deloitte and Touche Inc. (as Interim receiver for Anvil Range Mining Corporation) requested that Gartner Lee Limited and BGC Engineering Inc. prepare this report regarding the Fresh Water Supply Dam (FWS dam) at the Faro Mine Site, Yukon. The FWS dam is one component of the Faro mine water management system that includes downstream dams and dykes and the Rose Creek Diversion Canal.

Long-standing concerns regarding the physical stability of the FWS dam and the potentially significant consequences of a failure of the dam have created the desire to investigate approaches for reclamation. This report presents a comparative analysis of three alternatives for reclamation of the dam.

The FWS dam is one of the original (1968) mine structures that was used, prior to 1997, to provide water for ore processing. A recycle water system that was constructed in 1997 replaced the FWS dam as the primary supply of water to the processing plant and the FWS dam is no longer required for mine operations.

The south fork of Rose Creek provided freshwater fisheries habitat prior to construction of the dam. The dam represents two fundamental changes to the creek. The first change is the creation of good winter habitat in the reservoir upstream of the dam. The second change is the blockage of fish passage from downstream of the dam up into the reservoir by two hanging culverts below the overflow spillway. The consequences of these changes are that fish resident in the creek downstream of the dam do not have access to the high quality winter habitat in the reservoir and fish resident in the reservoir do not have access to the high quality spawning habitat below the dam. Nonetheless, the resident population appears to have been able to sustain itself by use of spawning grounds in Rose Creek upstream of the reservoir.

The FWS dam currently does not meet all of the requirements for factor of safety. The current factors of safety for a static condition for the upstream and downstream sides are 1.82 and 1.38, respectively, versus a standard of 1.5. The current factors of safety for the estimated maximum credible earthquake for the upstream and downstream sides are 0.91 and <1.0, respectively, versus a standard of greater than 1.0.

Reclamation objectives for the FWS dam are focussed on achieving acceptable long-term standards for physical stability by lowering the upstream pond water level. This would be accomplished by excavating a breach or notch into the dam in such a manner that the spillway overflow elevation was lowered. Enhancements of fisheries habitat (maintaining winter habitat in the reservoir and providing fish access) are additional objectives. The reclamation approach must consider modifications to the FWS dam in the context of the overall water control system including the downstream tailings retention dams and the downstream Rose Creek Diversion Canal. Three reclamation approaches were considered.

- communication with the Department of Fisheries and Oceans regarding reclamation of the FWS dam should continue and other affected parties, including the Ross River Dena Council, should also be included in the determination of the most appropriate reclamation approach.
- field investigations should be performed that would verify the findings of this report and that would allow detailed design of the preferred reclamation approach to proceed.
- modifications to the FWS dam must be developed in the context that the FWS dam is one component of the overall mine water and waste management system and that certain modifications to the FWS dam might increase the risk to downstream structures if not carefully considered.
- regulatory considerations including the possible need for an amendment to the Faro Water Licence should be investigated.

Table of Contents

1. Introduction

The Fresh Water Supply Dam (FWS dam), located at Faro Mine in the Yukon Territory, is a zoned earthfill dam that was constructed in 1968 on the south fork of Rose Creek upstream of the mine site. The dam was one of the original Faro mine facilities. The location of the FWS dam and related facilities is illustrated on Figure 1.

The FWS dam was used to store fresh water for processing operations during the operational life of the mine. A recycle water system was installed in 1997 that provided water to the mill for mill operations from the mined out Faro Main pit. The successful implementation of this system eliminated the need for the FWS dam as the primary source of water for the minesite.

Mine operating activities have been suspended since February 1998 and the mine site, including the FWS dam, has been under the management of Deloitte and Touche Inc. (Deloitte) as Interim Receiver for Anvil Range Mining Corporation since April 1998.

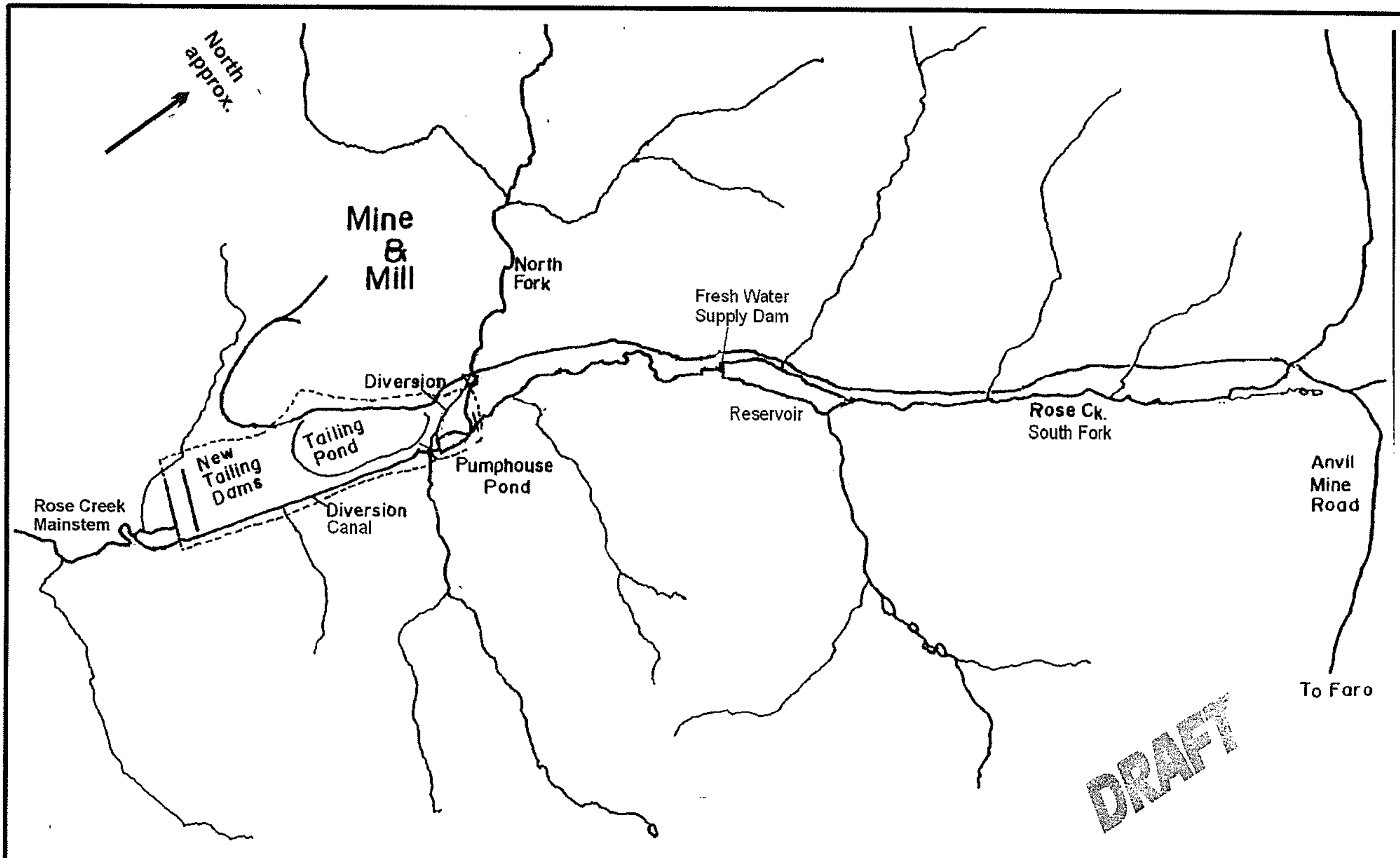
The FWS dam has a well-documented operational history that involved raising the water level in the upstream reservoir to as high as practical in the fall in order to provide as much water as possible for winter use. It is thought that, on occasion, the water level in the reservoir was raised to above the elevation of the top of the internal core of the dam. The water level in the reservoir at the end of winter would typically be very low due to the release of water for mill processing purposes via a low level outlet pipe buried at the base of the dam.

These operating factors are likely to have contributed to general concerns regarding the physical stability of the dam. Significant longitudinal cracking has been documented on the upstream side of the dam crest for nearly 20 years and has been professionally investigated on two occasions. A downstream toe stability berm was added to in the late 1980's.

A failure of the dam could result in significant environmental impacts including sedimentation and flood disruption of aquatic habitat in Rose Creek downstream of the FWS dam and flood impacts and possible failure of the downstream Intermediate and Cross Valley dams. The potential for failure of the downstream dams is of critical importance because these dams retain non-compliant water, tailings solids and treatment sediments that would be released into the aquatic habitat in the event of dam failure.

Deloitte is currently evaluating alternatives for breaching the dam and lowering the retained reservoir level as a means of reducing the environmental risks related to storing water behind the dam. Some amount of water may remain within the reservoir for conservation and fisheries purposes.

Any modifications considered for the FWS dam must be considered in the context of the overall mine waste containment facility and water conveyance system situated within the Rose Creek valley. For example, enlarging the spillway to reduce the potential risk of flood damage to the FWS dam may increase the risk to the diversion channels and dams further downstream.



SCALE: NTS	DATE: Nov. 2000	DRAWN: CPW	Gartner Lee	PROJECT:	Faro Fresh Water Supply Dam Evaluation of Reclamation Approaches
DESIGNED: LMH	CHECKED: LMH	APPROVED: LMH		TITLE:	**Study Area**
Source of Figure: Report by Ken Weagle Dated October 1981 Title: The Impact of the Scheme 2 Abandonement Plan On the Grayling Population of Rose Creek Figure 1, Details of Study Area			CLIENT: **Deloitte & Touche**	PROJECT No. GLL: 20-933	DWG. No. FIGURE 1 — REV. 0

1.1 Purpose

The purposes of this report are to:

1. synthesize the current geotechnical conditions of the dam
2. provide a technical assessment of the current status of the FWS dam with regards to fisheries considerations,
3. perform stability analyses to assess the Factor of Safety for the current dam configuration and then determine the incremental changes as the reservoir level is lowered,
4. provide a comparative evaluation of three reclamation approaches with regards to geotechnical issues, fisheries issues, cost and other considerations.

The three reclamation approaches that are described in this report are:

1. a nominal lowering of the reservoir water level by breaching the dam by 3 metres with the intent of reducing the risks associated with the dam for a relatively small effort,
2. a more substantial lowering of the reservoir water level by breaching the dam by 6 metres with the intent of achieving long term physical stability standards and allowing for an enhancement of fisheries habitat, and
3. complete breaching of the dam and elimination of the upstream reservoir.

1.2 Elevations

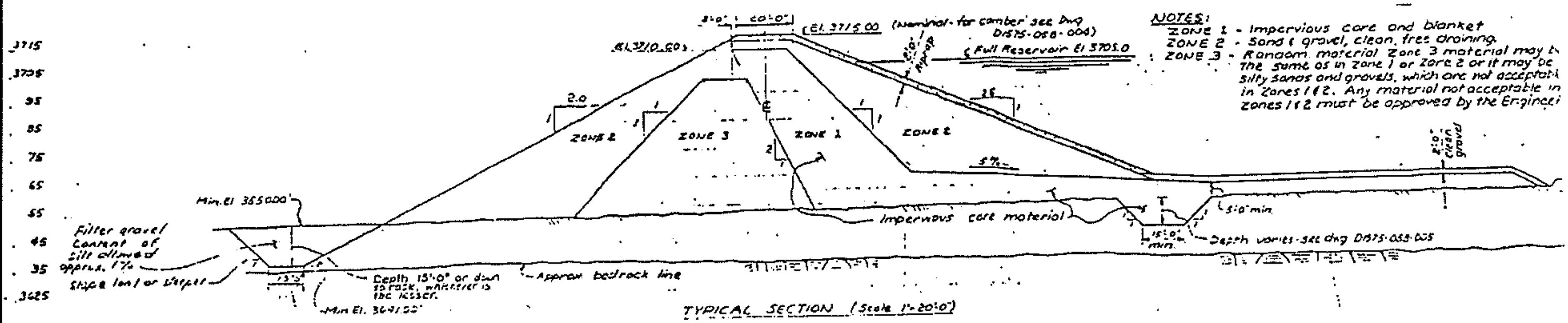
Elevations quoted for the Faro mine site can be confusing if not clearly referenced as with respect to "mine datum" or "above mean sea level". Arbitrary mine datums for the Faro pit and for the Down Valley were established during mine development or mine operations and were used as the basis of routine mine surveying.

Robertson (1996) states that the mine datum for the Faro pit is approximately 109.2 feet or approximately 33.3 metres lower than the mean sea level datum and that the local Down Valley datum is approximately 106.0 feet or approximately 32.3 metres lower than the datum for mean sea level. The exact conversion used and the exact datum for mean sea level used are factors to consider when precision in elevations is required.

A Dome Petroleum memo from 1984 makes reference to a 1974 survey by Energy, Mines and Resources that tied into a geodetic station and resulted in an elevation conversion at the FWS dam of 106.59 feet or 32.488 metres, which is close to that referenced in Robertson (1996) for the Down Valley area.

The level of precision being described is not an important consideration regarding the comparative analysis provided in this report. Nonetheless, it is important for the reader to recognize that precision in elevations at the Faro mine site is an issue that must be carefully investigated.

The intention for this report is to employ metric elevations above mean sea level datum wherever possible.



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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
Calgary, AB Phone (403) 250-5185

CLIENT: Deloitte & Touche

PROJECT: Faro Fresh Water Supply Dam
Evaluation of Reclamation Approaches

TITLE: FWS Dam Cross-Section from As-Built Drawing

PROJECT No.	DWG. No.	REV.
0168-007-01 GLL: 20-933	FIGURE 2	0

Foundation conditions for the dam vary across the length of the dam. In the middle portion of the dam, the dam rests on a competent till material. The abutments of the dam rest on a sloping bedrock surface.

The zoned earthfill dam is composed of three main zones, which are the following:

- Zone 1 - Impervious core.
- Zone 2 - Sand and gravel shell.
- Zone 3 - Random fill (material that did not meet the requirements for Zones 1 and 2).

Zone 1 material is composed of a silty sand or sandy silt material. Gradation tests (Ripley et. al. 1967) performed on this material revealed a silt content ranging from 30 to 60 percent. The permeability of the material was estimated (Ripley et. al. 1967) as ranging from $1x10^{-5}$ to $1x10^{-6}$ cm/s. Gradation specifications for the material used in Zone 1 is included as Figure 3.

Zone 2, the sand and gravel shell, is composed of cobbles, gravel and sand. Gradation tests (Ripley et. al. 1967) performed on this type of material determined silt content to be less than 5%. Gradation specifications for the material used in Zone 2 is included as Figure 4.

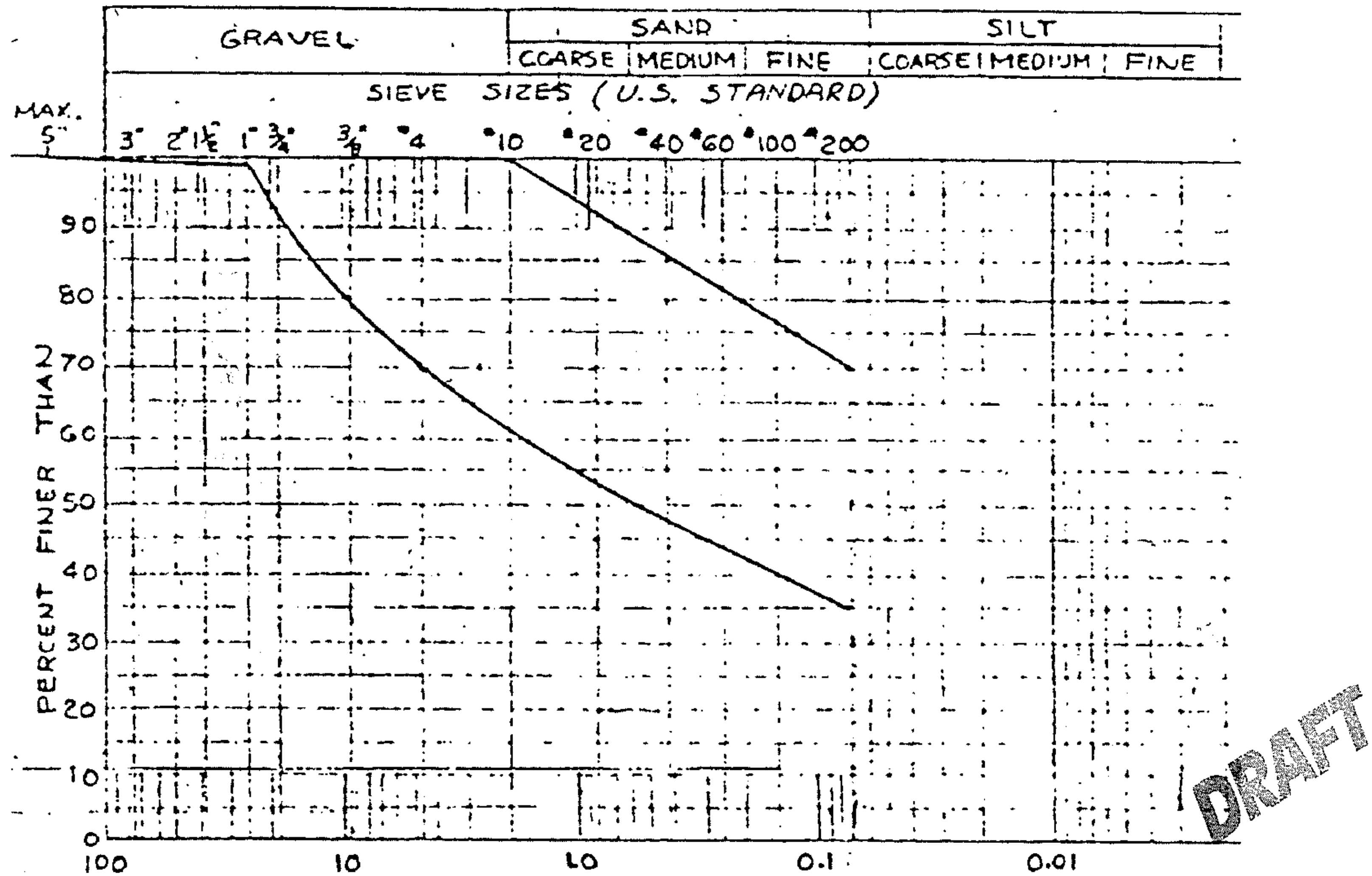
Zone 3 material is those materials that did not meet the requirements for Zone 1 or 2; i.e. Zone 1 material with not enough silt or clay and Zone 2 material with too much silt or clay.

Seepage concerns have existed since the construction of the dam. A near surface groundwater table and anticipated increase of pore pressure from the construction of the dam lead designers to expect seepage to occur at the downstream toe of the dam. Shortly after construction was completed, the appearance of considerable seepage and accompanying sand boils lead to the design and construction of a downstream toe drain/ berm in 1970. Although the amount of seepage at the toe was less than expected by the designers (as noted by Klohn 1969), construction of the berm went ahead. A drainage ditch now exists at the toe of the berm to carry seepage south parallel to the berm towards the valve house tail race. The flow from the ditch was estimated (Dome 1984) to be approximately 9 Lps and described as being "clear of solids". No information is available to BGC at the time of writing this report on the material that comprises the berm except that it is described as being "rock fill". The approximate dimensions of the berm are 4 m high, 20 m wide and approximately 150 m long.

Golder (2000) notes that an addition to the berm was completed in 1989. The berm addition contains a preferentially pervious lower section (0.5 m high) that provides easy exit for artesian seepage.

2.1.3 Water Conveyance and Hydrology

Water from the FWS dam is released from the reservoir by two means; an overflow spillway on the crest of the dam and a low-level outlet pipe, which runs through the dam at the base.



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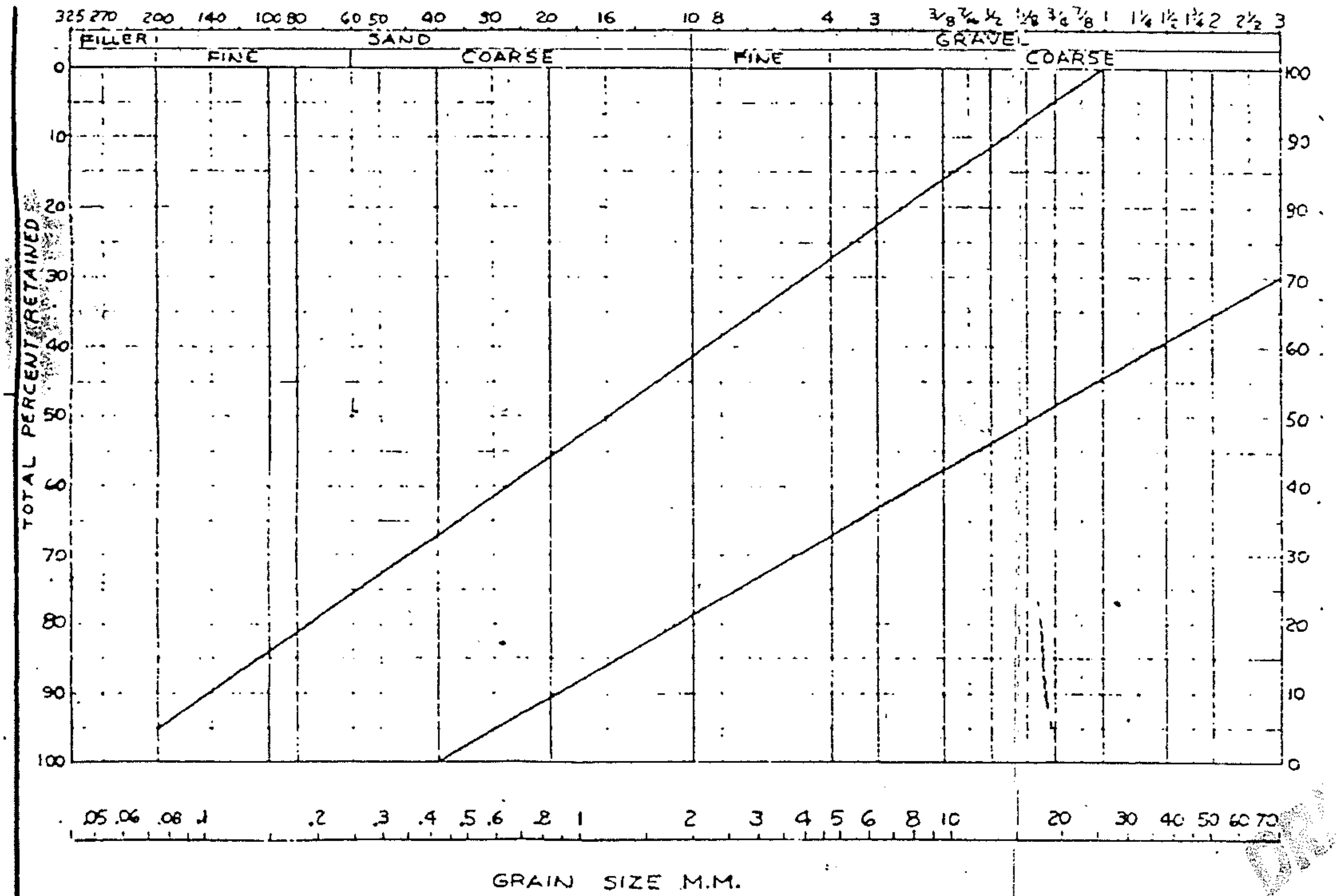
Phone (403) 250-5185

CLIENT: **Deloitte & Touche**

PROJECT: **Faro Fresh Water Supply Dam Evaluation of Reclamation Approaches**

TITLE: **Zone 1 (Core) Gradation Limits**

PROJECT No.	DWG. No.	REV.
0168-007-01 GLL: 20-933	FIGURE 3	0



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CLIENT: **Deloitte & Touche**

PROJECT: **Faro Fresh Water Supply Dam Evaluation of Reclamation Approaches**

TITLE: **Zone 2 (Shell) Gradation Limits**

PROJECT No.	DWG. No.	REV.
0168-007-01 GLL: 20-933	FIGURE 4	0

Executive Summary

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Long-standing concerns regarding the physical stability of the FWS dam and the potentially significant consequences of a failure of the dam have created the desire to investigate approaches for reclamation. This report presents a comparative analysis of three alternatives for reclamation of the dam.

The FWS dam is one of the original (1968) mine structures that was used, prior to 1997, to provide water for ore processing. A recycle water system that was constructed in 1997 replaced the FWS dam as the primary supply of water to the processing plant and the FWS dam is no longer required for mine operations.

The south fork of Rose Creek provided freshwater fisheries habitat prior to construction of the dam. The dam represents two fundamental changes to the creek. The first change is the creation of good winter habitat in the reservoir upstream of the dam. The second change is the blockage of fish passage from downstream of the dam up into the reservoir by two hanging culverts below the overflow spillway. The consequences of these changes are that fish resident in the creek downstream of the dam do not have access to the high quality winter habitat in the reservoir and fish resident in the reservoir do not have access to the high quality spawning habitat below the dam. Nonetheless, the resident population appears to have been able to sustain itself by use of spawning grounds in Rose Creek upstream of the reservoir.

The FWS dam currently does not meet all of the requirements for factor of safety. The current factors of safety for a static condition for the upstream and downstream sides are 1.82 and 1.38, respectively, versus a standard of 1.5. The current factors of safety for the estimated maximum credible earthquake for the upstream and downstream sides are 0.91 and <1.0, respectively, versus a standard of greater than 1.0.

Reclamation objectives for the FWS dam are focussed on achieving acceptable long-term standards for physical stability by lowering the upstream pond water level. This would be accomplished by excavating a breach or notch into the dam in such a manner that the spillway overflow elevation was lowered. Enhancements of fisheries habitat (maintaining winter habitat in the reservoir and providing fish access) are additional objectives. The reclamation approach must consider modifications to the FWS dam in the context of the overall water control system including the downstream tailings retention dams and the downstream Rose Creek Diversion Canal. Three reclamation approaches were considered.

The first reclamation approach that was considered was a breaching of the dam by 3 metres representative of an effort to reduce the risk associated with the dam with a relatively low cost. In this approach, the physical stability of the dam is not improved to meet the required standards and this approach is not considered further.

The second reclamation approach that was considered was a breaching of the dam by 6 metres representative of an effort to achieve acceptable physical stability, maintain winter habitat in the reservoir, and provide fish access. In this approach, acceptable physical stability can be achieved by constructing a rock fill berm on the upstream toe of the dam. The desired fisheries enhancements are also achieved in this approach.

The third reclamation approach that was considered was a complete breaching of the dam. In this approach, acceptable physical stability and fish access are achieved but the winter habitat is eliminated.

A comparison of the reclamation approaches indicate that the costs for implementation of the second approach is less than that for the third approach. The second approach presents the benefit of maintaining fisheries winter habitat but incorporates a slightly higher risk regarding physical stability. The third approach presents a virtual elimination of the risk of dam failure but also represents a loss of the fish winter habitat that was created by construction of the dam. The results of an assessment of benefit versus risk in this situation will depend, to a large degree, on the value that is placed on preserving the fish habitat and sport fishing resource.

The primary conclusions and recommendations of this report are:

- the current configuration of the FWS dam does not meet current dam safety guidelines and the configuration should be modified.
- a sustainable fisheries resource exists in the reservoir but could be improved with certain beneficial modifications to the FWS dam.
- The factor of safety on the upstream side is reduced when the reservoir water level is reduced to a "partial pond"; this is as expected for dams with a sloping core.
- a relatively small lowering of the maximum reservoir water level by 3 metres (option 1) does not achieve the required factors of safety for physical stability due to the preceding comment.
- lowering the maximum reservoir water level by 6 metres and constructing a toe buttress on the upstream side of the FWS dam is the preferred approach at this time because it appears to satisfy all of the objectives; additionally, minimum flow requirements in Rose Creek can be maintained with benefits in preventing downstream ice damming and enhancing winter fisheries needs; the rough estimated cost for this reclamation approach is $748,000 including a 20% contingency.
- a complete breach of the dam such that the upstream reservoir is eliminated provides a near elimination of the risk of failure of the dam and allows fish access but represents a loss of winter fish habitat; additionally, the current minimum flow requirements in Rose Creek might not be met; the rough estimated cost for this reclamation approach is $1.7 million including a 20% contingency.

- communication with the Department of Fisheries and Oceans regarding reclamation of the FWS dam should continue and other affected parties, including the Ross River Dena Council, should also be included in the determination of the most appropriate reclamation approach.
- field investigations should be performed that would verify the findings of this report and that would allow detailed design of the preferred reclamation approach to proceed.
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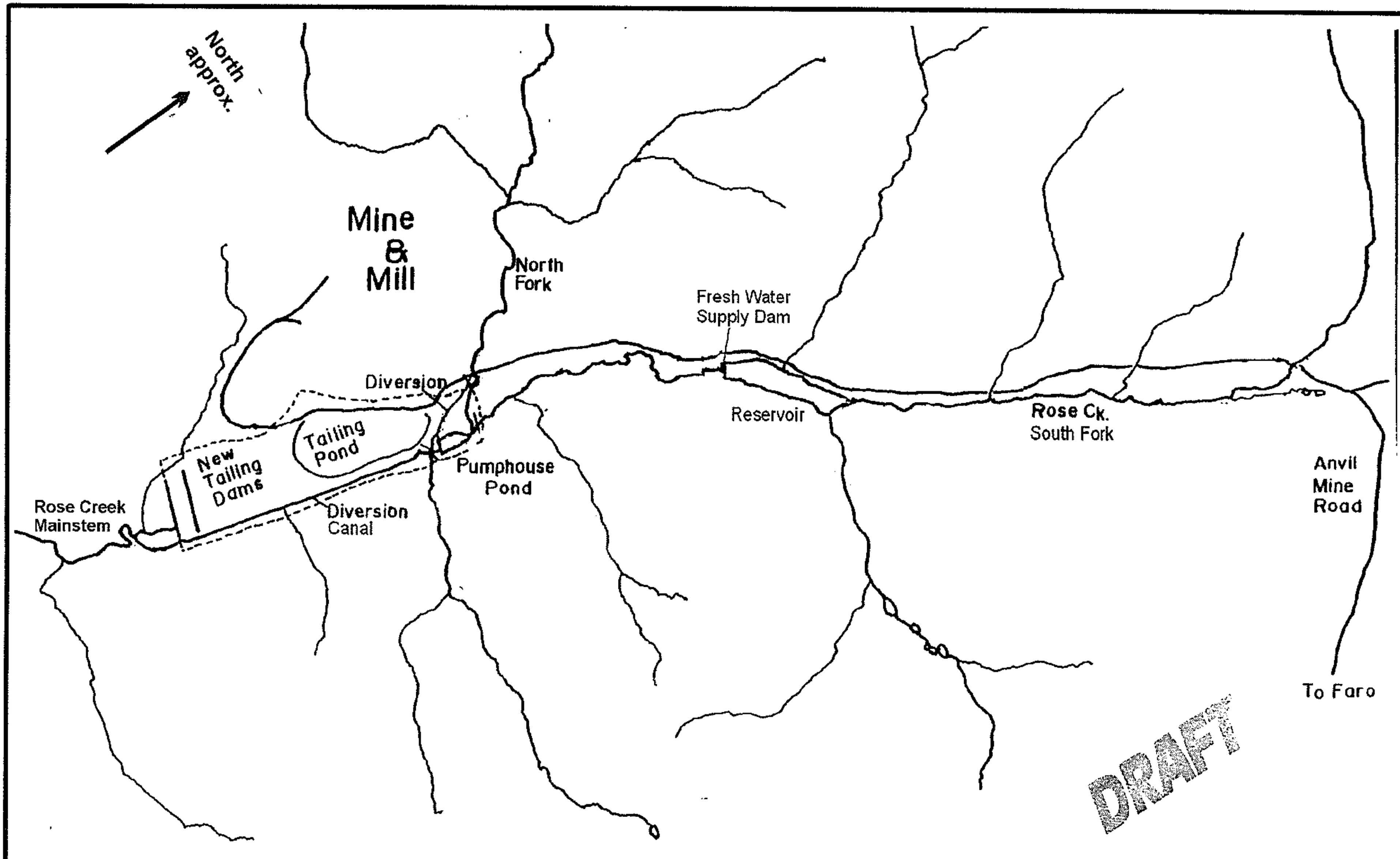

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Source of Figure:
Report by Ken Weagle Dated October 1981
Title: The Impact of the Scheme 2 Abandonement Plan
On the Grayling Population of Rose Creek
Figure 1, Details of Study Area

Gartner Lee

CLIENT **Deloitte & Touche**

PROJECT: **Faro Fresh Water Supply Dam Evaluation of Reclamation Approaches**

TITLE: **Study Area**

PROJECT No.	DWG. No.	REV.
GLL: 20-933	FIGURE 1	0

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The intention for this report is to employ metric elevations above mean sea level datum wherever possible.

2. Description of Current Status

2.1 Geotechnical Considerations

2.1.1 Data Sources Available

For this current stability assessment work, several sources of data and information specific to the FWS dam were obtained and reviewed, as partially summarized below:

- As-built plans and drawings by H.A. Simons International Ltd. (1968).
- Various letters from Ripley, Klohn and Leonoff International Ltd. between December, 1967 and May, 1968 on design issues and material testing results.
- Rose Creek flows and spillway capacity by Sigma (1975).
- Investigation report by Dome (1984) and an Internal Dome memo dated September 24, 1984.
- Inspection and monitoring reports by Golder Associates Ltd. (1999 and 2000).
- Inspection and Monitoring Report by BGC Engineering Inc. (2001).

Complete references for each of these information sources is provided in the reference section at the end of the report.

In addition to FWS dam info, numerous reports on the Down Valley tailings project (downstream from the FWS dam) and on the mine site in general were also reviewed, including the following:

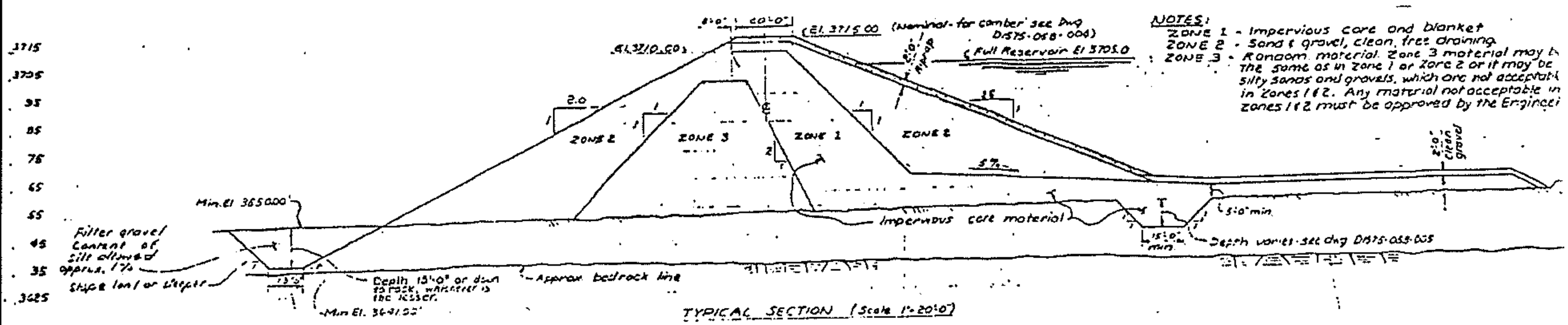
- Down Valley design documents as provided by Golder Geotechnical (1980).
- Down Valley hydrologic and hydraulic design as noted in Hydrocon (1980).
- Hydrology assessments as summarized by Curragh Resources (1988).
- Overall site characterization and closure plan provided in Robertson (1996).

In addition, both Mr. Eric Denholm (Gartner Lee Ltd.) and Mr. Jim Cassie (BGC Engineering Inc.) have worked extensively at the Faro site, and hence, have personal knowledge of site conditions and history.

Information from these reports was collected, reviewed and synthesized for use in the stability analyses provided herein.

2.1.2 Dam Geometry and Configuration

The FWS dam is approximately 410 m long, 20 m high at its highest point and 6 m wide at the crest. The slope of the upstream face of the dam is approximately 2.5H:1V and the slope of the downstream face of the dam is 2H:1V, as shown on Figure 2. The dam also has a sloping core that connects to an upstream blanket and cut-off trench.



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AN APPLIED EARTH SCIENCES COMPANY
Calgary, AB Phone (403) 250-5185

CLIENT: **Deloitte & Touche**

PROJECT: **Faro Fresh Water Supply Dam Evaluation of Reclamation Approaches**

TITLE: **FWS Dam Cross-Section from As-Built Drawing**

PROJECT No.	DWG. No.	REV.
0168-007-01 GLL: 20-933	FIGURE 2	0

Foundation conditions for the dam vary across the length of the dam. In the middle portion of the dam, the dam rests on a competent till material. The abutments of the dam rest on a sloping bedrock surface.

The zoned earthfill dam is composed of three main zones, which are the following:

- Zone 1 - Impervious core.
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Zone 1 material is composed of a silty sand or sandy silt material. Gradation tests (Ripley et. al. 1967) performed on this material revealed a silt content ranging from 30 to 60 percent. The permeability of the material was estimated (Ripley et. al. 1967) as ranging from $1x10^{-5}$ to $1x10^{-6}$ cm/s. Gradation specifications for the material used in Zone 1 is included as Figure 3.

Zone 2, the sand and gravel shell, is composed of cobbles, gravel and sand. Gradation tests (Ripley et. al. 1967) performed on this type of material determined silt content to be less than 5%. Gradation specifications for the material used in Zone 2 is included as Figure 4.

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Seepage concerns have existed since the construction of the dam. A near surface groundwater table and anticipated increase of pore pressure from the construction of the dam lead designers to expect seepage to occur at the downstream toe of the dam. Shortly after construction was completed, the appearance of considerable seepage and accompanying sand boils lead to the design and construction of a downstream toe drain/ berm in 1970. Although the amount of seepage at the toe was less than expected by the designers (as noted by Klohn 1969), construction of the berm went ahead. A drainage ditch now exists at the toe of the berm to carry seepage south parallel to the berm towards the valve house tail race. The flow from the ditch was estimated (Dome 1984) to be approximately 9 Lps and described as being "clear of solids". No information is available to BGC at the time of writing this report on the material that comprises the berm except that it is described as being "rock fill". The approximate dimensions of the berm are 4 m high, 20 m wide and approximately 150 m long.

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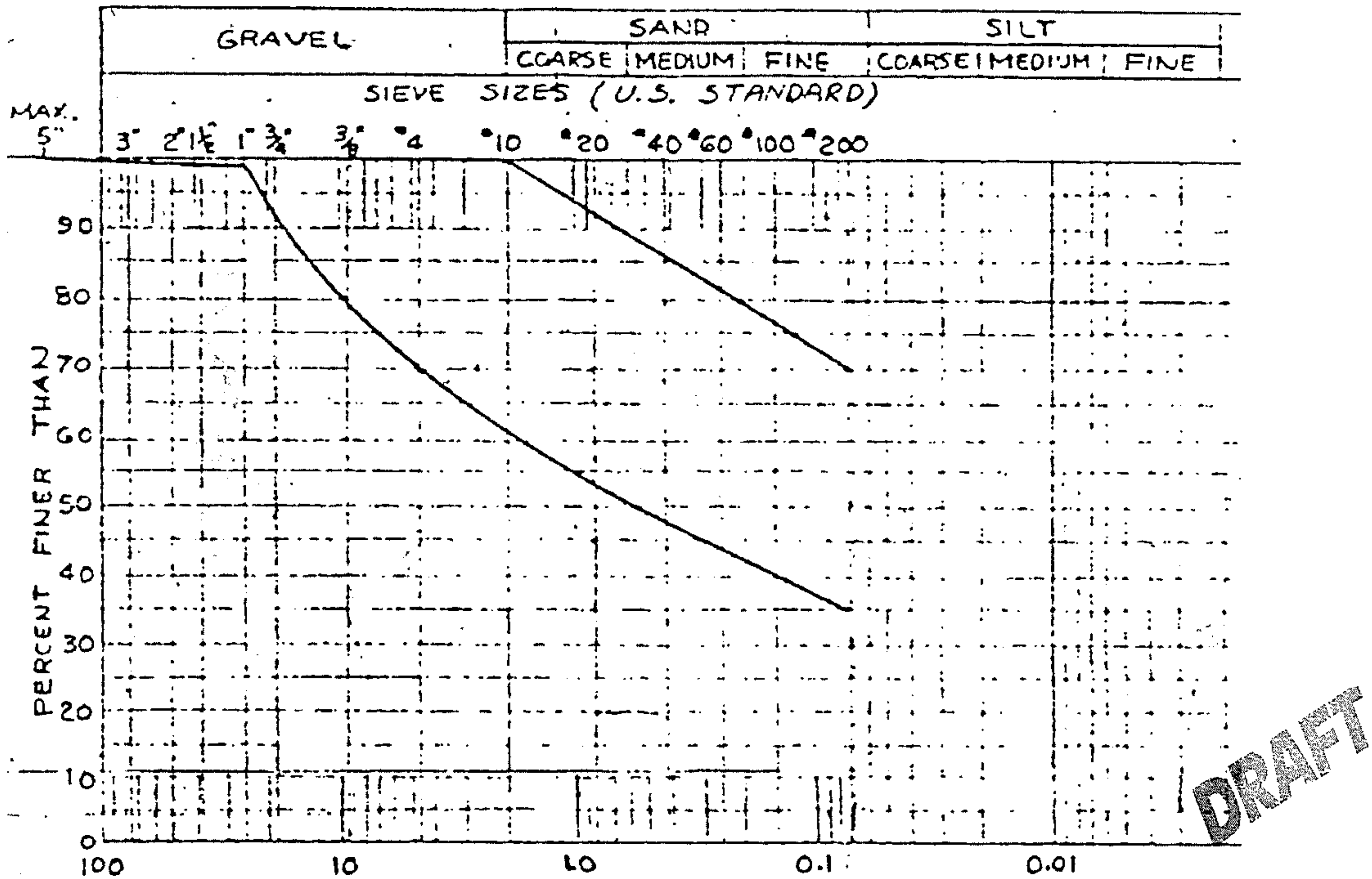
2.1.3 Water Conveyance and Hydrology

Water from the FWS dam is released from the reservoir by two means; an overflow spillway on the crest of the dam and a low-level outlet pipe, which runs through the dam at the base.



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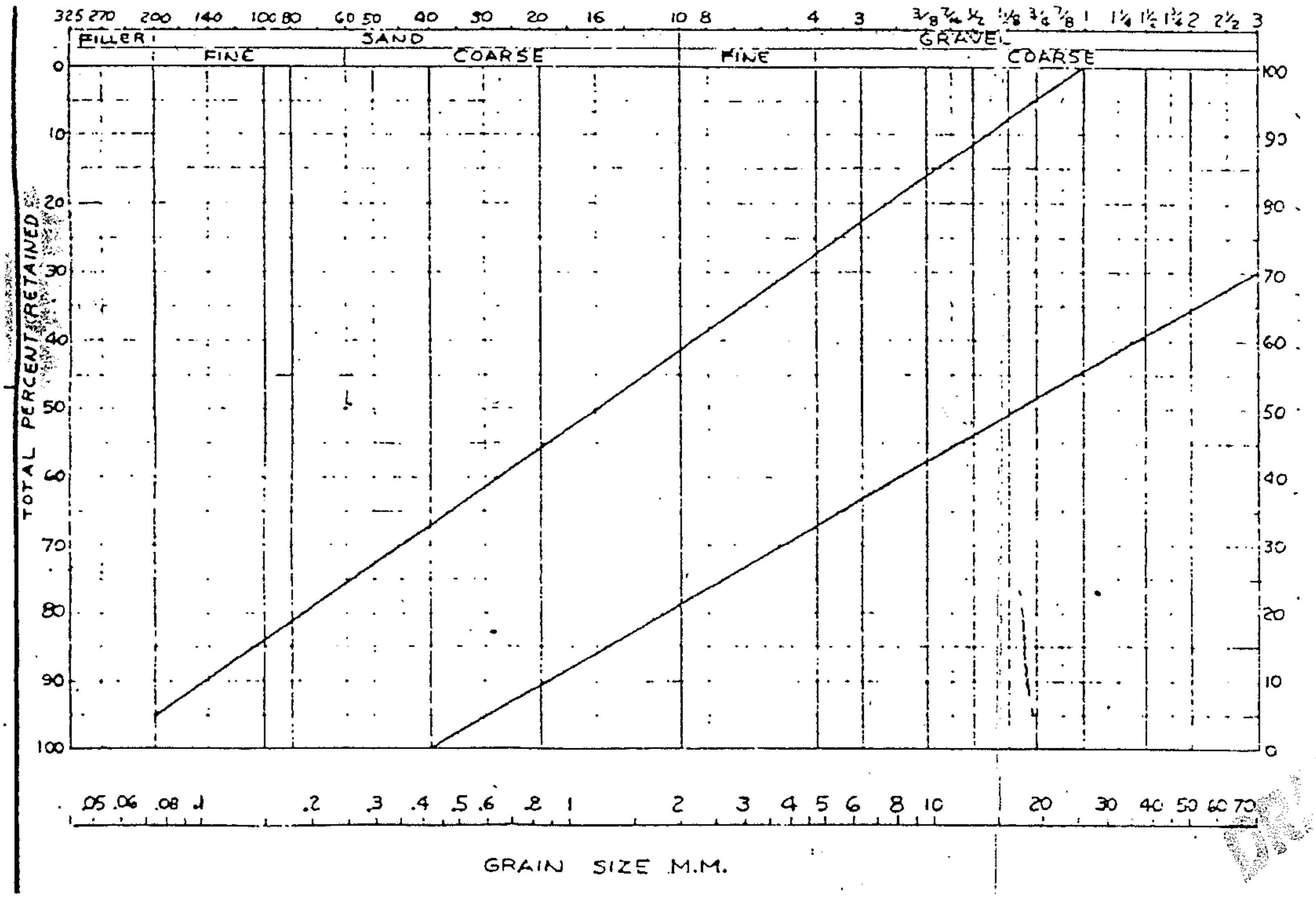
CLIENT **Deloitte & Touche**

PROJECT: **Faro Fresh Water Supply Dam Evaluation of Reclamation Approaches**

TITLE: **Zone 1 (Core) Gradation Limits**

PROJECT No.	DWG. No.	REV.
0168-007-01 GLL: 20-933	FIGURE 3	0



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TITLE: **Zone 2 (Shell) Gradation Limits**

PROJECT No.	DWG. No.	REV.
0168-007-01 GLL: 20-933	FIGURE 4	0

The spillway was constructed near the north abutment of the dam and consists of a 30 metre wide concrete structure with 3.2 m high wing walls. Design elevation for the spillway sill was 3705.0 ft. (mean sea level), but was actually surveyed as 3702.71 ft. (mean sea level) or 1096.11 (mean sea level) in 1974 by John Maissan (Energy, Mines and Resources staff member). Table 1 also provides some of the other relevant data, relative to the spillway:

Table 1. Summary of Dam Design and Surveyed Elevations

Location	Original Design Levels (feet above mean sea level)	1974 Survey Levels (feet above mean sea level)	Metric Equivalents of 1974 survey (metres above mean sea level)
Invert of spillway	3705.0	3702.71	1128.59
Top of core	3710.0	3707.71	1130.11
Top of spillway wall	3715.0	3713.26	1131.80
Top of dam (ends)	3715.0	3712.49	1131.57
Top of dam (center)	3716.0	3713.49	1131.87

Sigma (1975) noted that the standard broad-crest weir formula, $Q=3.0*B*H^{1.5}$ could be applied to this spillway, where B is the width (measured as 99.33 feet or 30.3 m) and H is the height of water above the sill level. Therefore, if the entire depth of the spillway was used, a discharge of 287 m^3/s could result. The internal memo by Dome in 1984 uses the Francis formula for a sharp crested weir, $Q=3.33*L*H^{3/2}$, where L is the spillway length and H is the reservoir height above the sill level. Based on Klohn Leonoff's abandonment plan prepared in 1981, the estimated 1:100 year flood of 24 m^3/s would create a height of 0.6 m (2 feet) in the spillway.

In 1976, steel I-beams were placed within the spillway to support the addition of stop logs. The stop logs were placed across the spillway allowing the water level within the reservoir to rise above the elevation of the spillway sill. The stop logs system was recently discontinued due to concerns that the excess water pressure caused by a higher reservoir elevation could lead to increased seepage at the downstream toe. The spillway empties into a discharge channel that is excavated through rock and overburden. The channel bed is composed of cobbles over bedrock.

The low level outlet pipe runs along the base of the dam near the south abutment and has an inlet elevation of approximately 1112.5 m (mean sea level). The system is composed of a submerged drop inlet pipe with outlet control valves. A trash gate exists on the inlet opening. The main pipe is 1066.8 mm (42 inch) in diameter. The downstream valve has a 610 mm (24 inch) opening. During discharge, the flow impinges against the lower downstream inside face of the valve house before discharging just below the valve house. The valve house is located within an excavated channel along the south abutment downstream from the toe of the dam. The flow is then directed into the excavated canal. The pipe was confirmed in 1984 to be able to pass a maximum discharge rate of 0.91 m^3/s (12,000 gpm).

A large area for over-wintering has been created by the reservoir. Fish located downstream of the dam likely over-winter in the pumphouse pond or other deep areas of Rose Creek, where water flows continue below the ice.

There are three major barrier points to fish migration within the study area. These include the culverts conveying flows from the FWS dam spillway within the south fork, the haul road at the north fork and the section of the south fork from the access road crossing to the haul road crossing (where the access road culvert, the stream gradient and the haul road each pose a barrier).

Despite the creation of a barrier to upstream fish migration at the FWS dam spillway culverts (some fish will be carried or choose to move downstream), it has been determined that the arctic grayling populations both upstream and downstream of the FWS dam within the study area are in good biological condition. In both areas, sufficient habitat exists to support all life phases of arctic grayling (Weagle, 1981).

2.3 Future Mine Operations Considerations

Each of the reclamation options that are described in this report would result in a reduction in the storage capacity of the fresh water reservoir. This is not considered to be an important issue regarding future mine operations as described below.

Prior to 1997, all of the water required for operation of the concentrator plant (approximately 7,000 USgpm continuous) was fresh water obtained from Rose Creek. In the spring, summer and fall seasons, an adequate flow of water was typically present in Rose Creek to supply water to the concentrator plant and to maintain an acceptable level of flow in Rose Creek downstream of the mine site as defined by the water licence. However, the natural flow in Rose Creek during the winter season was insufficient to supply these two uses. Therefore, the fresh water supply dam was constructed with the intention of storing water during the spring, summer and fall seasons for later controlled release through the winter season.

During years from 1976 to 1997 when the concentrator plant was operating, the typical operating plan for the fresh water supply dam is thought to have consisted of placing stop logs in the overflow spillway in late summer or fall in order to maximize the volume of water stored, and to release water at a controlled rate through the winter via a low level outlet pipe. This plan would supply both the needs of the concentrator plant and the minimum flow requirement for Rose Creek. The water level in the fresh water reservoir in early spring was typically very low and has been reported as being approximately 30 feet below the spillway invert on at least one occasion (Bud McAlpine, pers. comm.).

A recycle water system was constructed at the Faro mine site in 1997 subsequent to the water level in the mined out Faro Main pit rising to a practical pumping elevation and approaching the maximum recommended elevation for environmental protection purposes. The recycle water system was designed to deliver an adequate flow of water from the mined out Faro Main pit to the concentrator plant to support plant operations and the system was successfully used during the fall of 1997 and up to mine shut down in

January 1998. The volume of fresh water that was required from Rose Creek was reduced to less than 5% of the previous usage.

The demonstrated effectiveness of the recycle water system to provide water for operation of the concentrator plant with no observed negative impacts on metallurgical performance has eliminated the need for the fresh water supply dam as the primary source of water. That is, there is no longer a need for the storage of Rose Creek water for mine operations.

The only purpose that the existing fresh water supply dam would be anticipated to serve for future mine operations would be as a back up water supply that could be accessed in the event of a failure of the Faro pit recycle water system. However, the benefits of maintaining the fresh water supply dam for this possible secondary purpose are considered to be greatly outweighed by the costs and environmental risks associated with maintenance of the structure.

2.4 Reservoir Capacity

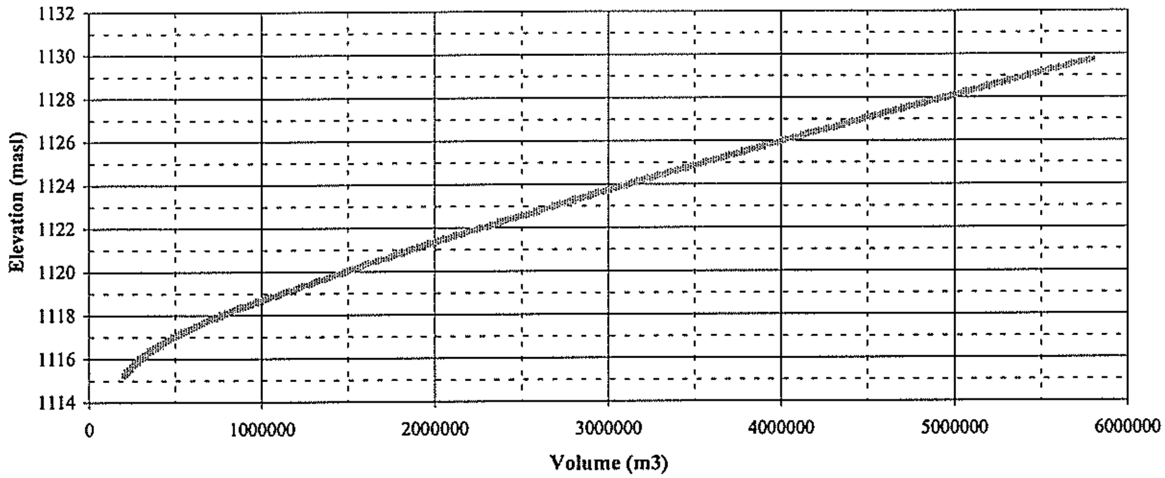
A storage capacity curve (Figure 5) was created for the reservoir that indicates a current reservoir storage capacity of 5.8 million m^3. This total capacity agrees with the storage volume that is quoted in the 1996 Closure Plan (Robertson).

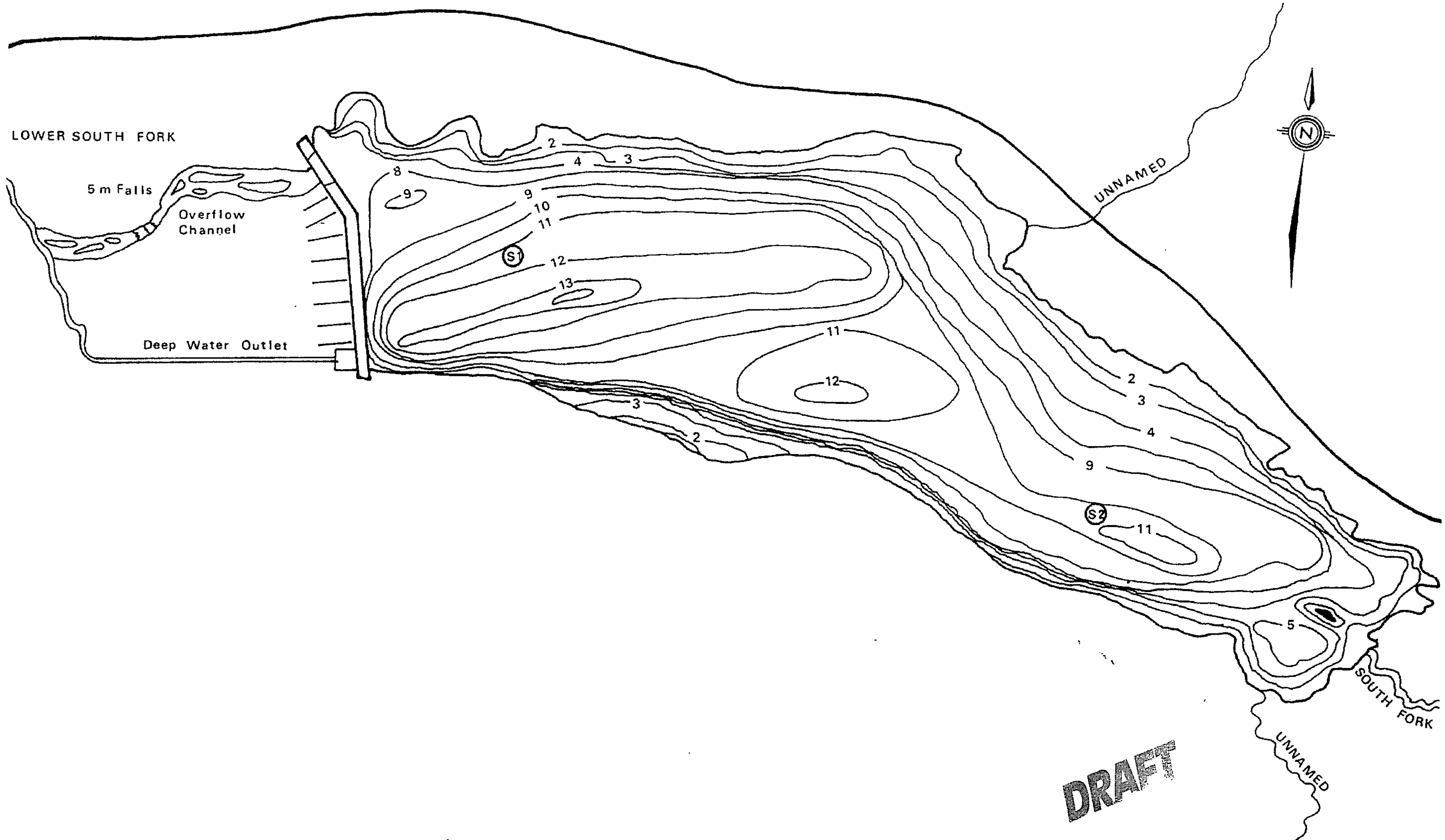
The storage curve was estimated from a representative cross section of the reservoir and a depth profile derived from the bathymetric contour map shown on Figure 6, which was taken from P.A. Harder (1991). The calculation assumed an average reservoir width (at full capacity) of 315 metres, a reservoir length of 1525 metres and average side slopes of 22%.

There is a discrepancy between the bathymetric contour map shown on Figure 6, which indicates a maximum water depth of 14 metres, and the design and as-built information, which indicates a maximum water depth of 17.5 metres. The design and as-built information is taken as being more precise since it is based, in part, on survey information near the dam. The methodology of the 1991 bathymetric contouring was not described in the P.A. Harder report and the method and spacing of depth measurements are unknown. Nonetheless, the bathymetric contours were used to provide an indication of the basin shape. The contours illustrate that the basin largely maintains the shape of the representative section for its length and that that the basin maintains significant depth along its length.

The storage capacity curve is preliminary in nature. While suitable for use in this comparative analysis of reclamation options, the bathymetry of the reservoir must be verified by field measurement prior to use in future design processes.

Figure 5. Preliminary Storage Capacity Curve





Source of Figure:
Report by P.A. Harder and Associates Ltd
Dated April 1991. Title: Overview Assessment of Fish Resources in Anvil and Rose Creeks
Appendix 2: Figure 2.1 Bathymetric Soundings for the South Fork Reservoir and Location of Water Quality Sites Aug, 1990.

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Gartner Lee

CLIENT: Deloitte & Touche

PROJECT: Faro Fresh Water Supply Dam Evaluation of Reclamation Approaches

TITLE: BATHYMETRIC MAP OF THE RESERVOIR (Measured August 1989/1990)

PROJECT No.	FIGURE. No.	REV.
GLL: 20-933	Figure 6	0.

3. Reclamation Objectives

3.1 Geotechnical Considerations

3.1.1 Physical Stability

CDA (1999) defines slope stability factor of safety as the factor required to reduce the mobilized shear strength parameters (of the soil or rock) of a potential sliding mass into a state of limiting equilibrium. A simpler definition notes the factor of safety as the ratio of the resisting forces in a sliding block (e.g. shear strength of the soil) to the driving forces (e.g. soil weight). As such, for a block to be considered "stable", the resisting forces must be in excess of the driving ones.

The objective of breaching the FWS dam and lowering the pond level is to reduce the potential future liability associated with this dam. Generally, a decrease in retained pond level increases the factor of safety for embankment dams, although not in all cases. Terzaghi and Peck (1967) note that for dams with a sloping core, such as the FWS dam, the stability of the upstream slope "may be more critical at an intermediate level, known as partial pool, than with the reservoir "full". Lowering the retained water level not only increases (generally) the factor of safety against failure but reduces the resultant consequences of any failure, should one occur.

CDA (1999) provides design criteria for the required factors of safety for static analysis of embankment dams, as summarized in Table 2:

Table 2. Factors of Safety, Static Assessment (after CDA, 1999)

Loading Conditions	Minimum Factor of Safety	Slope
Steady state seepage with maximum pond height	1.5	Downstream
Full or partial rapid drawdown	1.2 to 1.3[a]	Upstream
End of constriction before reservoir filling	1.3	Downstream and upstream

[a] Higher values may be required if drawdown occurs frequently during operations.

As such, the downstream toe of the FWS dam will need to achieve a factor of safety under static conditions of at least 1.5, in order to meet these generally accepted guidelines for dam design.

CDA (1999) also provides guidance on the design criteria for earthquake resistance of embankment dams, which states that dams (and associated components) shall be designed to resist the forces associated with the Maximum Design Earthquake (MDE). The MDE is also defined in CDA (1999). For a High Consequence Category dam (failure leading to some human fatalities and/or large socio-economic, financial, environmental damages), the MDE shall be either of the following:

- Flow control through the low-level outlet at the dam has ensured water flows downstream throughout the winter, potentially creating or expanding over-wintering habitat in the pumphouse pond and elsewhere in Rose Creek.

The Department of Fisheries and Oceans (S. Orban, pers. comm.) has suggested the following objectives for breaching of the FWS dam:

- Dam stability;
- The maintenance of adequate summer and winter habitat in the reservoir for arctic grayling;
- The maintenance of a sport-fishery within the reservoir; and
- Fish access to the reservoir from downstream.

Assurance that the dam structure is stable and maintenance of summer and winter habitat in the reservoir are the key issues. With adequate habitat maintained, the reservoir will continue to serve as a sport-fishing site. If seasonal fish access can be obtained through elimination of the culverts, then the arctic grayling currently located downstream will have increased access to over-wintering habitat in the reservoir and the arctic grayling currently located in the reservoir will have access to higher quality spawning habitat located in the downstream channel.

3.3 Extreme Winter Condition

A worst case scenario was necessary for the comparative evaluation of fisheries wintering habitat in the reservoir. The assessment of winter habitat as low, moderate or high is based, in part, on the minimum depth and volume of water that is available at the end of winter immediately prior to the onset of freshet inflows.

The primary consideration in this regard is the on-going necessity for the release of water from the reservoir through the winter season via the low level outlet pipe. In the comparative evaluation of options, it is necessary to release water from the reservoir in excess of the inflows. Although inflows into the reservoir typically continue throughout the winter season (based on direct observations by mine personnel), the inflows are assumed, at this time, to be insufficient to meet the outflow demands that are described below.

The Faro Water Licence (QZ95-003) requires that a minimum flow of 4.5 m^3/day (approximately 75 Lps) be maintained in the Rose Creek Diversion Canal (RCDC) throughout the winter for fisheries and conservation purposes. Additionally, operating experience has shown that 75 Lps is the minimum desired winter flow to maintain an open channel in and under the ice in the RCDC and to prevent ice damming and blockage.

Experience during the 1999/2000 winter season provides a good illustration of this issue. During that season, a consistent flow of approximately 100 Lps was released from the FWS dam with the result that the minimum licence requirement was generally achieved and significant ice damming in the RCDC was prevented. Although the FWS dam outlet flow of 100 Lps appears to exceed the minimum licence requirement by 25 Lps, flow measurement immediately downstream of the RCDC (location X14) indicated that the daily average flow dropped to as low as 50 Lps on several isolated days around late April and early May. It is possible that these low flow measurement gathered by a pressure transducer may be the result of water surging under an ice cover and they are not considered to represent a compromise of the fisheries and conservation intentions of the licence. This does suggest, however, that surface flow lost to groundwater and ice creation is substantial. This suggestion is further supported by consideration that flows also continued from the north fork of Rose Creek throughout the winter that entered the RCDC in addition to the 100 Lps that was released from the FWS dam.

During the 1999/2000 winter season, overflow from the reservoir ceased in early January and re-commenced in late May, a period of approximately 3½ months. It is possible that overflow might have re-commenced earlier if the management plan had called for ceasing or reducing the outflow from the FWS dam low level pipe once increased flows were observed in the north fork and other tributary creeks.

For the purposes of a worst case winter scenario, it is assumed that the release of 1.6 million m^3 of water is required over a six month period from December to May during which time there is no inflow into the reservoir. This is equivalent to a consistent release of 100 Lps in excess of any inflows over a six month period. This is taken as representative of a rare and extreme winter condition that would result in a rare and extreme minimum volume of water available as winter fisheries habitat.

The application of this worst case/extreme winter case provides for an assessment of the quality of winter fish habitat that would be available at the end of such an extreme season as described in subsequent sections of this report.

4. Characterization of Reclamation Approaches

4.1 Calibration and Assessment of Current Conditions

Before any analyses were undertaken on the breached dam configuration, it was first necessary to review two different initial stability cases, as noted below:

- The original designers case, which uses one estimated piezometric surface, along with two different sets of estimated friction angles. Since the dam was likely designed to current safety factors, this assessment permits the estimated parameters to be verified.
- In the second case, the existing dam configuration is assessed, using the two piezometric surfaces, which are indicated by instrumentation data collected to-date. Input parameters, validated in the initial case, are used, along with seismic design parameters as noted earlier.

Pore water pressure conditions for the full reservoir case were estimated from piezometric data collected from the pneumatic and hydraulic piezometers installed within the dam and downstream berm. Two piezometric conditions were analyzed. The initial considered the dam and foundation materials to have one common piezometric condition. The second case included a separate piezometric condition to exist within the foundation till. The case of two separate piezometric conditions existing within the model is based on information collected from pneumatic piezometers placed within the dam and foundation. The piezometer data suggest the existence of higher pore water pressures existing within the foundation till than the pore pressures that exist within the dam. Since the higher conditions are more critical for stability, they were assumed for the current case evaluation, although a critical review of observed pore pressures, coupled with a two-dimensional seepage analysis, is recommended for future design phases.

Material properties were estimated from lab data reported by Ripley, Klohn, Leonoff during the preliminary site investigation for the FWS dam in 1967. The gradation guidelines displayed on construction drawing D1575-058-006 were also taken into consideration when determining material properties for the stability analysis. Table 4 outlines the parameters estimated for the various materials:

Table 4. Parameters Used for Stability Analyses

Material	Unit Weight (kN/m^3)	Cohesion (kPa)	Effective Friction Angle
Zone 1 Core	17	0	27°/30°
Zone 2 Shell	19	0	38°/41°
Zone 3 Random	18	0	35°
Foundation till	19	0	33°

These parameters were estimated based on previous experience. In addition, Golder (1980) in their Down Valley dam design document, provides testing results for materials very similar to the Zone 1 and 2 materials. Their friction angle results were at the high end of the range noted in Table 4.

Stability analysis consists of postulating an expected failure block, breaking the failure block into a number of slices and then computing the summation of the forces and/or moments (driving and resisting) for that block. These calculations were performed with the geotechnical software package, SLOPE/W written by Geo-Slope Software of Calgary. The software can either analyze a fully-specified block or the program can search for the block with the minimum factor of safety.

There are several analytical methods available for stability assessments, based on the either the summation of forces, moments or both and the shape of the failure block. For the initial calibration case, Bishop's method for circular failures and Janbu's simplified method for circular and non-circular failures were used.

Figure 7 provides a view of the model geometry for the stability analysis. For the designers case, Table 5 outlines the results obtained by searching for the minimum factor of safety, using both of the analytical methods noted previously:

Table 5. Factors of Safety for Designers Case (One Piezometric Surface)

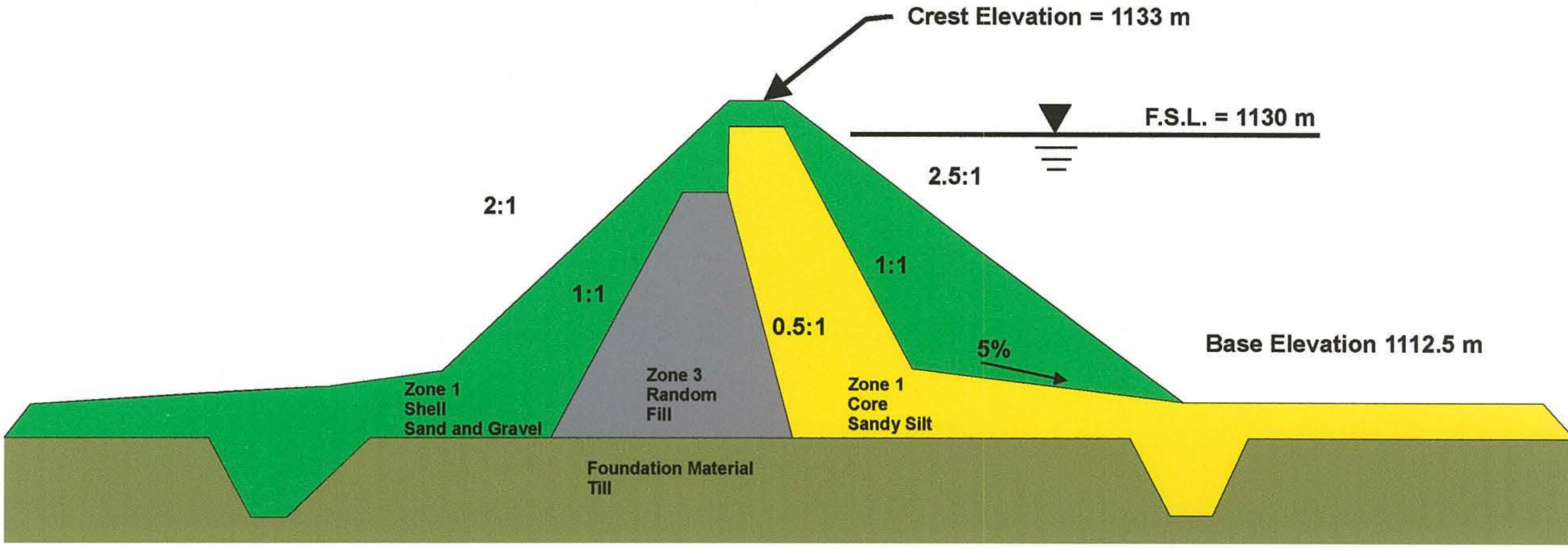
Dam Side	Downstream			Upstream		
Zones 1, 3 and 2 Friction Angles	30°/35°/41° Likely	27°/35°/38° Lower	Difference	30°/35°/41° Likely	27°/35°/38° Lower	Difference
Bishop's Circular Analysis	1.73	1.70	0.03 (1.7%)	1.86	1.71	0.15 (8.1%)
Janbu's Block Analysis	1.53	1.51	0.02 (1.3%)	1.67	1.49	0.18 (10.8%)

Stability of the downstream toe is always the most critical case for steady state seepage conditions, in agreement with the results of Table 5. The critical case is a block failure on the downstream toe, which reaches back through the random fill zone and foundation till. As noted earlier, the designers of this dam would have likely been designing for a static assessment value of 1.5, which has been achieved using the parameters assumed. These results, therefore, validate the assumptions made.

For the downstream side and using the Janbu method, the factor of safety decreases from 1.53 to 1.32 for a seismic factor of 0.07g and to 1.19 for 0.13g. It is unknown what seismic coefficient the designers may have used in 1968, but the current results are in line with current design criteria.

As can also be seen from Table 5, the factors of safety are insensitive (1.5% variation) for the downstream side and slightly sensitive (9.5%) for the upstream side. Since testing results from Golder (1980) validate the values for the likely set of parameters, these values are assumed for all further stability analyses.

As noted earlier, piezometric information collected from the dam indicates two different piezometric regimes within the dam and its foundation. This difference is due to the different permeability values of the various materials and the hydraulic gradients formed from the seepage paths. Figure 8 illustrates the



Note: Elevations noted are metric values, measured to mine Datum.

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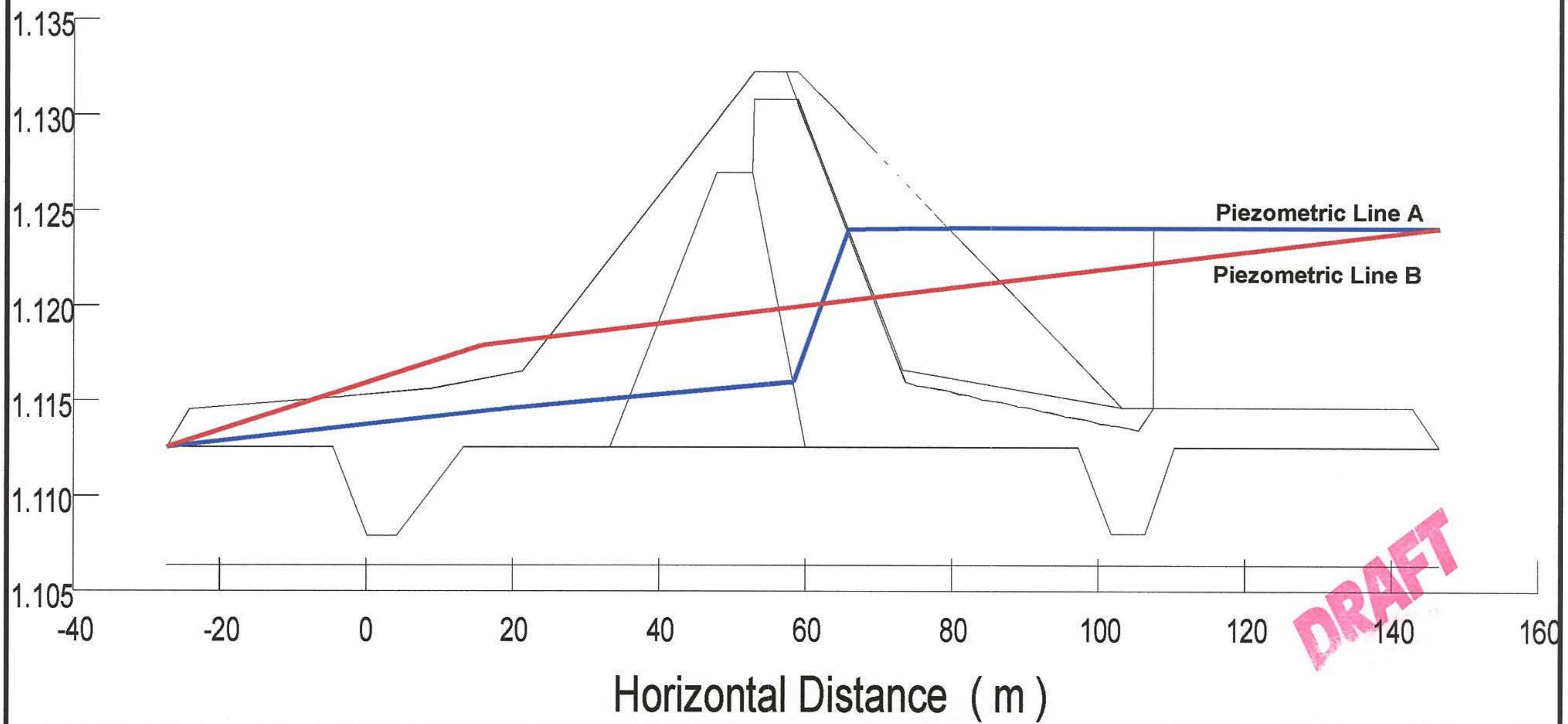

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model used in the analysis of the current conditions and shows two piezometric lines. Piezometric line A corresponds to the piezometric conditions within Zones 1, 2, and 3 of the dam. Piezometric line B corresponds to the piezometric conditions within the foundation till.

Table 6 provides a summary of the safety factors for the current dam, assuming the two different piezometric surfaces:

Table 6. Factors of Safety for Current Case (Two Piezometric Surfaces)

Dam Side	Downstream			Upstream		
Condition	Static	Difference from Calibration Case	With 0.13g	Static	Difference from Calibration Case	With 0.13g
Bishop's Circular Analysis	1.38	0.35	-	1.82	0.04	-
Janbu's Block Analysis	1.22	0.31	<1.0	1.63	0.04	0.91

The addition of the second piezometric surface lowers the factor of safety in all cases, and more for the downstream side than for the upstream side. This effect is to be expected given that the increases in the phreatic levels are more pronounced near the downstream toe. Again, on the downstream side, Janbu's method, is the critical case with a factor of safety of 1.22, significantly below the design standard of 1.5. In addition, both sides achieve a factor of safety of less than unity when the 0.13g seismic acceleration is applied. Hence, if the pore pressures assumptions are valid (based on the observations to-date), the FWS dam does not meet current design criteria for either the static or the seismic design cases. As such, either additional investigative, testing and analytical work needs to be undertaken to refine analysis assumptions or the dam configuration (e.g. reservoir level, piezometric levels, dam geometry) needs to changed to meet these criteria.

4.2 Factors of Safety for Physical Stability

4.2.1 General

Analyses were undertaken in order to determine the change in the factor of safety as the water level in the reservoir was dropped. Several different cases were analyzed, as noted below with their corresponding model reservoir elevations (mean sea level datum):

- Initial conditions (full reservoir) – 1130 m.
- Minimal lowering of water level – 1127 m.
- Substantial lowering of water level, but beneficial to fisheries aspects – 1124 m.
- Complete breach to original ground – 1112.5 m.

As the reservoir level is dropped, the corresponding steady state phreatic levels in the dam materials were estimated, based on the decreasing gradients expected in the various materials.

Table 7 provides a summary of the factors of safety obtained from the analyses. These values were for the Janbu method only (previously demonstrated to be the critical method) and for a fully-specified failure block as illustrated on Figure 9.

Table 7. Factors of Safety for Breached Cases (Two Piezometric Surfaces)

Dam Side	Downstream			Upstream		
Model Reservoir Elevation (m)	Static (% change)	With 0.07g	With 0.13g	Static (% change)	With 0.07g	With 0.13g
1130 (current full supply level)	1.34	1.16	<1.0	1.63	1.15	0.91
1127	1.49 (+11.2%)	1.30	1.17	1.47 (-9.8%)	1.09	0.88
1124	1.64 (+10.1%)	1.42	1.28	1.345 (-8.5%)	1.04	0.86
1121	1.68 (+2.4%)	1.45	1.31	1.35 (+0.4%)	1.08	0.91
1119	1.77 (+5.4%)	1.53	1.38	1.4 (+3.7%)	1.13	0.97
1112.5 (fully breached)	1.94 (+9.6%)	1.67	1.50	1.69 (+20.7%)	1.40	1.22
overall change	45%	44%	58%	4%	22%	34%
1124 ***with upstream toe buttress***	1.64	1.42	1.28	1.67	1.23	1.0

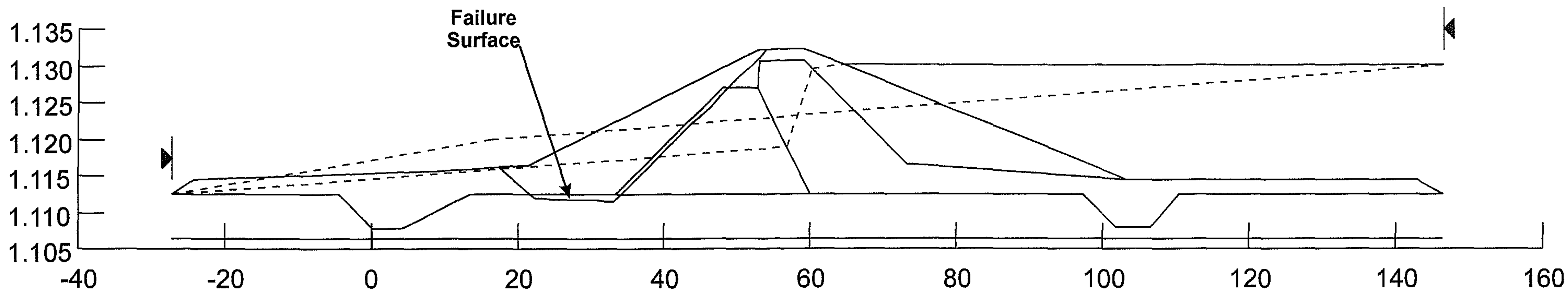
Table 7 indicates that the safety factor on the downstream toe increases as the reservoir level decreases, as would be expected. The total increase in the factor of safety for the static condition amounts to 45% if the entire reservoir was removed.

Table 7 indicates that the safety factor on the upstream side initially decreases as the reservoir level drops and then finally increases on complete breaching. These results are in agreement with the extensive experience note by Terzaghi and Peck (1968) on their discussion of partial pond levels and sloping dam cores. The total increase in factor of safety on the upstream side on complete breaching amounts to only 4%.

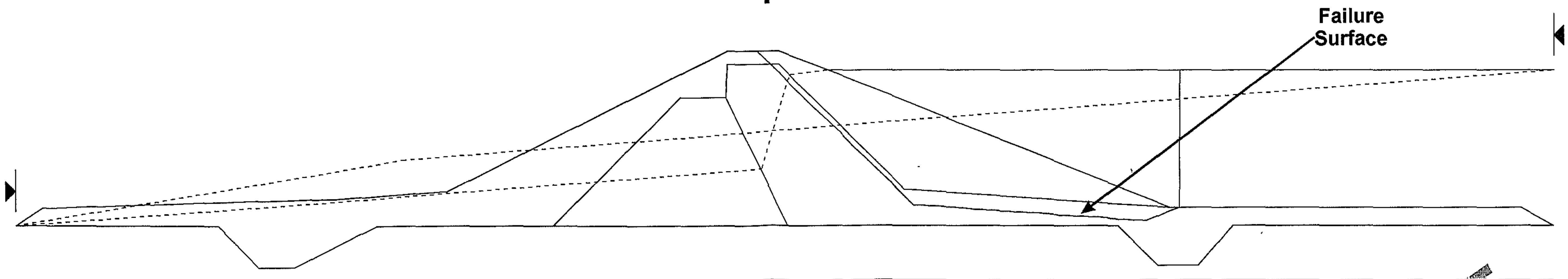
When the seismic loadings are applied for the pseudostatic analyses, the upstream side is the critical case with factors of safety generally below 1.1. The dam would only meet required dam design guidelines when it is fully breached.

The following sections provide additional commentary on the proposed three cases to be evaluated.

Downstream Side



Upstream Side



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PROJECT: Faro Fresh Water Supply Dam
Evaluation of Reclamation Approaches

TITLE: Specified Failure Surfaces for Breached Conditions

PROJECT No.	FIGURE. No.	REV.
0168-007-01 GLL: 20-933	Figure 9	0.

4.2.2 Option 1: Lowering of Maximum Water Level by 3 metres

A minimal lowering of the reservoir was assessed with the intent of reducing the risk of failure of the dam by dropping the maximum water level in the reservoir by 3 metres, to an elevation of 1127 m (above mean sea level). At this elevation, it is not possible to make the current geometry of dam meet the accepted dam design guidelines.

4.2.3 Option 2: Lowering of Maximum Water Level by 6 metres

A substantial lowering of the reservoir was assessed with the intent of reducing the risk of failure of the dam and preserving or improving the existing fish habitat by dropping the maximum water level by 6 metres, to an elevation of 1124 m (above mean sea level). Again, it is not possible to meet design guidelines with the current dam configuration; the upstream side is critical in terms of both static and seismic analysis.

Since this case is beneficial for fisheries habitat (as described elsewhere in this report), the stability of the dam was assessed with the placement of a 15 m wide rockfill berm on the upstream side of the dam. This berm was assumed to go from the water level at 1124 m down to the bottom grade. With this berm installed, the upstream side factor of safety increases to 1.67 for static conditions, 1.23 for 0.07g and 1.0 for 0.13g, which would just be marginal. Hence, it is likely that decreasing the water level and constructing a rockfill berm on the upstream side can be designed to meet required guidelines.

4.2.4 Option 3: Complete Breach of Dam and Removal of Reservoir

A case of complete breach of the dam, leaving no water in the reservoir, was analyzed with the intent of eliminating the risk of failure of the dam by dropping the water level by 17.5 metres to original ground at elevation 1112.5 m (above mean sea level). As previously noted, this option meets safety guidelines after the breaching is undertaken.

5. Evaluation of Reclamation Approaches

5.1 Geotechnical Considerations

5.1.1 Option 1: Lowering of Maximum Water Level by 3 metres

Option 1, lowering the reservoir maximum water level by 3 metres, is not evaluated as a feasible reclamation approach because it has been determined that the minimum requirements for physical stability are not achieved under this option.

5.1.2 Option 2: Lowering of Maximum Water Level by 6 metres

Under option 2, the maximum reservoir level would be lowered by 6 metres to 3685 ft. (mean sea level) and a 15 to 20 m wide (subject to initial design work) rockfill berm would be constructed on the upstream side of the FWS dam. H.A. Simon's drawing D1575-058-006 provides a summary of topographic and estimated bedrock elevations underneath the footprint of the dam. Based on a valley cross-section from that information, it becomes apparent that the current spillway is situated on both a local topographic (3707 ft.) and bedrock (3705 ft.) high point near the north end of the dam. This information also indicates a local low point in both topography (3700 ft.) and bedrock (3690 ft.) elevations, just immediately north of the current spillway location. Given the recommended spillway elevation of 3685 ft. for the breached spillway level, it makes practical sense to use this local low point for the breaching. The portion of the dam north of the current spillway is approximately 50 m long.

Unfortunately, there is little subsurface information in the third dimension, downstream from the dam. Based on the information currently available, and assuming the spillway width stays fixed to its current width (~30 m), a new spillway excavated down to 3685 ft. would require approximately 170 m^2/lin m. of excavated channel, assuming the following side slopes:

- Overburden materials – 3H:1V.
- Bedrock – 0.25H:1V.

If only bedrock materials were encountered, the excavated area would amount to 145 m^2/lin. m of channel excavated. It should be noted that these area values do not include removal of the existing dam structure, which exists to an elevation of 3715.0 ft. (mean sea level). For an estimated 4.5 m high dam and a spillway width of approximately 33 m, approximately 3,500 m^3 of dam excavation would be required.

The approximate distance from the current spillway to the dam access road, where the two large culverts are currently located, is approximately 280 m. For initial estimation, if the full area value of 170 m^2 was assumed at the spillway, decreasing to zero excavation at the access road, approximately 24,000 m^3 of excavation would be required. As noted earlier, at least 16,000 m^3 of rockfill is required for the upstream side stabilizing berm. Therefore, this initial excavation volume is greater than the upstream berm fill volume, although additional rip rap for dam protection will certainly be required to complete the project.

This conceptual description does not include the aspects of channel grade, which will be an important aspect of future design phases. Design parameters regarding channel slope, drop structures, flow velocities and other factors that have a bearing on fish access can be developed and a channel designed accordingly subsequent to a detailed topographic survey and geotechnical investigation of the area.

The excavation of a new spillway will require blasting, which could significantly impact the dam if not properly controlled. Hence, the effect of blasting on the dam and its integrity will need to be evaluated and the specifications for construction will have to note the controlled nature and, possibly, limits on the peak particle acceleration values allowed. Blast and vibration monitoring will be required during construction operations to ensure dam integrity.

5.1.3 Option 3: Complete Breach of Dam and Removal of Reservoir

Under Option 3, the entire dam would be breached and the reservoir water level brought down to the previous valley floor elevation. As such, a slot would be excavated completely down through the mid-point of the dam and a spillway re-established into the till foundation and over top of the granular toe berm. For this option, approximately 110,000 m^3 of bank dam materials would have to be excavated and wasted. In addition, placement of some bedding materials and rip rap would have to be placed to prevent erosion at the base of the new spillway, perhaps amounting to some 5,000 m^3 of rip rap. Temporary control of incoming water to the reservoir could possibly be handled by the low-level pipe, but secondary measures may be required.

5.2 Fisheries Considerations

The three rehabilitation options were compared to the current status to determine summer habitat, winter habitat and access for fish under each scenario. The results are summarized in Table 8.

Table 8. Comparison of the Quality of Fish Habitat in the Reservoir for the Various Reclamation Approaches

Reclamation Approach	Summer Habitat	Winter Habitat (Typical)	Winter Habitat (Extreme Condition)	Fish Access
Current	High	High	High	None
Option 1	High	High	High	Potentially Seasonal
Option 2	High	Moderate	Low / Moderate (Borderline)	Potentially Seasonal
Option 3	Low	Low	None	Yes

An additional fish habitat consideration to note is that under the current status, option 1 and option 2, flows through the low-level outlet will be maintained throughout the winter and will contribute to over-wintering habitat downstream. As well, under the current status, option 1 and option 2, a sport-fishery can be maintained at the reservoir.

The following were considered in the comparison of options:

- Seasonal fish access across the spillway can be attained by creating a channel to carry flows around the culverts in the spillway. Juvenile and adult fish could move across the spillway from spring (typically May) when the reservoir level reaches the spillway to mid-winter (typically January) when the reservoir no longer flows over the spillway.

- Lowering the reservoir would result in a permanent loss of littoral area (shallow water less than 5 m deep in the reservoir where light can penetrate and food production is high). Harder (1991) had previously calculated a 20% loss of littoral area with a reservoir lowering of 4 metres (similar to option 1, 3 metres). Options 2 and 3 would result in a further loss of littoral area. Under the current situation, option 1 and option 2, there is some reduction of productive littoral area as a result of the seasonal variation in water level.

- Harder also determined that dissolved oxygen would not be a limiting factor for fish habitat over the summer with a lowering of the reservoir of 4 metres (similar to option 1, 3 metres). As dissolved oxygen levels have not been measured in the reservoir over the winter, the levels cannot be predicted for options 1 or 2. It is assumed that there is not a great deal of organic material within the water or sediment, which would consume oxygen and lower overall oxygen levels (observations by mine personnel). In addition, on-going use of the low-level outlet will result in flushing of water and replenishment of dissolved oxygen in the lower reservoir. A concentration of 7.25 mg/L has been suggested as providing the highest degree of safety for the fish population (Weagle, 1981).

- The amount of summer and winter habitat in the reservoir was assessed based on the water levels outlined in Table 9 and the storage capacity curve illustrated on Figure 5. The water levels shown in Table 9 are at the deepest point in the reservoir. Higher water levels result in greater area for fish, a larger littoral area and greater dissolved oxygen concentration. The rating system is based on:

High	=	8.9 to 17.5 m water level (minimum volume > 2 million m^3)
Moderate	=	6.2 m to 8.9 m water level (minimum volume between 1 and 2 million m^3)
Low	=	< 6.2 m water level (minimum volume < 1 million m^3)

Table 9. Reservoir Water Levels for Fish Habitat

Reclamation Approach	Max. (summer) water depth	Min. (winter) water depth below ice (typical winter condition)	Min. (winter) water depth below ice (extreme winter condition)
Current Status	17.5 m	14.8 m	12.5 m
Option 1	14.5 m	11.8 m	10.3 m
Option 2	11.5 m	8.5 m	6.0 m
Option 3	2 m	0.5 m	< 1 m

The storage calculations used to determine the water depths were based on the following data and assumptions. Reference was also made to the reservoir storage capacity and to the extreme winter condition that have been previously described in this report.

- Current maximum water depth in the reservoir is 17.5 m
- The current storage capacity of the reservoir is 5.8 million m^3 based on the storage capacity curve (Figure 5)
- The water flow into the reservoir is greater than or equal to the water flow out for 8½ months (May to January) in a normal year and during six months (June to November) in the worst case/extreme winter condition that was previously described in this report
- Under the typical winter case, water flow out of the reservoir at the low level outlet pipe is a net outflow of 75 Lps for 100 days
- Under the worst case/extreme winter case, water flow out of the reservoir at the low-level outlet pipe during six months of the year (December to May) is 100 L/s with no flows into the reservoir for a total net outflow of 1.6 million m^3
- The winter ice level over the reservoir is 1.5 m thick

5.3 Cost Considerations

5.3.1 Common Costs

Before any construction can be undertaken, there are a number of data collection, design and tendering phases that will need to undertaken. The following provides an initial estimate of the various steps that need to be carried out relative to engineering and environmental components of the work:

- Site survey and base map preparation: $10,000
- Fisheries investigations: $10,000
- Water balance and hydrology review: $10,000
- Site investigation and data collection: $20,000
- Design work, drawings and specifications: $25,000
- Tender review and award: $5,000
- Estimate subtotal: $80,000

Further detail would be developed subsequent to finalization of the work scope and schedule.

5.3.2 Option 2: Lowering of Maximum Water Level by 6 metres

For the proposed lowering of the maximum reservoir water level by 6 metres to 3685 ft. (mean sea level), the following quantities and costs are estimated for the construction work to be undertaken:

- Mob/demob Heavy Equipment: lump sum: $20,000.
- Excavation of dam and wasting: 3,500 m^3 @ $10/m^3 = $35,000.
- Excavation of spillway (overburden) and wasting: 5,000 m^3 (assumed value) @ $10/m^3 = $50,000.
- Excavation of spillway (bedrock) and use as rockfill/rip rap: 19,000 m^3 (assumed value) @ $20/m^3 = $380,000.
- Subtotal construction: $485,000.
- Engineering construction supervision and management: 12% of $485,000 = $58,000.

Therefore, the estimated construction cost totals $543,000. Combined with the engineering and tender award work (Section 5.3.1), a budgetary value for this dam breaching option is estimated to total $623,000. For the current conceptual planning phase, a contingency of +20% is suggested bringing the conceptual project estimate to approximately $848,000.

5.3.3 Option 3: Complete Breach of Dam and Removal of Reservoir

For the proposed complete breaching of the dam, the following quantities and costs are estimated for the construction work to be done:

- Mob/Demob Heavy Equipment: lump sum: $20,000.
- Excavation of dam and wasting: 110,000 m^3 @ $10/m^3 = $1,100,000.
- Blasting of rip rap and placement in spillway: 5,000 m^3 @ $20/m^3 = $100,000.
- Subtotal construction: $1,220,000.
- Engineering construction supervision and management: 10% of $1,220,000 = $122,000.

Therefore, the estimated construction costs totals $1,342,000. Combined with the engineering and tender award work (Section 5.3.1), a budgetary value for this dam breaching is estimated total $1.42 million. For the current conceptual planning phase, a contingency of +20% is suggested bringing the conceptual project estimate to approximately $1.7 million.

5.4 Construction Considerations

The type of work that needs to be undertaken for option 2, 6 metre breach, and option 3, full breach, is similar in that the work is involves primarily heavy equipment and earth moving. Under option 2, a rock fill berm would be constructed on the upstream side of the dam using material blasted from the new spillway channel. Under option 3, no blasting is anticipated but rip rap rock would be required from an off site source and this might, in itself, involve blasting. The comments provided below are applicable to both options.

For the construction work to be undertaken, the following major tasks will have to be done:

- Lowering of the reservoir level below the new spillway sill elevation using the low-level pipe. The rate of lowering is to be compatible with the recommended rapid drawdown analysis.
- Removal of existing dam structure over top of the proposed new spillway location. Anticipate use of the excavated materials for placement in other locations.
- Exposed areas of the current dam structure, if any left after excavation, will have to be protected with appropriately sized rip rap and bedding materials.
- New spillway location and grade will have to be established through drill and blasting of bedrock and excavation of overburden materials for option 2. Rockfill and rip rap produced by the spillway excavation will have to be placed on the upstream side stabilizing berm (option 2 only) and on other areas to be protected.
- New spillway location and grade will have to be established through native overburden for option 3 and this will require appropriate bedding and rip rap materials.
- It is assumed that the new spillway for option 2 will be founded on bedrock and that no concrete work will be required.

The work would be recommended to be performed under thawed (summer) conditions.

This is a simplified description of the major tasks to be undertaken but provides context on the scope of the work involved.

Given the extent of work involved, the mobile equipment and manpower available on-site is not considered to be sufficient to undertake the work. Hence, it will be necessary to prepare construction drawings, estimated quantities and specifications so that the package of work can be tendered to contracting companies to bid on.

5.5 Future Mine Operations Considerations

Option 2, 6 metre breach with an upstream toe buttress, would preserve some ability of the reservoir to serve as a back up water supply for mine operations. Option 3, full breach, would not provide any water storage capability.

As described previously in this report, the requirement for the reservoir to serve as a back up water supply is not considered to be of major importance to future mine operations.

5.6 Comparison of Reclamation Approaches

The first reclamation approach (option 1) involving a lowering the maximum reservoir water level by 3 meters does not achieve the required long term standards for physical stability and, therefore, is not given further consideration.

The second reclamation approach (option 2) involving lowering the maximum reservoir water level by 6 metres with construction of an upstream toe buttress represents a good compromise between physical stability and fisheries habitat. The physical factors of safety are acceptable, the winter fisheries habitat is preserved and fish access to the reservoir is included. Additionally, on-going use of the low level outlet pipe ensures that the minimum flow requirements for Rose Creek are achieved and that current enhancements to winter habitat in Rose Creek due to the release of excess water from the FWS dam continue.

The third reclamation approach (option 3) involving a complete breach of the dam and virtual elimination of the upstream reservoir represents the highest degree of physical stability but eliminates the existing winter fisheries habitat. Additionally, it is unlikely that the minimum flow requirements for Rose Creek would be achieved under this approach wherein only natural winter flows would be present in the Rose Creek Diversion Canal.

Table 10 presents a summary comparison of the base/current case and the reclamation options. The items scored are physical stability, fisheries habitat, cost, and downstream protection with a scoring range from 0 (poor) to 3 (good) for each item. A brief description of each item is as follows:

1. physical stability: does the option achieve the required factors of safety for physical stability?
2. fisheries habitat: does the option achieve the desired fisheries objectives?
3. cost: what is the relative total cost for implementation of the option?
4. downstream protection: does the option provide any flood protection to downstream facilities and fish habitat?

The items described above are weighted as shown in Table 10 with physical stability given the greatest weight (5), followed by fisheries habitat (3), followed by cost and downstream protection (2 each). The fundamental approach to the weighting is that:

1. physical stability objectives are more important than fisheries habitat objectives,
2. a substantial amount of money could be spent on achieving physical stability objectives,
3. a smaller amount of additional money could be spent to achieve fisheries habitat objectives, and
4. the provision of some flood protection to downstream structures is important.

Under this scoring method, Option 2 (lower maximum water level by 6 metres with upstream toe buttress) scores the highest. Option 3 (full breach) scores closely. The base/current case scores lowest due, primarily, to unacceptable factors of safety for physical stability. Option 1 (lower maximum water level by 3 metres) is not scored because it does not meet the minimum requirements for physical stability.

Table 10. Summary Comparison of Reclamation Options

Item	Phys. Stability	Fisheries	Cost	Downstream Protection	Score
Weight	*5*	*3*	*2*	*2*	-
Base/Current Case	0	2	3	1	14
Option 1: 3 m breach	0	-	-	-	-
Option 2: 6 m breach	2	3	2	1	25
Option 3: full breach	3	1	1	0	20

This method of ranking options is somewhat subjective and different reviewers may rank the options in different order. Nonetheless, this method is useful and introduces a numerical basis for discussing the issues that are involved in ranking the options.

6. Conclusions and Recommendations

6.1 Geotechnical Considerations

The FWS dam, in its current configuration and with the observed piezometric levels, does not meet current dam safety guidelines, relative to the geotechnical stability of the dam. Therefore, additional investigative, testing and analytical work is recommended to verify major assumptions as a refinement on the level of detail provided herein. Alternatively, the current configuration should be changed by lowering the reservoir level and by construction of a rockfill buttress on the upstream side.

The lowering of the reservoir behind the dam causes significant changes of stability, based on the assumed and estimated parameters provided herein. In order to verify critical information and to further the level of design considerations for the breach, the following recommendations are provided in order to undertake the next step of initial design work:

- A topographic survey of the dam, downstream toe berm, spillway area and abutments should be completed to confirm the dimensions used in the stability analysis. This will be required in order to plan a site investigation program and then serve as the base information for initial design work.
- Subsequent to the above survey, the as-built cross section of the dam should be compared to the profile that has been assumed herein for stability analyses. If a significant difference is found, then the stability analyses should be re-run to determine revised factors of safety.
- A rapid drawdown stability analysis should be undertaken for the upstream slope of the dam to ensure an adequate safety factor during partial pond. This analysis should be completed before any significant decrease in the reservoir level is undertaken.
- A critical review of pore pressures in the dam, coupled with two-dimensional seepage analysis, should be completed to confirm the assumptions made about the piezometric conditions that exists within the dam and the foundation and to validate expected changes after reservoir lowering has occurred. Again, this analysis should be completed before any reservoir drawdown occurs.
- A geotechnical site investigation program, possibly using a combination of testpitting, drilling and geophysics, will be required to locate the overburden/bedrock contact in the spillway area downstream of the dam. This will be necessary for initial design work and costing.
- The hydrology and water balance of the reservoir and the downstream channel (Rose Creek Diversion Canal) should be reviewed by an experienced water resources engineer to ensure that breaching plans for the FWS dam do not significantly impact the overall mine waste facilities in the Rose Creek valley. In addition, this engineer should begin providing input relative to the hydraulic considerations for any proposed changes to the FWS dam spillway.
- The condition of the low level outlet pipe may represent the largest current liability to the dam. Its condition impacts on the current and future use for management of the upstream reservoir. An inspection of the low level pipe should be undertaken.

6.2 Fisheries Considerations

The reservoir represents good summer and winter fisheries habitat. The general operating method for the low level outlet pipe (release of excess water through the winter season) likely enhances the winter fisheries habitat in Rose Creek downstream of the reservoir and especially in the pumphouse pond.

Nonetheless, the current configuration of the dam itself is poor with regards to fisheries habitat. Fish that are resident in the south fork of Rose Creek downstream of the dam do not have access to the good winter habitat in the reservoir. Fish that are resident in the reservoir do not have access to the good spawning habitat in the creek downstream of the dam.

A lowering of the maximum reservoir water level by breaching the dam by 6 metres appears to represent a minimum volume of water that would be expected to maintain useable winter habitat through an extreme winter season. Under the extreme and rare winter case tested, the quality of winter habitat would drop just into the poor range. That is, a breach of greater than 6 metres would allow for a progressive reduction of the quality of winter habitat from moderate to poor and, finally, to none. This is not a precise determination but is based on a knowledgeable assessment of the site conditions and a review of existing information.

A breach of 6 metres would also allow the creation of fish access between the reservoir and the creek downstream of the reservoir. Further, a breach of 6 metres would allow continued operation of the low level outlet pipe which is considered an enhancement to winter habitat in Rose Creek and which may promote water and oxygen circulation within the reservoir.

A complete breach of the dam would eliminate the winter fisheries habitat in the reservoir but would allow free access to all areas of the south fork of Rose Creek. A complete breach would result in lower winter flows in Rose Creek which would eliminate any habitat enhancements presently in place and which might further reduce winter habitat by allowing ice damming in the Rose Creek Diversion Canal.

If a partial breach of the dam by about 6 metres is to be considered further, then a preliminary design for the new channel should be completed. This design should include estimates of flow volumes and velocities predicted at the outflow spillway and channel gradient in order to determine fish passage requirements. In addition, a management plan for the operation of the low level outlet pipe would be beneficial to regulate water levels in the reservoir.

If qualitative and quantitative habitat data is required to determine the carrying capacity of the reservoir under a partial breach of 6 metres, then a number of tasks could be completed. These might include a complete bathymetric survey of the reservoir basin, a more complete understanding of flows into the reservoir in the winter (flushing rate), more accurate storage capacity calculations and winter (and possibly summer) oxygen profiles. A fish population assessment would allow a comparison between the current population and the carrying capacity under the breach option. However, with access to the reservoir created for the downstream grayling population, the population in the reservoir could change from the current status as well as seasonally. At this time, the need for such studies is questionable.

6.3 Management Considerations

This comparative analysis indicates that there are two feasible approaches to reclamation of the Fresh Water Supply Dam: a breach of 6 metres with an upstream toe berm and a full breach.

The second reclamation approach (option 2) appears to be the preferred approach because it is the only approach that satisfies all of the reclamation objectives. The final determination of which approach is most appropriate will depend, to a large degree, on the value that is placed on preserving the winter fisheries habitat in the reservoir.

A breach of 6 metres will require on-going inspection and maintenance of the dam and is anticipated to require on-going operation of the low level outlet pipe to meet the minimum flow requirements in the Rose Creek Diversion Canal. These would not be expected to be onerous tasks and would fall within the scope of on-going inspection and maintenance activities for the mine site facilities in general.

The physical condition of the low level outlet pipe has been assumed, in this report, to be good. The recommendation has been made previously (Golder 2000 and BGC 2001) and is repeated here that an inspection of the pipe should be undertaken. If the pipe is found to be in poor condition, then this would require consideration regarding the method of water diversion for construction purposes (applicable to all options) and to the method of water management that is described for option 2, lowering the maximum reservoir water level by 6 metres.

A full breach of the dam would not require operation of the low level outlet valve. However, it is unclear whether, or not, the minimum flow requirements in the Rose Creek Diversion Canal would be met based only on the natural winter flows through the reservoir. The minimum flow requirements include both the licence requirement of 4.5 m^3/day and a flow velocity sufficient to prevent ice damming in the Rose Creek Diversion Canal and both requirements are considered of equal importance.

The modifications contemplated for the Fresh Water Supply Dam must be assessed in the context of the entire mine water management system. It is critical that modifications to the FWS dam do not compromise the integrity and environmental protection provided by the downstream structures. Of particular importance in this regard is the flood capacity of the Rose Creek Diversion Canal. Either of the two feasible FWS dam reclamation approaches could incorporate improved flood protection measures as desired to prevent passage of flood flows in excess of the capacity of the Rose Creek Diversion Canal.

This consideration of protection to downstream structures must continue to be considered until such time in the future that the downstream structures are themselves modified.

6.4 Regulatory Considerations

The regulatory issues regarding a potential loss of fish habitat should be considered. The Department of Fisheries and Oceans (DFO) should continue to be involved with regards to addressing this issue.

The requirement for an amendment to the existing Faro Water Licence to perform reclamation work at the FWS dam should be investigated. If an amendment is required, the length of time necessary for the Yukon Territory Water Board process should be estimated and incorporated into a reclamation planning schedule.

7. Recommended Management Approach

1. Finalize this report and distribute, in final format, to all affected parties for comment including, but not necessarily limited to, the Department of Fisheries and Oceans, Environment Canada, the Ross River Dena Council, and the Yukon Territorila . The final decision should consider input from these or other affected stakeholders.
2. Investigate the need for an amendment to the Faro Water Licence or for the need for some other form of authorization from the Yukon Territory Water Board.
3. Determine which reclamation approach is to be implemented and establish a conceptual implementation schedule with consideration of comments received from all affected parties as described in item no. 1.
4. Award an engineering design contract that includes the formulation and performance of necessary field investigations as recommended above.
5. Finalize and implement the engineering design.

The circulation of this report, in final format, to other affected parties will represent a delay in the process but is considered, in this case, to be critical because of the overlapping geotechnical, fisheries, and land use issues. The parties to be involved in project review should be selected with careful consideration of all issues at the outset because additional delays would likely be encountered if an organization is introduced into the process at a later time.

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