CYPRUS ANVIL MINING CORPORATION

PHASE I REPORT

FARO ABANDONMENT PLAN

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Our File: VA 2758

February 26, 1981

Cyprus Anvil Mining Corporation
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Mr. N.G. Cornish, P. Eng.
Superintendent, Environmental Control

Faro Abandonment Plan

Dear Sirs:

We are pleased to present our report on completion of Phase 1 of the the Scope of Work as outlined in our proposal dated December 24, 1980.

We look forward to discussing the contents of this report at your convenience.

Yours very truly,
KLOHN LEONOFF LTD.

VINOD K. GARGA, Ph.D., P. Eng.
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VKG/ae

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TABLE OF CONTENTS

	PAGE
1. INTRODUCTION	1
1.1 General	1
1.2 Scope of the Project	1
1.3 Terms of Reference	2
1.4 Acknowledgements	2
2. BRIEF REVIEW OF AVAILABLE INFORMATION	3
2.1 Physiography and Geology	3
2.1.1 Tectonic History	3
2.1.2 Regional Geology	4
2.1.3 Seismic Risk	4
2.1.4 Surficial Geology	5
2.1.5 Geomorphic Activity	6
2.2 Hydrology	7
2.3 Diversion Canal	10
2.3.1 Design for Mine Life Operation	10
2.3.2 Design Criteria for Abandonment	10
2.3.3 Canal Design for Abandonment	11
2.3.4 Modes of Sediment Transport	12
2.3.5 Rates of Sediment Transport	14
2.4 Groundwater	15
2.4.1 Regional Hydrogeology	15
2.4.2 Permeability	16
2.5 Mine and Mill Description	16
2.5.1 Ore Bodies	18
2.5.2 Milling Processes	19
2.6 Water Quality	24
2.6.1 Baseline Water Quality	24
2.6.2 Acid Generation Potential	30
3. PROPOSED ABANDONMENT SCHEMES	35
3.1 General	35
3.2 Secondary Facilities	36
3.2.1 Fresh Water Supply Dam	37
3.2.2 Pumphouse and Related Facilities	37
3.2.3 North Fork Rose Creek Diversion	37
3.2.4 North Valley Wall Interceptor Channel	36
3.2.5 Open Pits	38
3.2.6 Faro Creek Diversion	38
3.2.7 Waste Rock Dumps	38

TABLE OF CONTENTS
(continued)

PAGE

3.3 Down Valley Project 38

3.3.1 Rose Creek Diversion Canal (Scheme 1) 38
3.3.2 Abandonment Reservoir Scheme (Scheme 2) 40
3.3.3 Tailings Removal (Scheme 3) 42

4. PROPOSED FIELD INVESTIGATIONS 43

4.1 General 43
4.2 Surface Hydrology 43
4.3 Hydrogeology and Surface Geology 43

4.3.1 Piezometers 44
4.3.2 Permeability Testing 44
4.3.3 Surficial Geology 45

4.4 Water Quality 45

4.4.1 Sampling of Tailings Pore Water 46
4.4.2 Groundwater Quality Sampling 46
4.4.3 Stream Samples 47
4.4.4 Neutralization Capacity of Natural Waters 47
4.4.5 Tailings Oxidation Studies 47

4.5 Material Samples 48
4.6 Surface Treatment 48

5. PROPOSED ANALYSES (PHASE 3) 49

5.1 General 49
5.2 Seismic Risk Analysis 49
5.3 Hydrology and Hydrogeology 49
5.4 Fish 49
5.5 Surface Treatment 49
5.6 Geotechnical 50
5.7 Chemical Transport Studies 50

6. SCHEDULE 50

TABLE OF CONTENTS
(continued)

APPENDICES

Appendix I - Terms of Reference
- List of Information supplied by Cyprus Anvil Mining Corporation
- Water License Y2L3-0005

Appendix II - Data Analysis and Water Quality Modelling

DRAWINGS

A-2758-1 Location Plan

A-2758-2 Physiography of the Canadian Cordilleron

A-2758-3 Regional Geology and Fault Locations

D-2758-4 Rose Creek Bedrock Geology

A-2758-5 Seismic Risk Study - Extreme Value Analysis

B-2758-6 Flood Frequency Distribution

D-2758-7 Cross Section and Profile of Rose Creek Valley

B-2758-8 Mine Layout

A-2758-9 Mill Circuit

A-2758-10 Histogram of pH values, Station R8, Rose Creek (1974-1980)

B-2758-11 Concentration Ranges of Important Constituents, Station R8, Rose Creek

B-2758-12 Scheme 1 - Diversion Canal

B-2758-13 Scheme 2 - Abandonment Reservoir

B-2758-14 Scheme 3 - Tailings in No. 1 Pit

B-2758-15 Schedule of Work

1. INTRODUCTION

1.1 General

The Cyprus Anvil Mine is located about 200 kilometres north of Whitehorse, the capital of the Yukon Territories (see Drawing A-2758-1). The town of Faro, located in the Pelly River Valley, is about 20 kilometres from the mine site, and is linked to Ross River and Whitehorse by a gravel highway.

The mine is owned and operated by Cyprus Anvil Mining Corporation (CAMC) and exploits a lead-zinc sulphide deposit. Recently acquired ore reserves dictated that the mine expand their tailings impoundment facilites. The Yukon Water Board, under the jurisdiction of the Department of Indian and Northern Affairs (DINA) granted CAMC permission to begin the expansion, but withheld the issuance of a water license until an acceptable abandonment scheme had been presented.

1.2 Scope of the Project

In response to a request from Cyprus Anvil Mining Corporation (CAMC), Klohn Leonoff Ltd. submitted a proposal to prepare an acceptable abandonment plan for the Faro tailings project.

KLL had proposed that the project be divided into four portions. These were:

Phase I:	review of existing data, consideration of appropriate alternate schemes and preparation of a field investigation program.
Phase II:	field and laboratory studies.
Phase III:	office studies and analysis of field information.
Phase IV:	comparison of alternatives and report preparation.

This report is the result of our Phase I studies. It summarizes work completed to date and recommends studies to be carried out in Phase II, III and IV. The emphasis is on identification of parameters which influence the water quality of Rose Creek. It is based on information presented by CAMC to KLL (listed in Appendix I), readily available published information and data and experience available from other projects carried out by KLL.

1.3 Terms of Reference

Klohn Leonoff submitted a proposal dated December 24, 1980 at the request of Cyprus Anvil Mining Corporation. The request for the proposal was accompanied by the terms of reference for development of the Faro Abandonment Plan. These terms of reference have been included in Appendix I of this report. At a meeting on January 20, 1981 between members of Environment Canada, the Yukon Water Board, Department of Northern and Indian Affairs (DINA), Cyprus Anvil Mining Corporation (CAMC) and Klohn Leonoff Ltd (KLL), the latter's terms of reference were discussed and questioned. At this time, CAMC pointed out that the only viable alternative for tailings placement was the Down Valley Scheme and that KLL had therefore been requested to find an acceptable abandonment scheme for this project. Although the abandonment plan must protect water quality as a first priority, it became apparent at this meeting that aesthetics and fish were also of some concern to those present.

1.4 Acknowledgements

The phase one study is based on reports from many sources. We wish to acknowledge, especially the information used from reports by Golder Associates and reports and conversations with Cyprus Anvil Mines Corporation.

2. BRIEF REVIEW OF AVAILABLE INFORMATION

2.1 Physiography and Geology

2.1.1 Tectonic History. The Faro Mine Site is situated in the physiographic region of MacMillan Plateau, a sub-region of the Yukon Plateau (Bostock, 1948). The mine site is on the north side of Rose Creek Valley, approximately 20 kilometres northeast of the Pelly River and the townsite of Faro. The MacMillan Plateau, is characteristically composed of mountains and small mountain groups that rise above an undulating plateau surface. Into this tableland a network of valleys has been entrenched. Many of the streams, including Rose Creek, Anvil Creek and the Pelly River are underfit streams, that is, the valleys were formed at much higher flow rates than presently exist.

The evolution of the Canadian Cordillera (see Drawing A-2758-2) has not been fully reconstructed. However, the concept that the "Cordilleran eugeosyncline" is a composite terrain made up of fragments of varied origins and provenances is widely accepted by Cordilleran workers (Monger and Price, 1979). Roddick (1964) has reported 450 to 500 km of displacement on the Tintina Trench along some plutons that are as young as 100 Ma (Tempelman-Kluit 1977). Monger and Price (1979) suggest that this strike slip motion may link up with the Fraser system of southwestern British Columbia. This implies that the Stikine terrain, which is a large portion of the Cordilleran Interior, may have been emplaced partially by motions along the Tintina Trench system (See Figure 10, Monger and Price, 1979).

A recent paper by Tempelman-Kluit (1980) suggests that the present trench structure is the result of normal faulting along the trench boundaries leaving a graben structure between uplifted plateaus and mountain ranges. The majority of strike slip motion along the

Tintina Trench is believed to have occurred during the Paleogene up to the Oligocene (40 M.A.). Normal faulting and general uplift may have occurred about the late Miocene (25 M.A.). More recent scarps along the trench may be due to either uplift along normal faults or glacial activity during the last or Wisconsin glaciation. Templeman-Kluit (1980) believes that the drainage system in the Yukon Territory has been reversed. This would explain many of the misfit streams in the vicinity of the Faro site.

2.1.2 Regional Geology. The Anvil Range lies in the Selwyn Basin tectonic province (Wheeler and Gabrielse, 1972). The geology of the region has been reported by Tempelman-Kluit (1977). The core of the Anvil Range is underlain by granodiorite and porphyritic quartz monzonite that forms the Anvil Batholith, intruded in Mesozoic time. A sequence of Proterozoic and Paleozoic strata flanks the Anvil Batholith. The older rocks are mainly metamorphic and sedimentary, whereas the younger Pennsylvanian - Permian rocks are largely volcanic. Small intrusions of serpentine and altered peridotite are associated with the Permian volcanic rocks and the Vangorda fault north of the Pelly River (see Drawing A-2758-3). The bedrock geology of Rose Creek Valley is shown on Drawing D-2758-4.

2.1.3 Seismic Risk. An analysis of seismic risk prepared by the Department of Energy Mines and Natural Resources (EMR) was included in Golder Associates report dated June, 1980. KLL has also requested this analysis from EMR to include the most recent seismic data. Seismic ground motions expected at the site are required to design long-term structures.

The EMR approach to seismic risk is to apply extreme value statistics to the instrumented seismicity record. The data used are those instrumented earthquakes which could be "felt" at the site. The slope of the curve is found by a least squares solution of the data for the years when there was activity above the threshold level. The curve is represented by the equation:

$$\ln(a) = \text{Mode} + k\,(-\ln(-\ln(p)))$$

where p is the probability that ground motion "a" will not be exceeded.

In this case, the equation is:

$$\ln a = -2.23 + 0.65\,(-\ln(-\ln(p)))$$

The curve for this equation is presented on Drawing A-2758-5.

The source of seismic activity acting on the Faro Site is not considered in extreme value statistics, nor are the maximum credible earthquakes which are expected within tectonic zones. For these reasons as well as the short instrumented record period, care must be exercised in extrapolation of the EMR results. Golder Associates (1980) have used the 200 year return period earthquake supplied by EMR for long term stability of structures at the Cypress Anvil Mine.

2.1.4 Surficial Geology. Tempelman-Kluit (1977) noted that glaciation covered the entire region to elevations of 2000 metres or more. Extensive glacial and periglacial landforms are therefore expected at the site. Golder Associates (June, 1980) have noted glacial tills on the valley walls and fluvial terraces, tills and organic silts on the valley floor. The Rose Creek Valley downstream of the tailings dams has a gradient of approximately 0.6 percent. The stream channel has a flatter gradient as it meanders on the valley floor, and is incised greater than 10 metres into the fluvial terraces. Gradients both upstream and further downstream are steeper implying that the stream bed may be held up.

A report on landforms, soils and vegetation was prepared by Montreal Engineering for the Grum Deposit. The study included a portion of the Cyprus Anvil Mine Site. The report describes glacial related deposits, soil formations and the vegetation on these deposits at a map scale of 1:50,000.

Many steeply dipping faults occur locally, associated with and parallel to the Tintina Trench structure. One of these, the Rose Creek Fault, passes near the Faro site. A wide age range of rocks are found in outcrops between the faults. Both dip slip and strike slip motion is implied by the exposures.

2.1.5 Geomorphic Activity. Permafrost has been observed in many areas of the site. It is particularly prevalent on the north facing slope of Rose Creek. Identification of permafrost is necessary so that performance of structures and groundwater flow characteristics can be evaluated over a long term. Refraction seismic profiles, drill hole recovery and thermister data reported by Golder Associates indicate the presence and thickness of permafrost on the valley floor. Thicknesses in excess of 15 metres were recorded.

Solifluction occurs in the active zone over permafrost. Creep may occur in the active zone over unfrozen ground. Solifluction or creep may effect the long term stability of canals constructed for abandonment. An extensive volcanic ash deposit covers much of the southern and central Yukon. This ash deposit may affect the long-term creep and solifluction of slopes in the Rose Creek Valley.

All streams have an erosion and/or deposition pattern which is dependent on bed slope, bed load, channel dimensions and dominant discharge. Any changes within the system will cause the stream to begin depositing or eroding sediments in an attempt to attain its regime condition. Although no stream truly reaches a regime condition, almost all can be treated as regime over the time span of engineering structures (Morris, 1963, Chapter 11). Additional discussions on sedimentation in Rose Creek can be found in Section 2.3

Rose Creek presently appears to be down-cutting through alluvial gravels, probably in response to a change in base as the Anvil Range uplifts with respect to the Tintina Trench. This down-cutting clearly is a slow process but continues to occur at some rate determined by stream characteristics and the ability of local geology to "hold up" the profile downstream. Neither the channel hydraulics of Rose Creek nor the sediment loads carried (for evaluating performance after abandonment) have been documented.

2.2 Hydrology

Analysis of hydrology of the Rose Creek basin was included as Appendix IX of Golder Associates report "Final Design Recommendations for the Down Valley Tailings Disposal Project", prepared for Cyprus Anvil Mining Corporation in June 1980; Appendix IX was prepared for Golder Associates by Hydrocon Engineering (Continental) Ltd. Portions of the report relating to flows in the diversion canal adjacent to the new tailings storage area are summarized below.

Rose Creek streamflows were recorded below Faro Creek by Water Survey of Canada (WSC) in August and September of 1966, and from June, 1967 to July, 1969. Additional streamflow data were collected from May 10 to June 4, 1975 by Sigma Resource Consultants. Minimum and maximum flows recorded during these periods are included in Table 1.

TABLE 1

Annual Flow Extremes-Rose Creek

Year	Maximum Daily Discharge cfs	Maximum Daily Discharge m^3/s	Minimum Daily Discharge cfs	Minimum Daily Discharge m^3/s
1967	1150	32.6	6.1	0.2
1968	548	15.5	7.0	0.2
1969	349	10.0	7.3	0.2
1975	950	26.9	NOT AVAILABLE	

Sufficient flow data were not available to develop a flood frequency relationship for Rose Creek by traditional methods. However, the available data were analyzed in conjunction with regional data from other basins to provide the best estimate for a flood frequency distribution, Drawing A-2758-6. Flow magnitudes for selected return periods were obtained from Drawing A-2758-6 and are included in Table 2.

TABLE 2

Rose Creek Diversion Flow Magnitudes

For Various Return Periods

Return Period In Years	Flow In m^3/s	Flow In cfs
10	51	1802
50	88	3110
100	109	3851
500	160	5650

Design of the diversion canal for the life of the mine required only that flood flows be estimated for return periods up to about 500 years. Accordingly, no flow estimates were presented for more rare event floods, such as the probable maximum flood (PMF). This estimate would require more comprehensive regional and site specific investigations than have been conducted to date.

For discussion purposes only, the frequency curve on Drawing A-2758-6 was further extrapolated to estimate the magnitude of a rare event flood on Rose Creek with a return period of 10,000 years. A 10,000 year flood equal to 320 m^3/s, twice the magnitude of the 500 year flood, was estimated by this procedure. An extreme event flood equal to 320 m^3/s, included herein for discussion purposes, is probably of the same order of magnitude as more reliable flood estimates that would result from detailed analyses.

2.3 Diversion Canal

2.3.1 Design for Mine Life Operation. A brief description of the design and operation of the diversion canal during the life of Cyprus Anvil mine is included below. A detailed presentation of all aspects of design is included in Golder Associates' design reports.

The diversion canal is designed to convey a 50 year flood equal to 88 m^3/s without being overtopped or seriously damaged. In addition, channel freeboard of one metre above the 50 year flood level increases the ultimate canal cross-section such that the 500 year flood can generally be contained with no freeboard available.

The diversion canal is designed with a 0.19% grade and has a trapezoidal cross-section with a 12 metre base and 2:1 side slopes. For the 50 and 500 year floods, mean channel velocities were calculated as 2.2 and 2.6 m/s at depths equal to 2.4 and 3.4 metres, respectively.

Scour protection for a flood event with a 500 year return period is provided by an armour layer of rock along the channel bed and banks. The headwater pond created at the upstream point of diversion provides the secondary benefit of settling sediments transported from the upper basin before the water flows into the diversion canal. Hence, sediment deposition along the diversion canal is not expected to occur during the life of the mine.

2.3.2 Design Criteria for Abandonment. Design of the diversion canal for the abandonment stage requires substantially different considerations than operation during the life of the mine. Selection of a design flood with a return period equal to 50 years for the operation of the diversion canal during the 20 to 30 year mine life is in accord with standard engineering practice. Also, routine maintenance checks along the channel will detect any local instabilities that may occur during the life of the mine, and repairs can be readily made by mine crews already on site.

At abandonment, the diversion canal must satisfy more stringent design criteria as noted below:

1. Following mine operations, the canal must function for a much longer period than the 20 to 30 years for which it was originally designed. Hence, a flood event more extreme than the 50 year flood would be required for sizing the diversion canal. For the extended period of concern at abandonment, only the selection of the probable maximum flood (PMF) for design assures the adequacy of the canal capacity.

2. The long term stability, in addition to adequate capacity, of the diversion canal must be guaranteed. Maintenance crews will not be monitoring the channel for an indefinite period followng mine operations, and consequently, even a single instability that may breach the diversion cannot be tolerated.

2.3.3 Canal Design for Abandonment. In the absence of an estimate for PMF, the rare event flood with a return period equal to 10,000 years, estimated as 320 m^3/s, will be used for preliminary analyses. Hydraulic calculations show that a flood equal to 320 m^3/s would flow at a depth of 4.8 metres with a mean velocity equal to 3.1 m/s. For comparison, the depth of flow and mean velocity for the design 50 year flood are 2.4 metres and 2.2 m/s, respectively. Thus, from capacity considerations alone, the diversion canal would have to be enlarged substantially to convey all floods that may occur after abandonment.

The armour layer which was designed for the 500 year flood equal to 160 m^3/s would not be adequate for the PMF, especially at the downstream reach of the channel where rock drop structures have been included along a 5% grade. Thus, for abandonment, additional measures to stabilize the channel bed and banks would be required.

The long term stability of the diversion canal is affected by other natural events, in addition to flooding. For instance, a slide into the channel would likely create a permanent breach. While slides are common occurrences along many creeks, the flow paths quickly adjust and migrate laterally. The location of the diversion canal along the valley sideslope does not allow for lateral migration without causing erosion of tailings. Relatively simple measures that could be incorporated along the diversion canal to prevent the occurrence of slides are not available. A more detailed discussion of factors affecting stability of the diversion canal may be found in Section 3.1.

2.3.4 <u>Modes of Sediment Transport</u>. A general discussion is included below to define the terminology most commonly used in sediment transport analyses:

1. Sediment Classification by Source of the Sediment

   (a) Bed-material load: that part of the total sediment discharge which is composed of grain sizes represented in the bed and is equal to the transport capability of the flow.

   (b) Wash load (fine sediment load): that part of the total sediment discharge which is composed of particle sizes finer than those represented in the bed and is determined by available bank and upslope supply rate.

2. Sediment Classification by Mode of Transport

(a) Bed load (contract load): that part of the total sediment discharge that moves by rolling or sliding along the bed.

(b) Suspended load: that part of the total sediment discharge that is supported by the upward components of turbulent currents and that stays in suspension for an appreciable length of time.

3. Total Sediment Load

(a) the sum of bed-material load and wash load

(b) the sum of bed load and suspended load.

Sediment transport in the Rose Creek basin typically occurs in the following manner:

i. During periods of high runoff, fine sediment is eroded from the basin and is transported as wash load. The volume of transport in Rose Creek is determined by the inflow rate of eroded soils, not by the magnitude of the flow in Rose Creek. Hence, while potential transport capacity for Rose Creek can be calculated from hydraulic consideration, its actual transport of fine sediment is controlled by the upslope supply rate.

ii. The surface layer of the Rose Creek channel bed is comprised primarily of gravel material. During low flow periods, the gravel material generally provides a stable armour layer such that bed-material transport is minimal. In these instances, water will flow clear unless there is an upslope erosion of finer sediments into the Creek.

iii. During high runoff periods, bed shear forces can initiate transport of the gravel bed material. In these instances, the coarse bed materials will be transported as bed load, while the finer bed material and upslope eroded sediments will be transported as suspended load. The rate of bed material transport during high flow periods is limited by the transport capacity of Rose Creek.

2.3.5 Rates of Sediment Transport. Estimates for bed load transport of coarse bed material during high flow periods were not made for the present study. However, for discussion purposes, readily available empirical transport relationships were applied to provide a qualitative assessment for the transport of finer sediments. Comparison of sediment transport capacity in the diversion canal and in the natural Rose Creek channel is described below.

The potential transport capacities for fine sediments in the two channels were estimated by applying empirical transport relationships normally reserved for sand bed streams. These transport equations yield estimates that assume a sufficient quantity of sand is available in the channel bed to satisfy the transport capacity. However, for both the diversion canal and for Rose Creek, the channel bed is armoured by coarse material so that the amount of fine sediment available for transport is limited by upslope supply. Even with the limitation, the results from this analysis still provide, in relative terms, a basis for comparision of the diversion canal and Rose Creek.

Transport capacities are presented in relative terms for a range of sand sizes and discharges up to about a 70 year flood in Table 3.

TABLE 3

Ratio of Rose Creek: Diversion Channel
Transport Capacities

Discharge (m^3/s)	Sand Size 0.1 mm	0.5 mm	0.8 mm
20	1.30	1.27	1.41
60	1.36	1.31	1.52
100	1.04	1.25	1.00

These calculations illustrate that the sediment transport capacity of the diversion canal at a grade of 0.19%, is less than the capacity of the natural Rose Creek channel. However, as stressed previously these calculations estimate the potential capacity, while actual transport is limited by the delivery of sediments to the channels. Therefore, in the absence of conclusive site specific data, it must also be noted that the reduced capacity of the diversion canal may still be adequate to convey all sand supplied.

2.4 Groundwater

2.4.1 Regional Hydrogeology. The alluvial gravel in Rose Creek Valley probably carries a large proportion of the regional groundwater. This aquifer is recharged from regional flow paths which originate upstream and on the surrounding hillside. It is also recharged from precipitation occurring directly on the gravels. Drawing D-2758-7 shows sections and profiles of Rose Creek Valley and adjoining major landforms. At present, little is known regarding the direction of groundwater flows at depth. However, sub-vertical faults have been mapped between Rose Creek and the Pelly River (see Drawing A-2758-3) and these probably inhibit groundwater flows to the Tintina Trench from Rose Creek.

Till-like material is very common throughout the Rose Creek Valley. It is of significantly lower permeability than the fluvial gravels and therefore may be termed an aquitard. Correlation of stratigraphy between boreholes has not been possible to date due to the complex nature of the deposits.

The groundwater table is expected to be a subdued image of the topography. Locally, high downward gradients or artesian conditions may exist, dependent on topography, permeability and flow distributions.

2.4.2 Permeability. Various units in the valley have been given preliminary permeability estimates based on data presented by Golder Associates for the tailings ponds. The preliminary values are presented in Table 4. All permeability testing carried out in holes drilled with mud are suspect, as drilling mud will reduce permeabilities. Values estimated from air rotary water returns indicate the presence of a thick valley aquifer with a permeability of 10^{-2} to 10^{-4} cm/sec.

The approximate volume of subsurface flow at fill pond was estimated by Golder Associates (June, 1980) to be 0.04 m^3/s at the Intermediate Dam and 0.03 m^3/s at the Cross Valley Dam.

2.5 Mine and Mill Description

The following description was taken from a report on the Cyprus Anvil Concentrator by William N. Wallinger, who at the time of writing was the General Mill Superintendent at the Cyprus Anvil Mine.

TABLE 4

Preliminary Estimates of Permeability

Hole	Material	Depth (m)	Test	Permeability (cm/s)
79-6	till	33-40	falling head test drilled with mud rotary	$4 \times 10^{-7} - 2 \times 10^{-6}$
79-7	till	22-26	Same as above	$1 \times 10^{-5} - 3 \times 10^{-5}$
79-15	till, sand, gravel and schist	23-38	Same as above	$7 \times 10^{-6} - 1 \times 10^{-5}$
79-16	silt, sand and schist	20-30	Same as above	5×10^{-6}
79-19	sand, gravel and schist	16-24	Same as above	8×10^{-5}
79-21	till and schist	26-37	Same as above	6×10^{-6}
79-20	sand, gravel and schist	22-37	falling head test drilled with air rotary	$3 \times 10^{-6} - 4 \times 10^{-5}$
79-27	Brown sand and gravel	22	*air rotary return flow	$1 \times 10^{-4} - 1 \times 10^{-2}$
	Brown sand and gravel	26		$6 \times 10^{-4} - 4 \times 10^{-2}$
	Brown silty sand and gravel	33		$2 \times 10^{-5} - 1 \times 10^{-3}$
	Brown sand and gravel	38		$3 \times 10^{-4} - 2 \times 10^{-2}$
	Weathered Bedrock	43		$3 \times 10^{-5} - 2 \times 10^{-3}$
79-28	Brown sand and gravel	21	*air rotary return flow	$6 \times 10^{-4} - 4 \times 10^{-2}$
	Brownish red sand and gravel	29		$6 \times 10^{-4} - 4 \times 10^{-2}$
	Greenish grey schist	37		$3 \times 10^{-5} - 2 \times 10^{-3}$
79-30	Till with silt layers	16	*air rotary return flow	$9 \times 10^{-4} - 7 \times 10^{-2}$
	Greenish grey schist	19.5		$3 \times 10^{-5} - 2 \times 10^{-3}$
79-31	Brownish red silty sand	11	*air rotary return flow	$3 \times 10^{-4} - 2 \times 10^{-2}$
	Brownish red silty sand	13		$3 \times 10^{-4} - 2 \times 10^{-2}$
	Brownish red silty sand	15		$3 \times 10^{-4} - 2 \times 10^{-2}$
	Brownish red sand and gravel	21		$3 \times 10^{-4} - 2 \times 10^{-2}$
	Grey silty sand and gravel	29		$6 \times 10^{-4} - 4 \times 10^{-2}$
	Weathered schist in till matrix	38		$1 \times 10^{-3} - 1 \times 10^{-1}$
79-33	Grey silty sand and gravel	14	*air rotary return flow	$6 \times 10^{-4} - 4 \times 10^{-2}$
	Brown sand and gravel	18		$6 \times 10^{-4} - 4 \times 10^{-2}$
	Greenish grey schist	21		$3 \times 10^{-4} - 2 \times 10^{-2}$
79-34	Grey silty fine to medium sand	9	*air rotary return flow	$3 \times 10^{-4} - 2 \times 10^{-2}$
	Brown silty sand and gravel	18		$3 \times 10^{-4} - 2 \times 10^{-2}$
	Brown sand and gravel	25		$9 \times 10^{-4} - 7 \times 10^{-2}$

* The lower coefficient of permeability is estimated by assuming the return flow rate is recorded with the aquifer in a transient state. The higher one assumes the aquifer is in steady state. The actual permeability may be between the two values.

2.5.1 Ore Bodies. The zinc-lead-silver massive pyritic deposits of the Anvil District occur in a Cambrian meta-sedimentary, meta-volcanic terrain on the southwestern slope of the Anvil Range in the Selwyn Basin of Central Yukon.

The Faro Number One orebody, contains 57 million tons of massive sulphides averaging 3.4% lead, 5.7% zinc and 37.5 g/ton of silver, with a specific gravity of 4.5.

The ores have a granular texture averaging about 70% sulphide minerals with quartz or barite being the most common non-sulphide gangue minerals present. In the central portion of the deposit, pyrite occurs commonly as coarse porphyroblasts (to 5 millimetres) with inclusions of sphalerite and galena in a fine-grained (0.2 to 0.3 millimetre) matrix of sphalerite, galena, and minor chalcopyrite.

At the margins of the deposits, pyrrhotite forms fine-grained aggregates with veinlets and fine disseminations of chalcopyrite, sphalerite and galena. Other primary sulphides present in minor or trace amounts are tetrahedrite, bournonite and arsenopyrite. Marcasite and magnetite are important secondary minerals with anglesite, goethite and gypsum occurring sparingly.

A zone of low iron, disseminated galena and sphalerite ores in gangue of sericitic or graphitic quartzites envelopes the massive sulphide zone.

In 1979, Cyprus Anvil Mining Corporation ~~discovered and/or acquired~~ began developing for production additional ore reserves totalling 7 million tons adjacent to Faro Number One. ~~Exploitation of these reserves in Pit No. 2 was initiated soon after and~~, it is estimated that ~~they~~ these reserves will be depleted by the end of April, 1981. Subsequent ore will originate from a combination of Pit No. 1 and the Grum or Vangorda deposits. A diagram of the mine layout is shown in Drawing B-2758-8.

2.5.2 Milling Processes. (see Drawing A-2758-9). Ore is presently hauled from the pit to the primary crusher in 120 ton ore trucks. The ore is then crushed to minus 15 centimetres and conveyed to the coarse ore storage bin. From here, the ore is fed through two secondary crushers and reduced in size to minus 0.97 centimetres. The discharge is conveyed to the fine ore bin where it is directed into three parallel grinding circuits. Each circuit consists of a rod mill, a ball mill, and a tertiary ball mill. The average daily throughput is 9000 tons. 9200 tonnes

At the end of the grinding circuit, the ore is required to have 70 percent finer than 74 microns (No. 200 U.S. Standard sieve) to achieve reasonable results on the flotation feed followed by substantial regrinding to attain the desired concentrate grades.

From the grinding circuit, the ore is pumped to the lead rougher/ scavenger flotation cells. The scavenger tails are routed to the zinc circuit, while the scavenger concentrate is reground, re-treated and pumped to the cleaning section. After three cleaning stages, the concentrate contains 67% lead. Before shipping, the lead concentrate is thickened, filtered and dried.

The scavenger tails from the zinc rougher/scavenger flotation circuit form the greater part of the plant tailings. The scavenger concentrate is reground and treated several times before being discharged to the cleaning circuit. The zinc concentrate undergoes a 4-stage cleaning and is then thickened, filtered and dried. The final concentrate contains about 51 percent zinc.

Tables 5 and 6 show the metallurgical results of the Cyprus Anvil concentrator.

TABLE 5

Comparison of Metallurgical Results by Years from Wallinger

Year	Lead Conc. % Lead	Zinc Conc. % Zinc	Total Lead *Recovery %	Total Zinc *Recovery %
1970	66.2	49.3	76.0	66.3
1971	67.1	49.8	82.7	70.3
1972	68.5	50.7	84.5	73.5
1973	66.5	51.1	84.3	77.3
1974	65.0	51.5	83.4	77.1
1975	66.9	50.8	85.8	80.1
1976	67.3	51.4	81.7	79.6

TABLE 6

Metallurgical Balance 1975 from Wallinger

Product	Tonnes	Assays %			Distibution %		
		Pb	Zn	Fe	Pb	Zn	Fe
Mill Feed	2 925 858	4.03	5.41	32.87	100.00	100.00	100.00
Lead Conc.	131 952	66.03	5.07	6.37	74.90	4.23	0.87
Zinc Conc.	209 100	2.04	50.80	10.78	3.62	67.13	2.34
Bulk Conc.	69 955	18.37	29.34	15.53	10.91	12.97	1.13
Final Tailings	2 514 851	0.50	0.99	36.58	10.57	15.67	95.66

TABLE 7

Typical Screen Analyses
Size Percent Retained, from Wallinger

Microns	177	149	105	74	44	-44
U.S. Standard Sieve No.	80	100	140	200	325	-325
Flotation Feed	8.0	5.0	8.0	10.5	15.5	53.0
Lead Conc.				0.5	1.5	98.0
Zinc Conc.				4.0	10.0	86.0
Bulk Conc.				9.0	16.0	75.0
Final Tailings	8.5	5.5	8.5	11.0	16.0	50.5

At certain points along the milling circuit, various reagents are added to the ore. Table 8 shows the addition points and the typical reagent addition rates at those points.

Since 1975, the water consumption of the milling process has averaged 3230 gpm. To maintain an adequate water source, CAMC has dammed Rose Creek approximately 4 kilometres upstream of the mine site. A variable discharge lets enough water past the dam to satisfy the mill requirements and to keep the Rose Creek ecosystem in balance. There is a pump station near the confluence of Rose Creek and the North Fork where the water is pumped from the creek to the mill.

At the present time Cyprus Anvil Mine is modifying the grinding and milling circuit. The new circuit is designed to yield a much finer grind to increase the recovery of lead and zinc from the ore. The sieve analyses and output data may differ as a result of these modifications.

TABLE 8

Typical Reagent Addition Rates kg/ton
From "The Cyprus Anvil Concentrator" by W.N. Wallinger

Addiiton Point	NaCN	Na_2Co_3	$Ca(OH)_2$	$CuSO_4$	Z-11	MIBC	1012	Na_2So_3	pH
Primary Grinding	0.020	1.1			0.040				
Secondary Grinding	0.030								
Tertiary Grinding	0.055				0.005			0.3	
Lead Roughers						0.006			10.0
Lead Scavengers					0.025	0.004			10.0
Lead First Cleaner	0.010		0.020						10.5
Lead Second Cleaner					0.005				10.9
Lead Third Cleaner			0.055						11.5
Lead Retreat					0.010				10.5
Zinc Roughers			0.320	0.210	0.060		0.002		11.0
Zinc Scavengers					0.055		0.002		11.0
Zinc First Cleaner			0.040						11.3
Zinc Second Cleaner			0.050	0.020	0.055				11.6
Zinc Third Cleaner			0.090						11.9
Zinc Fourth Cleaner			0.180						12.2
Zinc Retreat				0.085	0.020				11.3
Total	0.105	1.1	0.755	0.315	0.225	0.010	0.004	0.3	

Note: Reagent addition rates have been altered since publication of Wallinger's report

The waste rock is hauled to waste piles adjacent to the pit. Typical particle sizes are from 3 m to rock flour. The waste dumps will ultimately contain approximately 135 million cubic metres of material with top elevations varying from 1220 m to 1265 m. The ultimate extent of the waste dumps is shown on Drawing D-2758-8.

Data in Table 6 shows that approximately 85 percent of the milled rock is discharged as tailings. Table 7 gives an average particle size distribution of the tailings.

From the zinc flotation circuit, the tailings are piped down to the tailings pond in the form of a slurry containing 35 percent solids. Slurry was spigotted from the dam crest at 30 metre intervals, to form the dam. At the present time, however, the tailings line discharges unclassified material from a single point on the northwest wall.

To date, the pond contains an estimated 11 million cubic metres of tailings and is nearly full. A new tailings dam is presently being constructed down-valley from the existing pond which will provide adequate storage for the mill waste from the present ore reserves (See Drawing D-2758-8).

2.6 Water Quality

2.6.1 Baseline Water Quality. Long term water quality trends after abandonment will be largely dependent on the natural neutralization and assimilation capacity of surface and groundwater in the region. Waters presently unaffected by mining discharges provide a baseline for evaluating future trends. The impact of various abandonment strategies should be evaluated in terms of potential changes in water chemistry, both groundwater and surface water, as a function of a particular plan. Rose Creek would be the logical choice for assessing background surface water quality in the immediate region. It appears that Rose Creek is the primary receiver of mining wastewater and tailings discharges at the present, and may continue to be affected, perhaps to a lesser extent, after closure of mining operations. The water quality of Rose Creek has been compiled and reviewed by the Environmental Protection Service (EPS, 1979). The data base included observations for approximately a three year period (1974 - 1976). Additional water quality was obtained from the Cyprus Anvil Mining Corporation as yearly summaries and water quality data sheets (Cyprus Anvil Mining Corporation, 1981).

Water quality analysis focused upon the sampling station located upstream from the pumphouse pond. This station is identified alternatively as Station 1 in the Environmental Protection Service documents and as Station R8 in the water quality surveys performed by Cyprus Anvil (See Drawing B-2758-8). Water quality at this station is believed to be unaffected by mining activity. Measured parameters included temperature, turbidity, colour, hardness, conductance, alkalinity, dissolved solids, dissolved oxygen, sulphate and cyanide, as well as the following total metal concentrations: antimony, arsenic, garium, cadmium, calcium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium and silver. Both the quantity of the data base (frequency of analysis) and the quality of data (detection limit) is somewhat variable.

Parameters such as temperature, pH, dissolved solids, conductance, hardness, alkalinity and metal levels including arsenic, copper, cadmium, lead, manganese, mercury, and zinc have been routinely assessed by both the mining company and ~~the Environmental~~ Water Resources ~~Protection service~~ Branch of DIAND, while the data base for other constituents is either sparse or the measured concentrations fall consistently below the analytical detection limit. Nevertherlss, the accumulated information is sufficent to establish a preliminary baseline with regard to the critical water quality constituents. The latter include the pH and the buffering capacity (total carbonate content) of natural waters, as well as the normal concentration and variability of heavy metals.

The histogram of pH values in Rose Creek is given in Drawing A-2758-10. The waters are slightly alkaline with characteristically low variability. Over 60% of the observations lie between pH of 7.4 and 7.8. The average pH value is 7.78 with a 95% confidence interval of ± 0.2 pH units. Consequently, the annual mean at this location is expected to be 7.5 - 8.1 pH units (12 observations per year) while any individual measurement is likely to range from 6.9 to 8.7. No definite seasonal trends with respect to pH were detectable. It should be noted, that most of the data have been collected from May to November. The singular extreme value (pH = 9.5), however, occured in January. The analysis of pH has been based on laboratory measurements. Only a few pH determinations made in the field were available. In some cases, individual field measurements differed from the laboratory measurements. However, no significant differences could be found between mean pH values (lab pH = 7.78, field pH = 7.49, standard error = 0.45) by statistical analysis (Student's t-test).

Traditionally, the alkalinity (as Ca CO_3) has been regarded as a measure of the buffering capacity of surface waters. Generally, alkalinity is dependent on the total carbonate (dissolved carbon dioxide, bicarbonate, and carbonate) and the pH - dependent equilibrium relationship. In predicting changes in water quality, (for example, acid generation) it is scientifically more rigorous to express the buffering capacity in terms of an ionic equilibrium. (Stumm and Morgan, 1970). If the water is unpolluted with weak ionic species (ammonia, for example), the alkalinity is defined as follows:

(1)

$$(Alk) = (HCO_c^-) + 2\ (CO_3^{2-}) + (OH^-) - (H^+)$$

(Alk) = Alkalinity in equivalents/liter

( ) = ionic species (moles/liter)

In surface waters at pH values of 7.0 or above, the hydroxyl and hydrogen ion contribution to the ionic balance are negligible. The alkalinity, therefore, can be expressed as a sole function of the total carbonate content, the dissociation of carbonic acid to bicarbonate (pK_1), and bicarbonate to carbonate (pK_2). The pH dependence of alkalinity is then given by the following expression:

(2)

$$(Alk) = C_T \frac{1 + 2 \times 10^{(pH - pK_2)}}{1 + 10^{(pK_1 - pH)} + 10^{(pH - pK_2)}}$$

where:

(Alk) = Alkalinity in equivalents/liter

C_T = total dissolved carbonate content (moles/liter)

pK_1 = carbonic acid/bicarbonate dissociation constant

pK_2 = bicarbonate/carbonate dissociation constant.

If the alkalinity is measured under laboratory conditions (20 ^{o}C) and the ionic strength is low, as in the case of uncontaminated Rose Creek water, the numerical values of pK_1 and pK_2 are 6.4 and 10.4, respectively (Stumm and Morgan, 1970). From the alkalinity data, the corresponding pH measurements, and the respective equilibrium constants, the total dissolved carbonate content in Rose Creek as defined by Equation 2 can be calculated. The results are given as monthly average values and, whenever possible, ranges of calculated values, in Table 9.

As shown in Table 9, the total carbonate content in Rose Creek possesses a definite seasonal trend. Minimal values are observed during the Summer when, due to the higher temperatures, the solubility of dissolved carbon dioxide is reduced. During the cooler months the total carbonate content increases and the waters may become super saturated (i.e. higher than the equilibrium value with atmospheric carbon dioxide) during ice cover. The summer average total carbonate content of 1.18×10^{-3} M is characteristic of surface waters in the slightly alkaline range and indicates good buffering capacity. The above value is equivalent to a total bicarbonate alkalinity, hence, buffering capacity, of 57 mg/l (as $Ca\ CO_3$).

In Drawing A-2758-11 the heavy metal content of Rose Creek is presented. The shaded area of the histographs represents the 95% confidence interval of the mean values, while the open bars correspond to the ranges of the observations. The confidence intervals were generated by applying conventional t-statistics at the appropriate degrees of freedom. During the calculations, indeterminate values ("less than" concentrations) and outliers have been excluded. The statistical approach was based on normal sample distribution, since none of the heavy metals possessed seasonal trends. In fact, the statistical variance of a constituent for a given month was equal to or greater than the variance for the entire set of observations.

TABLE 9

Seasonal Variation of Total Carbonate Content in Rose Creek

from EPS

Month	Number of Observations	Mean Total Carbonate (mM)	Range of Total Carbonate (mM)
January	1	2.48	———
February	ND	———	———
March	1	5.14	———
April	ND	———	———
May	1	1.10	———
June	3	0.57	0.45 - 0.78
July	2	1.02	0.94 - 1.11
August	3	1.30	1.12 - 1.40
September	4	1.59	1.22 - 1.78
October	1	2.20	———
November	1	2.41	———
December	ND	———	———

Clearly, alkali earth metals (calcium and magnesium) are the predominant metallic constituents. The concentrations of iron and manganese, and, to a lesser extent, lead and zinc, appear elevated in comparison to surface waters in other regions. This reflects obvious lithoral sources of these metals in the vicinity of the Cyprus Anvil mine. Most of the metals in the water occur as colloidal suspensions (probably colloidal hydroxides), since the dissolved metal concentrations (EPS, 1979) are substantially below the total metal level. The water is essentially calcium/magnesium bicarbonate type with sulphate being a secondary anionic constituent. The following ionic equilibrium has been found to represent the water quality in Rose Creek with reasonable accuracy:

(3)

$$(H^+) + 2\,(Ca^{2+}) + 2\,(Mg^{2+}) = C_T \frac{1 + 2\,\frac{K_2}{(H^+)}}{1 + \frac{(H^+)}{K_1} + \frac{K_2}{(H^+)}} + 2\,(SO_4{}^{2-}) + (OH^-)$$

Where

(Ca^{2+}) = calcium ion concentration (0.53×10^{-3} M)
(Mg^{2+}) = magnesium ion concentration (0.14×10^{-3} M)
C_T = total dissolved carbonate concentration (1.2×10^{-3} M)
$(SO_4{}^{2-})$ = dissolved sulphate concentration (0.10×10^{-3} M)

The concentrations listed above for the various ionic constituents are measured averages. The pH value predicted by the above expression is 7.7, which is essentially identical to the mean pH value in Rose Creek. The temporal variations in pH reflect minor fluctuations in dissolved constituents and the temperature effect on the carbonate equilibrium.

To date, no comparable data base is available to assess natural groundwater chemistry. For this reason, the establishment of long term groundwater stations and a sampling programme are recommended as outlined in Section 4.

Any acid generation from pyritic deposits (i.e. sulphate) would alter the ionic equilibrium expressed by Equation 3. It is, therefore, necessary to examine the long term acid generation potential after abandonment. A preliminary assessment of this acid generation potential is presented below. The purpose of the assessment is to identify deficiencies in existing data and formulate alternative abandonment plans to minimize this potential.

2.6.2 Acid Generation Potential. Acid generation from pyritic sources has been well documented in the scientific literature (Hauley, 1972). Several abandoned pyritic tailings areas have become acid generators in the Elliot Lake Region of Northern Ontario (Halbert et al, 1980) and the highly acidic (pH = 2.5), iron bearing seepage has contaminated a large portion of the surface waters in the Serpent River system. Although tailings can oxidize by purely chemical means, the oxidation process is greatly accelerated by chemolithotrophic bacteria, particulary *Thiobacillus ferrooxidans*. The optimal temperature of pyrite oxidation is 30°C to 40°C. Below this temperature, bacterial oxidation declines, as the Arrhenius activation energy is 45 to 68 kJ/mole. Therefore, pyrite oxidation is strongly pH dependent below 30°C. The upper pH limit of bacterial oxidation is approximately 6.0. *Thiobacillus ferrooxidans* becomes active at pH = 5.0 reaching a maximum oxidizing activity

TABLE 10

Acid Production Potential of Cyprus Anvil Samples

from Duncan

Sample Type	Sample	% Pb	% ZN	% Fe	% Cu	% Ba	% S	Natural pH	Acid Consumption (lb/ton)	Theoretical Acid Production (lb/ton)	Theoretical Acid Producer	Actual Acid Producer
Tailings	16-h composite Jan. 23	0.33	0.80	28.8	0.10	______	37.5	6.8	41	2250	Yes	Yes
	8:00 a.m. grab Jan. 24	0.22	0.54	31.2	0.08	______	37.9	5.2	17	2274	Yes	Yes
Waste Rock	diorite dike	0.04	0.06	3.9	<0.01	0.09	0.98	9.1	59	59	?	No
	diorite dike A (unaltered)	______	0.01	3.7	<0.01	______	0.26	9.2	73	16	No	______
	diorite dike B (unaltered)	______	0.01	3.0	<0.01	______	0.29	8.9	58	17	No	______
	diorite dike C (altered)	______	0.04	4.9	0.02	______	0.24	7.5	19	14	No	______
	diorite dike D (altered)	______	0.02	3.8	<0.01	______	0.16	7.8	21	10	No	______
	biotite schist	<0.01	0.01	4.9	<0.01	______	0.09	9.2	30	5	No	______
	muscovite schist	<0.01	0.02	4.9	<0.01	______	0.09	7.9	40	5	No	______
	calc silicate	0.06	0.08	4.6	<0.01	______	0.46	9.4	145	28	No	______
	sandy pyrite	0.30	0.45	48.5	0.03	______	52.7	6.0	45	3162	Yes	Yes
	drill cutting in muscovite schist at ore contact	0.28	0.51	7.3	0.04	0.28	3.6	6.4	74	216	Yes	Yes

Despite the high acid generation potential, acid formation in fresh tailings discharges is minimal (Beak, 1976). The tailings are discharged to the pond are at highly alkaline pH values (pH of 9 - 10). Upon exposure to atmospheric carbon dioxide, the high calcium content of the tailings water brings about the formation of calcite ($Ca\ CO_3$) and a coincidental pH decline to 7.5 - 8.5 range. Although some of the constituents of the discharge are amenable to acid generation at this pH range (ammonia as nitrate, thio salts as sulphate), the concentrations of these constituents are insufficient to demonstrate any significant effect. It should be noted, that freshly precipitated calcium carbonate is an excellent buffering agent.

Exposure of tailings to weathering could result in the gradual erosion of the buffering capacity. Both rain and snowmelt are slightly acidic and unsaturated with regard to calcium carbonate. As calcium carbonate dissolves, layers in contact with air develop microclimates where oxidation of pyrites can proceed. Sulphuric acid production in these locations would further accelerate calcium carbonate dissolution and a gradual increase, both lateral and vertical, of the oxidation zone would take place. The overall oxidation process is usually dependent on the oxygen transport rate.

Field data on tailings oxidation and acid generation in Cyprus Anvil tailings deposits are not extensive at the present. A recent field survey of exposed, old tailings was performed by Cyprus Anvil in October, 1980. Old, undisturbed tailings deposits showed evidence of pH depression.

Surface pH values ranged from 2.7 to 4.5, the oxidation depth being 15 to 46 cm. In general, surface pH values varied inversely with the oxidation zone; the mean surface pH value was 2.9 when the oxidation depth exceeded 20 cm in contrast to a surface pH of 4.3 above shallower zones.

In March, 1975, dam failure in the tailings area resulted in a shallow pyrite tailings deposit (mean depth = 4.4 cm) below the tailings pond in Rose Creek valley. A monitoring site has been established in the affected area and water quality has been the subject of several reports (Tailings Oxidation Project, 1975). Apparently, the exposed tailings surface has undergone rapid oxidation. By August 1975, the mean pH had declined to 3.6 although the oxidizing zone comprised no more than a few millimeters at that time. No adverse pH depression of Rose Creek was evident. Acid seepages from spilled tailings ranged in pH values from 3.16 to 3.76 (mean pH - 3.4) in the 1979 - 1980 survey. The seepage contained characteristically high total dissolved solids (1600 - 3500 mg/l), sulphate (800 - 2100 mg/l) and iron (36 - 110 mg/l), indicating continued pyrite oxidation activity. The low pH values brought about the apparent solubility of heavy metals, evidenced particularly by elevated concentrations of manganese (15 - 48 mg/l), zinc (15 - 29 mg/l) and copper (0.06 - 0.8 mg/l).

To evaluate the effect of tailings oxidation after abandonment, the rate of the oxidation, which controls the rate of acid generation is of critical importance. This rate, of course, is dependent on the abandonment plan. The ranges of oxidation rates and their dependence on temperature, pH, and presence of bacteria, will be studied further in Phase II of this project.

3. PROPOSED ABANDONMENT SCHEMES

3.1 General

Klohn Leonoff's scope of work for this study calls for an acceptable abandonment scheme for the Down Valley Project and other secondary facilities of the mine in which water quality will be addressed as a first priority. We understand that an "acceptable abandonment scheme" is one where effluent standards in the current Cyprus Anvil Water Licence (Appendix I) are not exceeded. Consideration of fish and aesthetics, while relevant to the discussion of an acceptable abandonment scheme, are secondary to consideration of water quality.

The components of the mine facilities which have be be considered in the abandonment plan include the following:

- tailings pond and its physical and chemical stability
- Rose Creek diversion canal
- open pits, as they pertain to water quality.
- waste dumps (as pertaining to water quality)
- water supply reservoir
- pumphouse, pond and associated facilities
- North Valley wall diversion ditches
- Faro Creek diversion
- North Fork Rose Creek and diversions

In the context of water quality, the chemical and physical stability of the tailings ponds and the proposed Rose Creek diversion canal (the Down Valley project) assume primary importance in comparison to impacts from other facilities (referred to as secondary facilities).

Replacement of proposed Down Valley scheme with a totally different scheme on a new site has not been considered in this report.

On abandonment, water quality of Rose Creek may be affected negatively from two principal phenomena:

i. groundwater leaching and contaminant water transport downstream of the mine facilities;

ii. physical transport of stored tailings.

The first factor may take place as a result of contaminant transport issuing from the tailings pond and some secondary facilities such as waste rock dumps and open pits. Physical transport of tailings may be caused as a result of wind erosion of tailings and from transport of tailings in water as a consequence of failure of either the proposed diversion canal or the tailings dam. In order to derive an acceptable abandonment scheme, a critical appraisal of the stability of the Down Valley Scheme is essential.

The following sections present a brief discussion of the alternatives for the various facilities.

3.2 Secondary Facilities

Many of the structures that must be abandoned in an acceptable manner will not be influenced by the routing of Rose Creek. These structures are given singular tentative solution below. Although further study may be required to verify the adequacy of a few of these schemes, it is believed the proposed concepts will not be affected radically.

3.2.1 Fresh Water Suppy Dam. Ultimately this dam will be removed and the stream bed and valley restored. This is necessary to remove the risk of flooding downstream if the reservoir should fail. The removal of this dam also provides the secondary benefit of restoring fish passage up Rose Creek. Care must be taken when the dam is removed to reduce the suspended sediments released to Rose Creek. Sediment deposits on the bottom of the reservoir may be used to assist vegetation programs elsewhere on the site or may be simply covered with vegetation in place.

(It is relevant to note that on abandonment in approximately 20-30 years time, there may be valid demands to utilize this dam as an environmentally acceptable and relatively cheap source of power for a community. We understand that the water dam as constructed is capable of generating approximately 100 H.P. continuously).

3.2.2 Pumphouse and Related Facilities. The pumphouse will be removed and the foundation covered and rehabilitated. The pumphouse pond will be drained and the dam removed. Care must also be exercised in removing this dam so that the suspended solids released to Rose Creek is minimized.

3.2.3 North Fork Rose Creek Diversion. The diversion structure will be removed and the channel improved to return the creek to pre-mine conditions. Some sediment deposits resulting from the old Faro Creek diversion are found in the stream bed. These deposits should be evaluated to determine their effect on stream water quality.

3.2.4 North Valley Wall Interceptor Channel. This channel may either be stabilized or backfilled on abandonment depending on the abandonment scheme adopted for Rose Creek.

3.2.5 Open Pits. Open Pit Number 2 will be backfilled with waste rock in the near future. Open Pit Number 1 will be allowed to fill with water forming an abandonment reservoir. The water will inhibit oxidation of the mineralized rocks near the pit bottom and thereby reduce the production of acid. Lack of acid generating rocks on the walls near ground surface must be verified. The overflow from the open pits can be directed into North Fork Rose Creek or the tailings pond area depending on the abandonment scheme adopted. If the flow is directed towards the tailings pond area, the water will flow beneath the waste rock. The effect of this underflow on the stability of waste piles needs to be investigated. If the flow is directed towards the North Fork-Faro Creek, a designed channel will be required.

3.2.6 Faro Creek Diversion. The diversion structure will be removed and the presently operating diversion channel will be backfilled. Faro Creek will be allowed to flow into the open pit after abandonment.

3.2.7 Waste Rock Dumps. The ultimate dimensions of the waste rock dump is shown on Drawing D-2758-8. Approximately 25 to 35 x 10^6 cubic metres remain to be removed from the pit and placed above ground. The constraints on the present waste rock dump are the power line on the south side and North Fork Rose Creek on the east side. Final slopes in the vicinity of North Fork Rose Creek may require flattening to increase the factor of safety against sliding during extreme events. In addition, special toe berms may be required in zones where water is allowed to flow through the waste rock. Vegetation on top of the waste rock dumps may be initiated during the active life of the mine.

3.3 Down Valley Project

3.3.1 Rose Creek Diversion Canal (Scheme 1). This scheme relies on the ability to modify the presently designed canals to remain operational on abandonment, as shown on Drawing B-2758-12.

Several factors affecting the long term feasibility of this scheme must be addressed before this option becomes acceptable. These include:

a) design of the canal section to carry the probable maximum flood without overtopping or eroding. A brief discussion on this aspect has been presented previously under Section 2.3.

b) elimination of possible channel filling which could reduce the channel cross-sectional area and result in overtopping. Channel filling could be initiated by the following agents:

   - slope wash due to solifluction and creep of the hill slope. The canal is located in an area of discontinuous permafrost. Freeze thaw action could create debris which could accumulate in the canal. The hill slope runoff is a high fraction of total precipitation in this climate. The possibility of slope wash assumes increased importance after a large forest fire.

   - transport of deltaic deposits from hillside streams. At least two perennial and several intermittent streams ~~may be~~ have been identified over the length of the proposed diversion canal.

   - aggrading stream bed from bed load transport.

   - glaciation within the channel or from the tributaries entering the main stream.

It is important to note that none of the above phenomena can be dealt with in terms of numbers or precise factors of safety. However, should the diversion canal fail due to any of the above reasons, then water will be channelled to the tailings pond area.

(c) surfacing of tailings to reduce wind erosion and infiltration will be required. The surfacing material may include vegetation.

The positive aspect of this scheme is that it channels the stream flow away from the tailings. It is also economically attractive since it utilizes the engineering works (tailings pond, diversion canal, etc.) required for the operational stage of the mine. However, in view of the geomorphological and hydraulic constraints, it may not be possible to demonstrate the long term, maintenance-free operation of the diversional canal.

3.3.2 Abandonment Reservoir Scheme (Scheme 2). The second alternative (Drawing B-2758-13) involves flooding the tailings and creating an abandonment reservoir. All streams would be allowed to flow into this reservoir. This scheme would require an overflow structure capable of handling the probable maximum flood. The design of the cross valley dam or the intermediate dam would have to be modified so that a broad-crested weir constructed of waste and selected rock may be incorporated on the crest of the dam. The design of the new structure would be based on flow through and overflow rockfill dam technology. The downstream section of the dam would also be modified to accept new flow condition.

Ideally, all tailings must be submerged in order to reduce potential acid production. In the scheme designed by Golder Associates, the old tailings deposits will remain above the final height of the proposed intermediate dam at El. 1083 m. In order to flood all tailings, it would be necessary either to increase the crest elevation of the abandonment dam to El. 1115 m, or to some intermediate elevation where all tailings above that elevation would be excavated and placed below the crest elevation.

It may be possible to incorporate a separate low flow structure in this scheme which would provide an access for fish. However, maintenance-free operation of such an outlet remains in question.

The concept of flooding the tailings and providing a massive outlet structure has the following advantages.

(a) the abandonment reservoir will act as a sedimentation basin capable of handling all flows from tributary creeks, slope wash, and glaciation.

(b) outlet flows will be controlled since the reservoir will route floods.

(c) problems associated with wind erosion of tailings are eliminated.

(d) free water above tailings will provide an excellent barrier against diffusion of oxygen in tailings.

The disadvantages of the scheme are as follows:

(f) a well designed, substantial and relatively expensive flood control and overflow rockfill structure is required.

(g) increased infiltration in the tailings can effect water contaminant transport and water balance in the reservoir. However, this effect would be significantly reduced if the coarse, semi-classified tailings were capped with a low permeability material (e.g. till) prior to flooding.

(h) fish passage cannot may not be guaranteed forever.

From the information so far available, it is our opinion that it is possible to design an acceptable outlet structure, and that this scheme would enable water quality of Rose Creek to be safeguarded.

3.3.3 Tailings Removal (Scheme 3). On abandonment, the tailings may be removed and pumped back in the open pit for storage. Rose Creek would be permitted to return to the valley bottom.

The advantages of this scheme are that the probability of long term water contamination is minimized and that fish access is brought back to the pre-mining stage. The major disadvantage is the high capital cost of implementation after mining has terminated.

We consider this scheme to be a "last resort" alternative, should unexpected field data during the course of our study preclude consideration of other options. For completeness, this scheme has been presented on Drawing B-2758-14.

4. PROPOSED FIELD INVESTIGATIONS

4.1 General

The primary concern of the abandoned facilites is the water quality. Water quality can be altered by groundwater leaching of chemical constituents and physical movement of mine waste with wind or water. The investigation program will therefore concentrate on establishing present conditions in Rose Creek Valley and in evaluating water quality in future.

The information required can be grouped under the following categories.

(a) Surface Hydrology.
(b) Hydrogeology and Surficial Geology
(c) Water Quality
(d) Material Properties
(e) Surface Treatment

4.2 Surface Hydrology

A permanent hydrometric station may be installed to better estimate probable stream flows after abandonment. This station can be installed with the assistance of Water Survey of Canada (WSC). Servicing can be carried out by the WSC for a small annual fee.

In addition, samples of stream-bed material will be collected and the particle size distribution determined.

4.3 Hydrogeology and Surface Geology

As described earlier in this report, it will be necessary to identify the flow directions and rate of flow in Rose Creek Valley in order to characterize contaminant transport. The following investigations would be necessary:

4.3.1 Piezometers. Three different piezometer installation techniques are proposed.

(a) Approximately 8 holes are anticipated using a Shramm air rotary drill rig. A KLL representative will inspect the drilling program to maximize the information obtained from the drill holes. Four of these drill holes will be instrumented with 3-one inch diameter piezometers. Two of these drill holes will be completed using 4 inch wells with stainless steel screens. These installations are to be used for long term monitoring of the Down Valley scheme. The remaining two holes will be completed with a multi-position valved piezometer system. This system has been specifically developed for monitoring piezometric pressures and water quality. The holes would be backfilled using sized materials and water filled packers.

(b) Approximately 12 minipiezometer installations are anticipated on the surface of the tailings pond. These installations will be made by hand using a sledge hammer, a one-half inch pipe and PVC drive points. A small PVC tube with a special screening material is left in these holes to monitor the tailings pore water.

(c) In addition, three hand borings (using a tripod) are anticipated to a maximum depth of 20 feet to sample tailings materials. One inch diameter PVC standpipes will be installed in these holes.

4.3.2 Permeability Testing. Permeabilities of selected aquifers and aquitards at the Faro site will be estimated using the following procedures:

1. falling head test in sealed piezometers.
2. constant head tests in sealed piezometers.
3. permeability estimates using a borehole dilution apparatus.
4. permeability estimates based on water return from Shramm drill rig.
5. permeability estimates based on particle size gradations.

Any of these methods of determining permeability may produce unreliable values. However, by using more than one procedure, systematic errors in permeability determination can be identified, and corrected.

4.3.3 Surficial Geology. Surficial geology mapping is required at Faro site for the following reasons:

1. to extend borehole data and allow construction of an acceptable hydrogeological model.
2. to identify periglacial and other features so that their influence on abandoned structures may be evaluated.
3. to identify stream channel morphology so that the future patterns of Rose Creek may be estimated.
4. to identify the material at the toe of ultimate waste piles.

The surficial geology mapping will be based on airphoto interpretation, borehole information from this study, field mapping as the snow cover melts and information available in previous reports.

4.4 Water Quality

The following program is intended to expand the existing water quality data base and to provide information for objective evaluation of various abandonment alternatives.

4.4.1 Sampling of Tailings Pore Water. It is recommended that mini-piezometers be installed in at least 3 locations on the existing tailings where surface pH values (pH of 2.0 to 3.0) indicate significant acidification at present. The pore water will be sampled at 4 depths, at least two of the depths being within the oxidation zone, one at the edge, and one approximately 25 cm below the oxidation zone.

4.4.2 Groundwater Quality Sampling. To establish baseline control, sampling of groundwater is required in piezometers at the following locations:

a) Upstream of the water reservoir,

b) Left abutment of the Intermediate dam,

c) Right abutment of the Intermediate dam,

d) At the Intermediate dam centerline,

e) Two multi-piezometer wells downstream of the present tailings pond,

f) Two wells downstream of the future tailings containment area. These would serve as permanent sampling locations of the major aquifer.

Each piezometer will be flushed to remove contamination due to drilling and the influences of the well. Each water sample will be analyzed for the following parameters: temperature, pH, alkalinity, total dissolved solids, dissolved sulphate, arsenic, calcium, cadmium, copper, iron, lead, magnesium, manganese, mercury, zinc, and nutrients. The following parameters will be measured in the field at the time of sampling: pH, eH, conductivity, temperature and dissolved oxygen.

4.4.3 Stream Samples. Established water sample stations will be re-sampled for this study as well as some additional stations established to improve control. Stream sediment samples will also be taken at each station. Stream sections and velocities will be documented as will pH and conductivity profiles at the time of sampling.

All samples will be tested in the field for pH, eH, conductivity, temperature and dissolved oxygen. Laboratory tests will be carried out as indicated in Section 4.4.2.

4.4.4 Neutralization Capacity of Natural Waters. To assess the neutralization capacity of natural waters (Rose Creek water and groundwater) it is recommended that a number of known volumes (100 ml) of acidic seepages be titrated with natural waters of known pH and akalinity. During the titration, the volume of water added and the resulting pH will be recorded. The titration will continue until the pH rises above 7.0.

4.4.5 Tailings Oxidation Studies. Tailings oxidation studies will be performed under laboratory conditions. Fresh tailings will be leached of residual neutralizing agents with dilute sulphuric acid and washed with distilled water. A known weight of dried, leached tailings (100 g) will be resuspended in 300 ml of natural surface water and incubated by gentle shaking for approximately 120 days. In these oxidation studies, the effect of the following parameters on the oxidation rate will be established: temperature, initial pH, and the presence of pyrite oxidizing bacteria (from duplicate samples inoculated with Thiobacillus ferrooxidans). A 3 x 2 factorial experimental design is proposed with the following factors: temperature (4^oc and 20^oc), initial pH (7.0 and 3.0), biochemical oxidation (with and without bacterial inoculant). Sampling would involve bi-weekly analysis of the following: pH, dissolved oxygen, dissolved iron, and dissolved sulphate.

4.5 Material Samples Samples will be collected in the field for laboratory testing. Samples will include:

a) Sand and gravel from fluvial terraces for grain size and permeability testing.

b) Tailings samples for chemical analyses, grain size, and acid generation tests.

c) Ore samples for chemical analyses and acid generation tests.

d) Waste rock samples for chemical analyses and acid generation tests.

e) Representative samples from walls of pit 1 for chemical tests.

f) Samples of tailings from previous spill on banks of Rose Creek, downstream of existing ponds.

g) Samples of sediment materials from North Fork Rose Creek for chemical analyses.

4.6 Surface Treatment

Information will be gathered to explore the possibility of stabilizing the exposed tailings.

5. PROPOSED ANALYSES (PHASE 3)

5.1 General

Sections below outline the range of analyses and office studies that may be required. Some of these office studies shall commence immediately while in other cases field data must first be assembled.

5.2 Seismic Risk Analysis

Seismic loading under long term conditions will be determined using a probablistic approach developed by Cornell (1968).

5.3 Hydrology and Hydrogeology

The following studies will be undertaken:

- Estimate of probable maximum flood
- Establish seasonal flows for all creeks in Upper Rose Creek basin
- Sediment transport capacity
- Undertake flood routing studies
- Establish groundwater flow paths and flow rates.

5.4 Fish

An office study is being undertaken by the Environmental Biology department of Beak Consultants Ltd. This will address the particular merits and difficulties of each of the abandonment schemes with regard to fish passage.

5.5 Surface Treatment

An investigatation of the surface treatment of exposed tailings will be undertaken.

5.6 Geotechnical

- Evaluation of stability of natural slopes in the area of interest.
- Stability of waste dumps as it pertains to water quality
- Prepare design concepts for overflow rockfill structure and canals. In view of the State-of-the-Arts nature of the design of the abandonment dam we have arranged for Mr. J.R. Wilkins, a noted international authority on the design of such structures, for a review of our work.

5.7 Chemical Transport Studies

- Establish groundwater and surface water quality model
- Evaluation of long term conditions to select an appropriate solution to reduce contaminant transport to an acceptable level

A commentary on the chemical aspects of Data Analysis and Water Quality Modeling is presented in Appendix II.

Phase 4 of our work remains identical to that outlined in our proposal of December 24, 1980.

6. SCHEDULE

Field work is scheduled to start on March 10, 1981 and continues until the first week in May, 1981. A schedule of our activities is shown on Drawing B-2758-15.

The drilling and piezometer installation program is on a critical path. The unconventional nature of the program should also be emphasized. Therefore, the selection of a drilling contractor and the immediate mobilization of this equipment is imperative.

KLOHN LEONOFF LTD.

H. RODNEY SMITH, P.Eng
Project Engineer

VINOD K. GARGA, P.Eng
Head, Mining Engineering
Services Division

VKG/HRS/ktt

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APPENDIX I

APPENDIX I

- Terms of Reference
- List of Information Supplied by Cyprus Anvil Mining Corporation
- Water License Y2L3-0005

TERMS OF REFERENCE FOR DEVELOPMENT OF FARO MINE ABANDONMENT PLAN

1. Components of mine facilities to be considered in abandonment plan:

   (a) Water supply reservoir
   (b) Tailings pond surface physical and chemical stability
   (c) Rose Creek diversion canal
   (d) North Valley wall diversion ditches
   (e) Faro Creek diversion
   (f) Pit
   (g) Waster dumps
   (h) Pumphouse pond and associated facilities

2. The abandonment plan must evaluate all possible alternatives for permanently reclaiming the above structures, identifying the best option from environmental and economic points of view.

3. The investigation must be balanced such that components of little significance or concern are covered relatively superficially, allowing maximum focus of effort on the obvious problem areas.

4. The emphasis throughout will be on arriving at an abandonment plan which protects water quality as a first priority, with aesthetics and possible alternative land uses as secondary objectives.

5. The development of the abandonment plan should proceed in stages, with formal CAMC/consultant/government review at each stage.

   Stage I: Selection of consultant and development of terms of reference and schedule.
   - complete by December 31 -

   Stage II: Site visit and review of all CAMC/government information. Overview of all project components to determine areas needing detailed study and intensive effort. Outline of proposed "plan of attack" on problem areas. Identify those components of the mine facilities which can be reclaimed easily with existing technology and which will not present long term maintenance problems - eliminate these from further consideration with superficial treatment.
   - complete by January 31 -

..... 2

Stage III: Carry out whatever detailed investigations are needed to get acceptable solutions to the problems identified in stage II. These detailed investigations will include development of ways to guarantee the stability of the Rose Creek diversion in the long term and will include a detailed evaluation of present "state-of-the-art" options for physically and chemically stabilizing the tailings surface, but will not necessarily be limited to these. In most cases more than one method of reclamation may be possible at different levels of environmental risk and economic cost.
- complete by May 31 -

Stage IV: Compilation of final report and presentation to the Water Board.
- complete by June 31 -

VA 2758 February 23, 1981

LITERATURE LIST SUPPLIED TO VINOD GARGA

KLOHN LEONOFF

GOLDER ASSOCIATES

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5-PR-73-8.1973

Indian and Northern Affairs   Affaires indiennes et du Nord

WATER LICENCE

issued pursuant to
Northern Inland Waters Act and Regulations

CYPRUS ANVIL MINING CORPORATION LTD.
(Licensee)

Licence Number [illegible] Issued on [illegible] 19[illegible]

Location Rose Creek near Faro, Yukon Territory

YUKON TERRITORY WATER BOARD

Pursuant to the Northern Inland Waters Act and Regulations the Yukon Territory Water Board, hereinafter referred to as the Board, hereby grants to

CYPRUS ANVIL MINING CORPORATION LTD.
(Licensee)

of P.O. Box 1000, Faro, Yukon Territory
(Mailing address)

hereinafter called the Licensee, the right to alter, divert or otherwise use water subject to the restrictions and conditions contained in the Northern Inland Waters Act and Regulations made thereunder and subject to and in accordance with the conditions specified in this licence:

Licence Number Y2L3-0005

Water Management Area 02 Yukon

Location Rose Creek near Faro

Purpose To obtain, store and return a flow of water

Description Storage Reservoir, Industrial use in milling process and a tailings impoundment.

Quantity of Water Not to be Exceeded 2×10^9 Gallons per Year

Rate of Use of Water Not to be Exceeded 5,000 Gallons per Minute

Effective Date of Licence 1 December 1974

Expiry Date of Licence 30 November 1979

This Licence issued and recorded at Whitehorse includes and is subject to the annexed conditions.

Yukon Territory Water Board

Witness

Chairman

Approved by

Minister of Indian Affairs and Northern Development

PART A - GENERAL CONDITIONS

1. Definitions:

   a) "Act" means Northern Inland Waters Act, R.S.C. 1970 (first supplement) Chapter 28 and any amendments thereto;

   b) Regulations mean the regulations made under the Act;

   c) Board means the Yukon Territory Water Board;

   d) Controller means the Controller of Water Rights for the Yukon Territory;

   e) All terms in this licence, unless otherwise expressly stated, shall be defined in the same manner as in the Act and Regulations thereunder.

2. The licensee shall pay the fees prescribed in the regulations, annually in advance on the 1st day of January in each and every year of the term.

3. Security:

   This licence shall not come into effect until the licensee has deposited with the Board security in the amount of

   One Hundred Thousand Dollars ($100,000.00)

4. In the event the licensee fails to comply with any provision or condition of this licence the Board may, subject to the Act, cancel the licence.

5. Notice. Where any direction, notice or order under this licence is required to be in writing, it shall be given:

   a) to the licensee, if left at or mailed by registered mail to the following address:

      Cyprus Anvil Mining Corporation Ltd.
      P.O. Box 1000
      Faro, Yukon Territory

   b) to the Board, if left at or sent by registered mail to the following address:

      Yukon Territory Water Board
      200 Range Road Takhini
      Whitehorse, Yukon Territory
      Y1A 3V1

6. An appeal may be filed with the Board within Ten (10) days from any action taken by the Controller.

PART B - CONDITIONS APPLYING TO CONSTRUCTION

1. The construction of the tailings containment is to be carried out as per the submitted plans and specifications by Golder, Brawner & Associates Ltd., July 1974. Any changes to the plans and specifications are to be filed with the Board. Until the completion of this project, interim limits of the elements listed in Part C 1(f) may be proposed to and approved by the Board.

2. When the Controller determines it to be necessary, facilities for collecting and disposing of tailings pond seepage flows are to be proposed to and approved by the Controller.

3. Stabilization of Faro Creek Diversion

   The diversion channel for Faro Creek is to be stabilized to prevent excessive erosion. Methods are to be proposed to and approved by the Controller. This work is to be completed by 1 November 1975.

4. The licensee shall construct each structure and carry out all work in accordance with the plans and specifications filed and approved.

1. Waste Discharge:

a) Without restricting the generality of the definition of "waste" in the Act, "waste discharge" in this licence includes the tailings pond effluent, tailings pond seepage, all mine water drainage and contaminated surface drainage prior to entering the receiving waters, and including the Faro Creek diversion waters.

b) No waste discharge shall exhibit constituents or characteristics exceeding the following limits.

Suspended solids	not greater than 15 mg/l
pH	not less than 6.5 pH units
Colour	not greater than 20 Pt-Co units
Turbidity	not greater than 15 Jackson Turbidity units

c) No waste discharge shall contain floating solids.

d) No visible or floating oils or greases shall be present in any waste discharge.

e) No waste discharge shall be toxic to fish.

f) The concentrations of elements which shall not be exceeded in any waste discharge are listed below:

			Concentration mg/l	
Ammonia	(asN)	total	1.00	ppb
Antimony	(Sb)	extractable	0.10	
Arsenic	(As)	dissolved	0.05	50
Barium	(Ba)	extractable	1.00	
Cadmium	(Cd)	extractable	0.02	20
Copper	(Cu)	extractable	0.20	200
Cyanide	(asCN)	total	0.05	
Lead	(Pb)	extractable	0.20	200
Mercury	(Hg)	extractable	0.005	5
Molybdenum	(Mo)	extractable	0.50	
Nickel	(Ni)	extractable	0.5	
Selenium	(Se)	extractable	0.05	
Silver	(Ag)	extractable	0.10	
Zinc	(Zn)	extractable	0.5	500

2. Clean-up:

The licensee shall on the expiration and when a renewal of this licence is not under consideration or sooner termination of this licence or sooner discontinuance or abandonment of operations by the licensee:

a) remove and dispose of all stock-piles and containers of reagents, fuels or other chemicals which could directly or indirectly affect the quality of water of any watercourse, in accordance with methods proposed to and approved by the Controller;

b) bury or remove and dispose of all garbage heaps, piles of construction materials and piping and other surplus materials which could directly or indirectly affect the quality of water of any watercourse, in accordance with methods proposed to and approved by the Controller;

c) Where there exists potential impairment of the quality of water of any watercourse because of its proximity to waste rock piles, the waste rock piles are to be stabilized in accordance with methods proposed to and approved by the Controller. Proposals may include, but are not necessarily limited to, flatting of slopes, installation of rip rap, construction of water course diversions or water collection and impoundment for treatment.

3. Stabilization and Construction of Tailings Pond

a) On the expiration and when a renewal of this licence is not under consideration or sooner termination of this licence or sooner discontinuance or abandonment of operations by the licensee where there exists potential impairment of the quality of water of any water course, the licensee shall stabilize the tailings pond. Proposals of embankment reconstruction, wastewater treatment or disposal, and vegetation procedures or any other methods shall be presented to and approved by the Controller before such work is undertaken.

b) Proposals for construction of additional ponds shall be presented to and approved by the Controller before such work is undertaken. If, after completion of work under 3a) or 3b) and during the term of the commercial land lease #1646, the Board is of the opinion that re-stabilization of the tailings pond or construction of additional ponds is required, the necessary work shall be the responsibility of the licensee.

4. North Fork of Rose Creek

When the North Fork of Rose Creek is being diverted into the pumping reservoir an overflow of 1000 gallons per minute must be maintained over the pumping reservoir spillway. To prevent a fish barrier to the North Fork of Rose Creek this diversion may only be operated from 1 November to 30 April.

PART D - GENERAL PROVISIONS FOR REPORTS, SAMPLING AND ANALYSIS

1. a) The licensee shall file annual reports with the Board pursuant to Section 15 of the Regulations, not later than the first day in March of each year of the term, the first report to be filed on the first day of March, 1975.

b) The annual report shall summarize the year's operation with regard to the actual water use, including the average daily consumption and detail of any amount in excess of that authorized, and shall contain both tabular and graphical summaries of the water quality monitoring data obtained during the previous year.

2. a) The licensee shall submit to the Board monthly reports based on the previous month's monitoring data and shall include the date and time each sample was taken and analyzed.

b) The licensee shall each month send an additional sample from sampling points 9BC-S1 and 9BC-S6 taken at the time this location is sampled for the monitoring program to:

Water Quality Branch Laboratory
Pacific Region
Environment of Canada
1305 Welch Street
North Vancouver, B. C.

c) The licensee shall collect a maximum of four bioassay samples each year from sampling points 9BC-S1 and 9BC-S6 on the dates stipulated by the Controller, and ship the same to:

Environmental Protection Service Laboratory
4160 Marine Drive
West Vancouver, B. C.

d) Sampling procedures, containers and analytical services for the bioassays shall be obtained from the Environmental Protection Service.

3. a) The licensee shall comply with the attached monitoring program attached as Schedule A hereto and with any variations thereof made by the Controller and shall comply with all provisions for sampling, sample preservation and analysis specified by the Controller.

b) Unless otherwise specified or approved by the Controller, all analyses shall be conducted in accordance with the 13th edition of "Standard Methods for the Examination of Water and Waste Water", prepared and published jointly by the American Public Health Association, the American Water Works Association and the Water Pollution Control Federation.

c) All analyses shall be performed in a laboratory approved by the Controller.

ACCEPTANCE BY LICENSEE

Above Terms and Conditions are hereby accepted by the Licensee this ___ day of __________, 19__.

CYPRUS ANVIL MINING CORPORATION LTD.

Per: ____________________
Name

Per: ____________________
Name

____

(Witness - if individual)
(Seal - if company)

APPENDIX II

APPENDIX II

Data Analysis and Water Quality Modelling

DATA ANALYSIS AND WATER QUALITY MODELLING

Water quality models have been proven to be useful tools for predicting trends in water chemistry. In the present case, such a model could be applied for evaluating the relative impact of alternative abandonment strategies on receiving waters. Any predictive model, particularly a long term one, is subject to a number of assumptions and uncertainties. Nevertheless, is is expected to demonstrate the relative benefit (or shortcoming) of a given abandonment plan. This water quality model must be tailored to site specific conditions reflecting the existing water environment (both surface and groundwater) as well as effluents from contaminated areas.

The model comprises three components; namely a hydrological component, tailings/waste rock oxidation component, and water quality behavior component. The hydrological component attempts to simulate the flows of surface and groundwater. The tailings oxidation component reflects the rate of oxidative processes. These processes are, in turn, dependent on other ambient conditions (temperature, pH, oxygen, presence of chemolithotrophic bacteria, etc.) within a particular, affected area in the watershed. The water quality behavior component takes into account the various physiochemical phenomena including solubility equilibrium, ionic equilibrium, and dynamic processes, which ultimately determine the chemistry of water. The evaluation is performed at certain "nodes" representing the confluence of "affected" water with natural and/or groundwater flows. The ensuing discussion attempts to summarize the basic concepts to be applied in this particular case.

Oxidation Rates in Pyritic Deposits

The oxidation of pyritic ores has been the subject of numerous studies. The oxidation rate is known to be a function of a number of parameters including ore composition, particle size, temperature, pH, presence of chemolithotrophic bacteria, and oxygen concentration.

Tailings at Cyprus Anvil have been demonstrated to be acid producers. The rate of acid production, however, is not known. The laboratory studies , as outlined in the recommendations, are designed to yield site specific information with regard to tailings oxidation rates under various conditions.

Assuming that pyrite is the primary oxidizable constituent of tailings, the stoichiometry of the oxidative process is as follows:

$$F_e S_2 + 7.5\ 0_2 + 7H_2O = 2\ Fe(OH)_3 + 8H^+ + 4\ SO_4^{2-} \quad (1)$$

The rate of oxidation is best measured in terms of sulphate (SO_4^{2-}) generation per unit mass of tailings per unit time (i.e. moles/kg day) for the following reasons. Sulphate is a conservative constituent inasmuch as neither its oxidation state nor its degree of ionization would change upon mixing with natural surface water. On the other hand, the concentration of dissolved metallic constituents (iron in equation 1) is largely dependent on the pH and formation of sulphate, carbonate, and hydroxo complexes. Similarly, the hydrogen ion activity, hence, the pH, is dependent on the ionic equilibrium. Thus, metal ions and the pH are generally non-conservative upon mixing with other water bodies.

At a defined set of conditions, (temperature, pH, etc.), let r_s represent the rate of sulphate production per unit mass of pyritic tailings in the following manner:

$$\frac{1}{m} \frac{d(SO_4^{2-})}{dt} = r_s \qquad (2)$$

where; m = mass of tailings (kg)
(SO_4^{2-}) = moles of sulphate
t = time

Although in laboratory-scale experiments the rate, r_s can be readily determined, in water quality models the rate expression on a volume basis is more useful. If the density of tailings is known, the latter is given by:

$$R_s = \rho r_s \qquad (3)$$

where; R_s = moles of sulphate produced/m^3 day
ρ = density of tailings kg/m^3

In tailings areas, active oxidation is restricted to an oxidizing zone within the tailings (Ricco et al., 1979). If "λ" represents the thickness of such zone, the areal oxidation rate is described as:

$$\lambda R_s = \lambda \rho r_s \qquad (4)$$

The temperature effects on the oxidation rate, R_s, can be described by an Arrhenius relationship in the following manner:

$$R_s (T) = A \exp^{(\Delta E/RT)} \qquad (5)$$

A = Arrhenius pre-exponential constant
ΔE = activation energy (J/mole)
R = universal constant (J/mole ^oK)
T = absolute temperature ^oK

Equation (5) expresses the oxidation rate as an explicit function of temperature. Two of the parameters (A and ΔE) of the expression depend on the tailings composition and the presence (or absence) of bacterial activity, thus must be determined by experimentation. The proposed factorial experimental design would provide a sufficient and efficient means to estimate the magnitude of the above parameters. Similarly, the pH effects on the oxidation rate can be established from the experimental portion of this study.

Oxidation in Tailings Basins

One of the abandonment alternatives includes flooding the tailings basin. Therefore, in the tailings oxidation model we assume a water cover of some height, h, above the tailings. Exposed tailings, of course, should represent a boundary condition corresponding to zero water height. The first task, however, is estimating the thickness of the active oxidizing Zone, λ (see equation 4), within the tailings bed. It is generally accepted that the oxidizing zone is dependent upon the diffusion of oxygen as well as the reactivity of oxygen within the oxidizing one. Oxygen reactivity, in turn, is inherently related to the rate of sulphate generation as illustrated by the stoichiometry of equation 1. From equation 1, this reactivity can be expressed as:

$$R_{O_2} = \frac{-7.5}{4} R_s = -1.88 R_s \qquad (6)$$

R_{O_2} = oxygen reactivity (moles/m^3 day)

It has been shown that the oxidation process remains constant until the oxygen concentration is essentially exhausted. In this case, the differential equation describing the concentration of oxygen at some depth, z, in the tailings, neglecting infiltration rates, is given by:

$$\frac{\partial (O_2)}{\partial t} = D_T \frac{\partial^2 (O_2)}{\partial z^2} - 1.88 R_s \qquad (7)$$

where; (O_2) = concentration of oxygen (moles/m^3)

D_T = diffusivity of oxygen in the tailings (m^2/day)

Since the oxidation process is expected to proceed for long time periods at a slow rate, the partial differential with respect to time ($\frac{\partial (O_2)}{\partial t}$) would be zero or nearly so. Furthermore, equation (7) is subject to the following boundary conditions at the water-tailings interface:

$$\frac{d (O_2)^2}{d z} = 0 \quad \text{at} \quad z = 0 \qquad (8)$$

The integration of equation 7, together with the boundary conditions yields the following:

$$(O_2)_z = C_o - \frac{1.88 R_s z^2}{2 D_T} \qquad (9)$$

where; C_o =- is the concentration of oxygen in the water phase (moles/m^3)

z = distance within the tailings

It should be noted that equation (9) predicts a critical thickness at which the oxygen concentration within the tailings bed becomes zero. This depth defines the thickness of the active oxidation layer, λ, as follows:

$$\lambda = \sqrt{\frac{2 D_T C_o}{1.88 R_s}} \quad \text{or} \quad \sqrt{\frac{D_T C_o}{R_s}} \qquad (10)$$

It is interesting to note that the areal acid productivity, defined by equation (4) varies with the square root of the reaction rate:

$$\lambda R_{0_2} = 1.88 \sqrt{C_o D_T R_s} \qquad (11)$$

Equation 11 implies, that any decline of the oxidation rate is partially negated by the increase of the thickness of the oxidation zone, hence, the sulphate production on a unit area basis does not change rapidly with time.

The oxygen requirement expressed by equation (11) must be balanced by the oxygen uptake from the atmosphere at the surface of the water cover. At or near stationary conditions, the oxygen uptake over a free, natural surface is given by:

$$k_L (C^* - Co) = 1.88 \lambda R_s + R_o h \qquad (12)$$

where:
- k_L = reaeration coefficient (m/day)
- C^* = dissolved oxygen concentration at saturation with the atmosphere (moles/m^3)
- C_o = concentration of oxygen in the water (moles/m^3)
- Ro = oxygen demand of waters above the tailings (mole/m^3)
- h = height of water above tailings (m)

The left hand side of equation (12) expresses the oxygen uptake, while the right hand side expresses the oxygen demand; the first term by the tailings benthos, the second by the water column.

Several methods have been suggested to evaluate the reaeration coefficient, k_L. The Dobbins - O'Connor relationship has been perhaps the most successful relating the reaeration to morphological data as follows:

$$k_L = \sqrt{\frac{D\ u}{2\ \pi\ h}} \tag{13}$$

D = diffusivity of oxygen in water (m^2/day)
u = mean eddy circulation velocity (m/day)
h = height of water (m)

In most surface waters, the mean eddy velocity (u) ranges between 100 m/day to 800 m/day, while the diffusivity of oxygen is 2.4 x 10^{-4} m^2/day.

To find a solution, the suggested approach is to calculate λ as a function of water depth by a judicious combination of equations 10, 12, and 13 to yield:

$$\lambda^2 + 4.70 \frac{D_T h^{\frac{1}{2}}}{D^{1/2} u^{1/2}} \lambda + 2.51 \frac{D_T R_o h^{3/2}}{D^{1/2} u^{1/2} R_s} - \frac{C^* D_T}{R_s} = 0 \tag{14}$$

According to equation 14, the oxidizing layer reaches a maximum value when no water cover exists. In this case, the thickness of the zone is given by:

$$\lambda = \sqrt{\frac{C^*\ D_T}{R_s}} \tag{15}$$

Equation (15), of course, is identical with equation (10), provided that the oxygen concentration at the surface of the tailings is the equilibrium concentration with air. The increase of water cover, however, effectively reduces the reacting zone.

An added advantage of water cover is the reduction of the maximum temperature, hence, the reaction rate during the summer. The annual thermal budget of northern lakes (Alaska) is 10,000 cal/cm^2 year. Approximately 10% of the budget is conserved in the sediment. The summer temperature rise of the sediments (minimum temperature being 4^{o}C) is inversely related to the depth of water, provided the water exceeds some critical depth:

$$T_s - 4^oC = \frac{1000 \text{ cal/cm}^2 \text{ yr}}{h} \qquad h \geq h \text{ critical} \qquad (16)$$

h = depth of water (cm)
T_s = summer temperature of sediment

In northern lakes, the critical depth is expected to be 1 to 2 m. At depths less than 2 m, the sediment temperature is essentially identical with surface temperatures. In deeper waters, the summer maximum declines. According to equation 16, the summer temperature is expected to be 9^{o}C at 2m, 7.3 ^{o}C at 3 m water cover. This temperature dependence with water cover can be readily incorporated into the respective rate expressions.

Water Quality Behavior

As indicated previously, water quality would be evaluated at certain nodes representing the confluence of tailings discharges, groundwater and surface water flows. Since sulphate is essentially a conservative parameter, the concentration in the combined flow is given by:

$$(SO_4^{2-}) = \frac{\sum_j Q_i \Sigma (SO_4^{2-})_i}{\sum_j Q_i} \qquad (17)$$

Q^i = flow in the j-th month (m^2/sec)
(SO_4^{2-}) = concentration of sulphate (moles/m^3)
j = the j-th flow element

This sulphate concentration, together with other cationic and anionic constituents, defines an ionic equilibrium in the following manner:

$$(H^+) + 2\,(Ca^{2+} + Mg^{2+}) + \Sigma I^+ = C_T \frac{1 + 2K_2/(H+)}{1 + \frac{(H+)}{K_1} + \frac{K2}{(H^+)}} + 2\,(SO_4^{\,2-}) + (OH^-) \qquad (18)$$

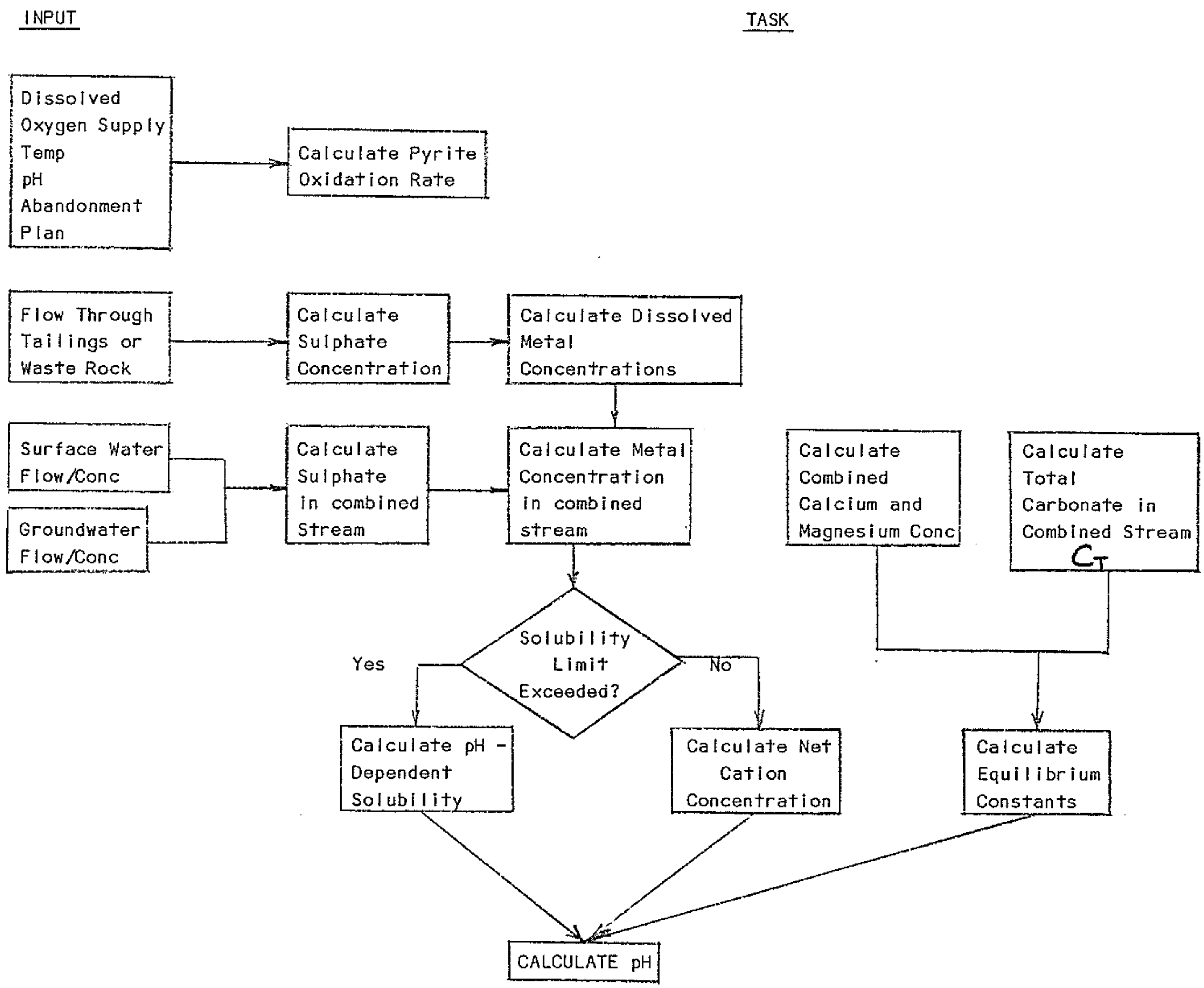
ΣI^+ = sum of cationic constituents (equivalents/m^3)

The equilibrium concepts expressed by equation (18) have been used by Halbert et al., 1980, in simulating water quality behavior in surface waters affected by mining discharges.

The quantity ΣI^+ in the above expression represents the sum of cationic species resulting from tailings discharges. Generally, they correspond to solubility limits under defined conditions of ionic strength. For example, this term would include all soluble, stable ferric zinc and lead ion complexes, their solubility being expressed explicitly as a function of pH. The hydrogen ion concentration, in turn, would be obtained by solving equation (18). The application of equation (18) can be experimentally confirmed by performing titrations of tailings water with natural surface water.

The general computational approach is summarized in Figure 3. Assuming a pH and a water height (ranging from zero), the rate of sulphate oxidation would be computed. The depth of the oxidizing zone can then be derived from equation (14). The combination of the oxidation rate (R_s (pH,T)) and the depth of oxidizing zone (λ) would give the oxidation rate per unit area. If the total tailings area is known, the calculation of total sulphate production can be performed.

FIGURE 3 - SCHEMATIC DIAGRAM OF THE WATER QUALITY MODEL



Other conservative constituents would be established in a manner as indicated in Table 3, while non-conservative constituents are derived from equilibrium relationships (solubility equilibrium, for example). Water quality in the combined stream is inherently a function of an overall ionic equilibrium represented by equation 18. This equation can uniquely define the hydrogen ion activity (pH). The pH, in turn, governs the solubility of the heavy metal cations with regard to their respective stable solid phase. Thus, the effect of tailings effluents on the pH and the soluble metallic constituents of receiving waters would be assessed and the environmentally most desirable abandonment alternatives could be identified.

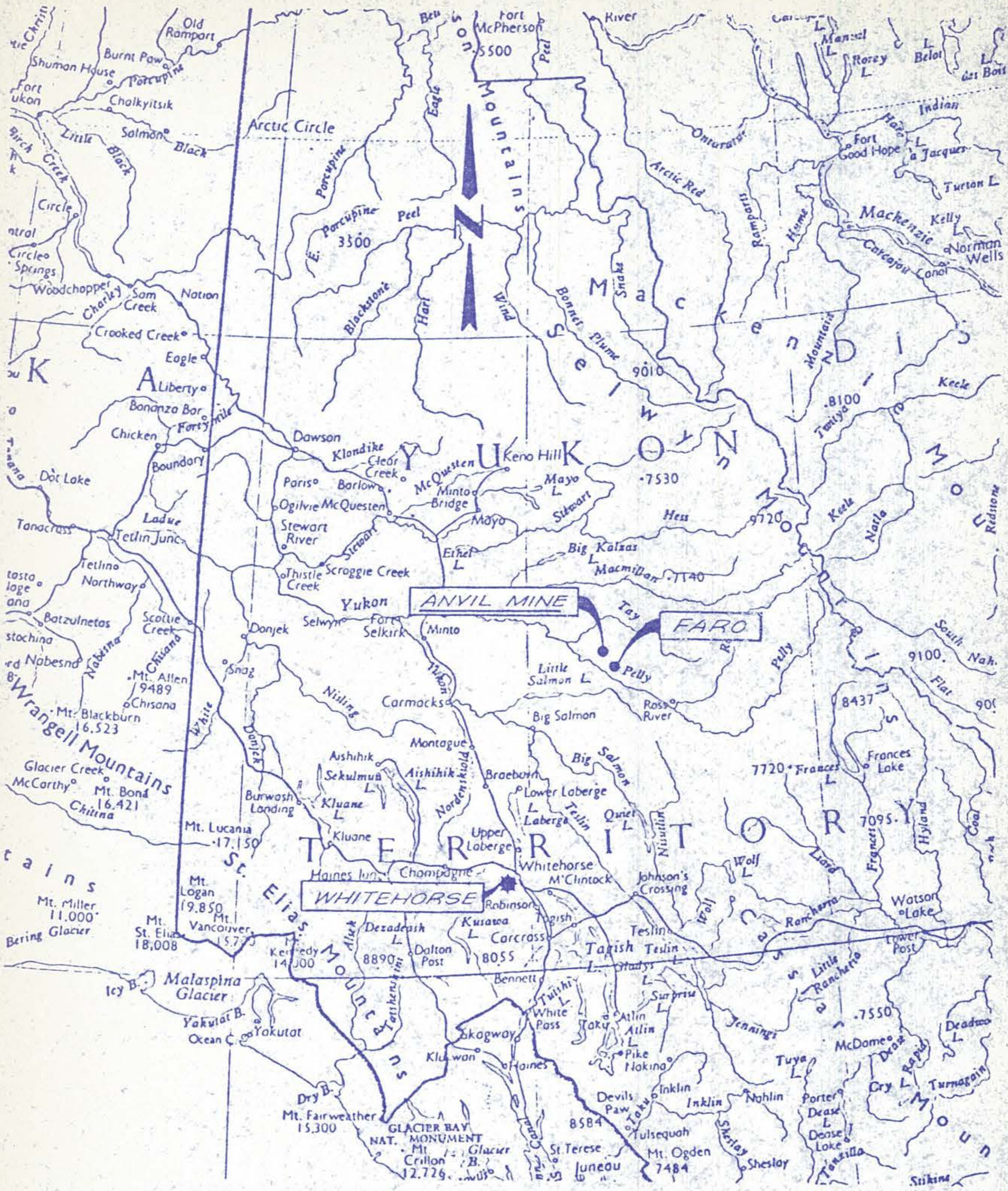
ADDITIONAL REFERENCE

Ricca, V.T. and R. Schultz (1979); "Acid Mine Drainage Modelling of Surface Mining". Mine Drainage International Mine Drainage Symposium, Denver, Colo. p. 651-671.

DRAWINGS

DRAWINGS

A-2758-1	Location Plan
A-2758-2	Physiography of the Canadian Cordilleron
A-2758-3	Regional Geology and Fault Locations
D-2758-4	Rose Creek Bedrock Geology
A-2758-5	Seismic Risk Study - Extreme Value Analysis
B-2758-6	Flood Frequency Distribution
D-2758-7	Cross Section and Profile of Rose Creek Valley
D-2758-8	Mine Layout
A-2758-9	Mill Circuit
A-2758-10	Histogram of pH values, Station R8, Rose Creek (1974-1980)
B-2758-11	Concentration Ranges of Important Constituents, Station R8, Rose Creek
B-2758-12	Scheme 1 - Diversion Canal
B-2758-13	Scheme 2 - Abandonment Reservoir
B-2758-14	Scheme 3 - Tailings in No. 1 Pit
B-2758-15	Schedule of Work



REFERENCE : MAP PROVIDED BY GOLDER BRAWNER ASSOCIATES.

SCALE 1 in. = 88 mi.

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PROJECT: FARO ABANDONMENT

TITLE: LOCATION PLAN

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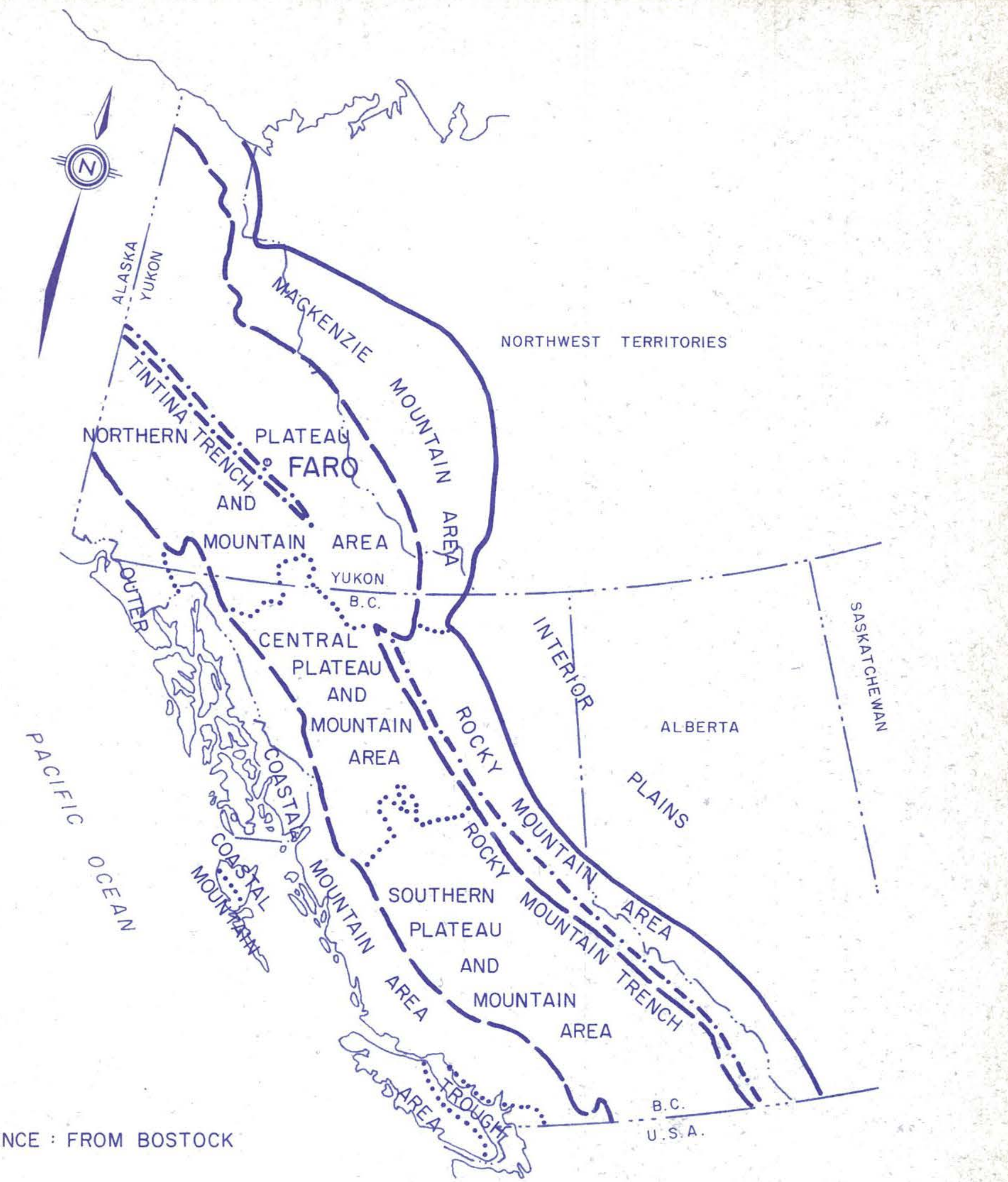

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100 0 100 200 300

Scale : Miles

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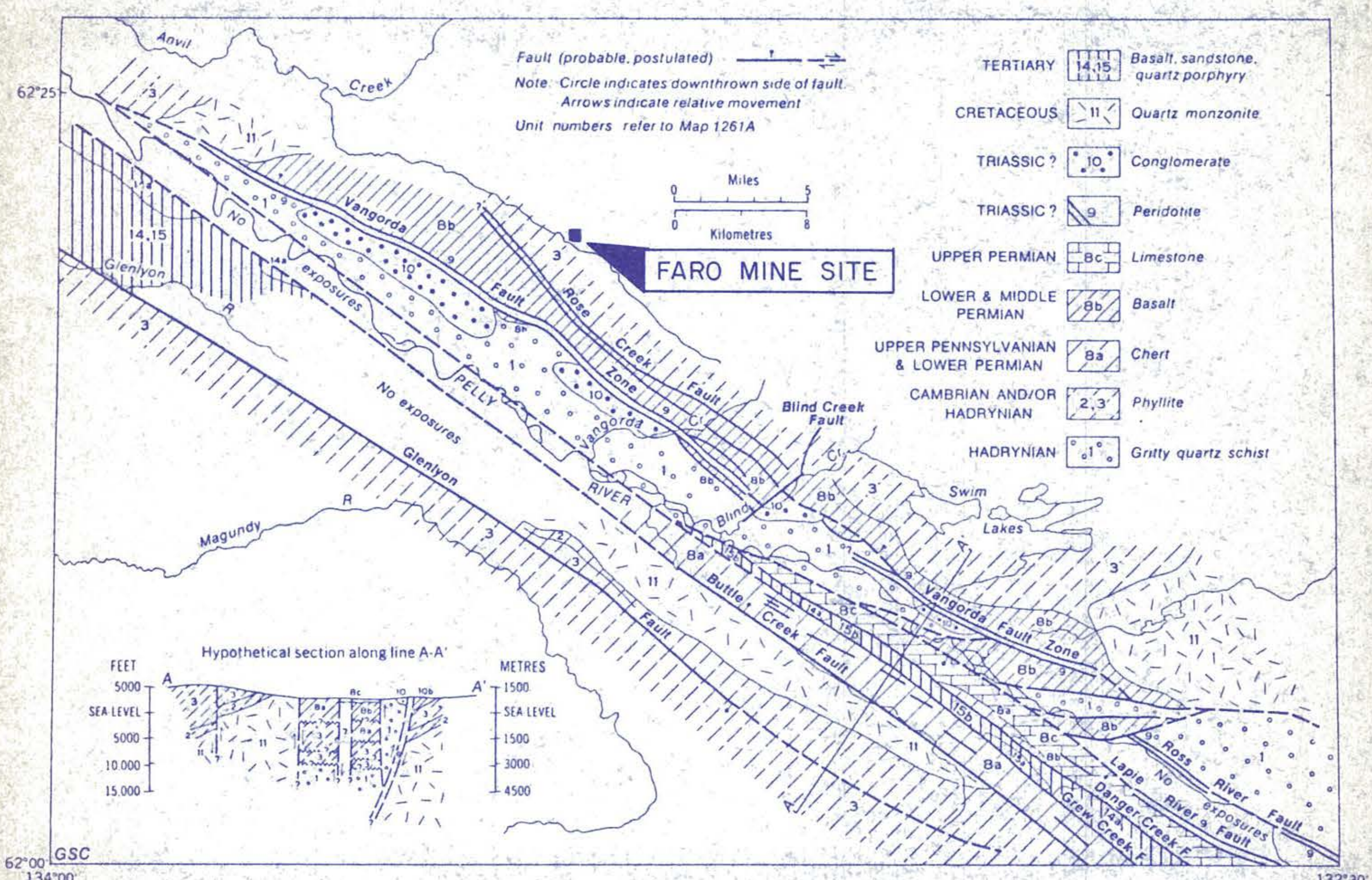

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TITLE	REGIONAL GEOLOGY AND FAULT LOCATIONS

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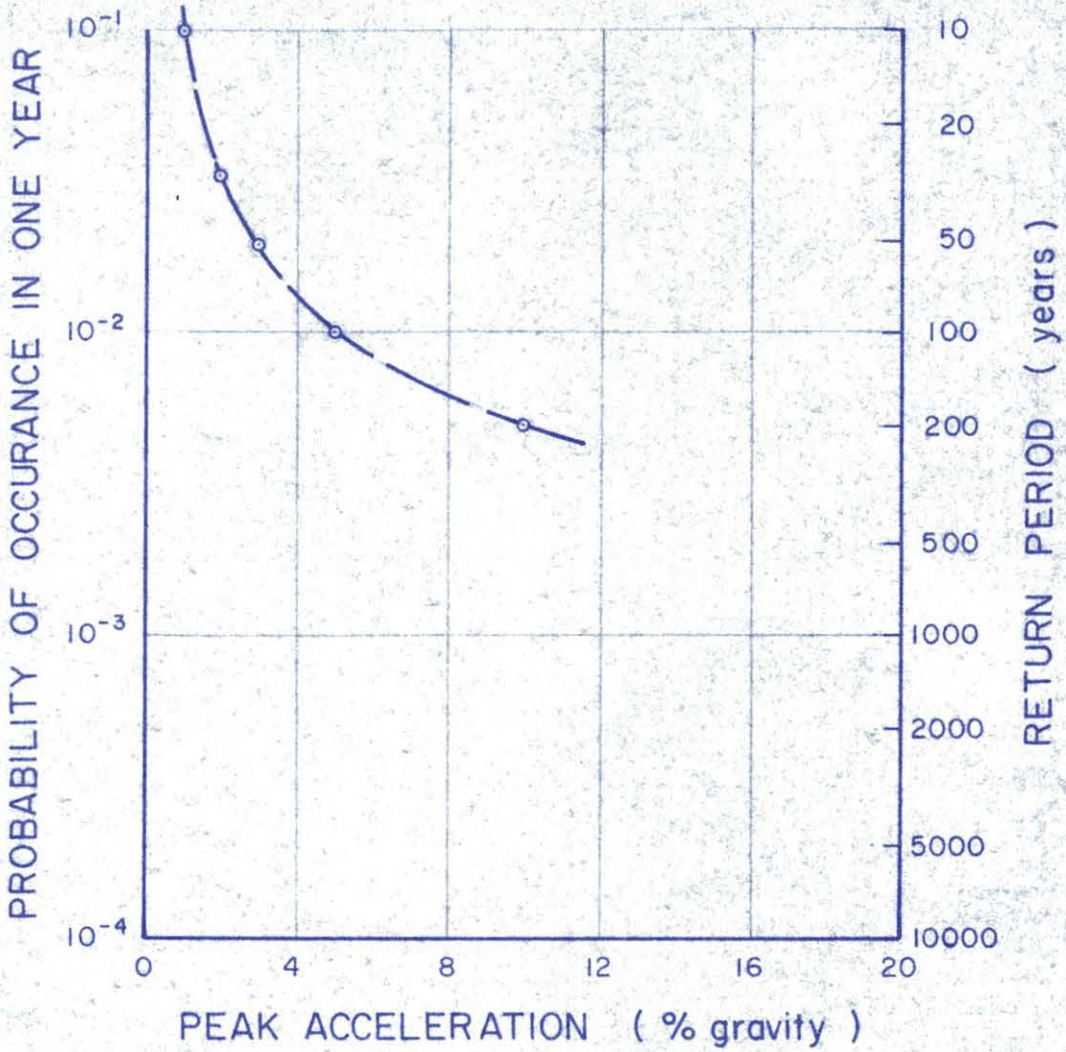

DATA SOURCE : PACIFIC GEOPHYSICAL OBSERVATORY, VICTORIA, B.C.

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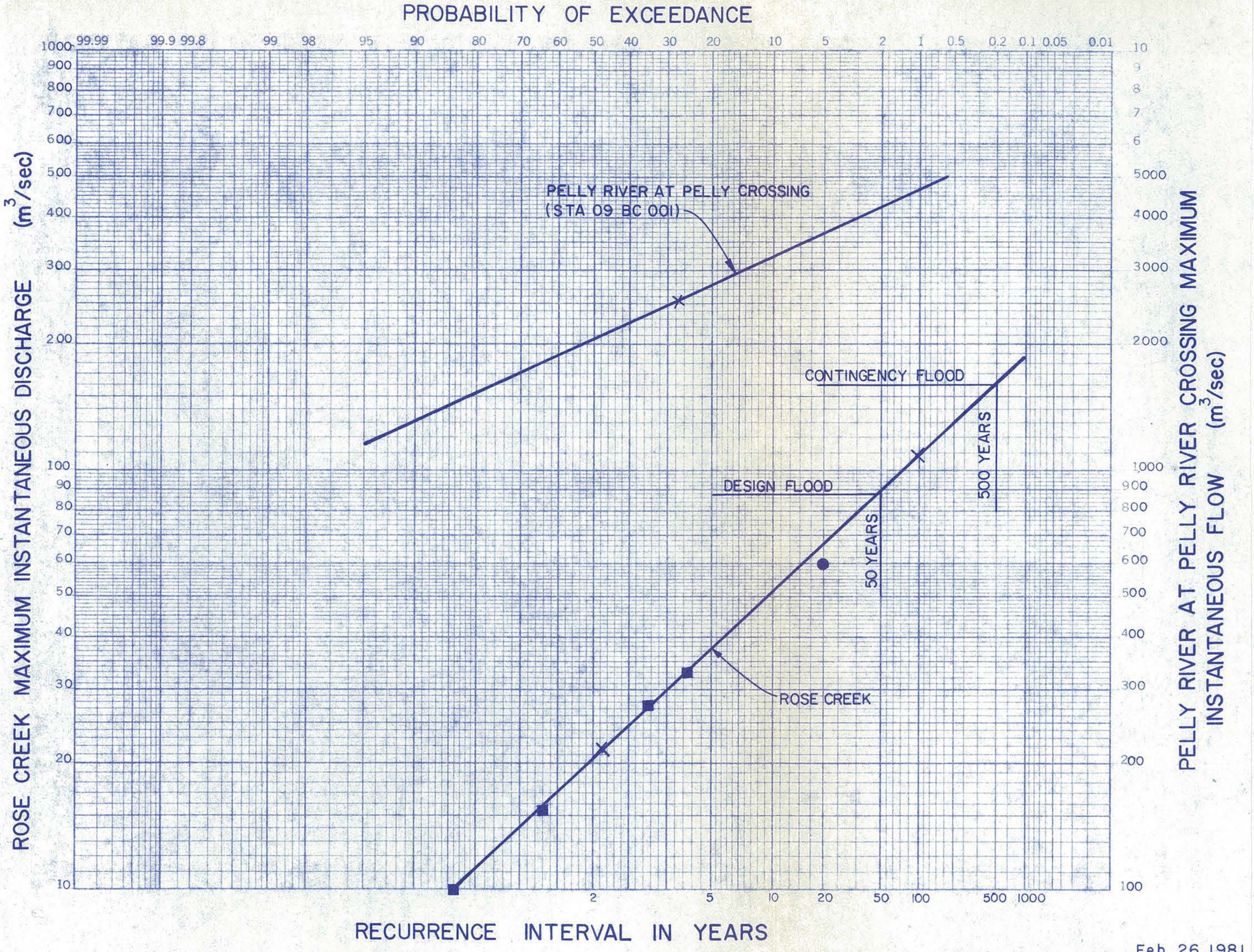

LEGEND

× FREQUENCY CURVE POINTS AS DETERMINED FROM REGIONAL CORRELATIONS

● 20 YEAR FLOOD COMPUTED BY MECO

■ RECORDED MAXIMUM INSTANTANEOUS FLOW

REFERENCE

HYDROLOGIC AND HYDRAULIC DESIGN OF DOWN VALLEY TAILINGS DISPOSAL PROJECT BY HYDROCON ENGINEERING (CONTINENTAL) LTD. MAY 8, 1980.

TO BE READ WITH KLOHN LEONOFF REPORT DATED Feb. 26,1981

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DWG. No.	B-2758-6
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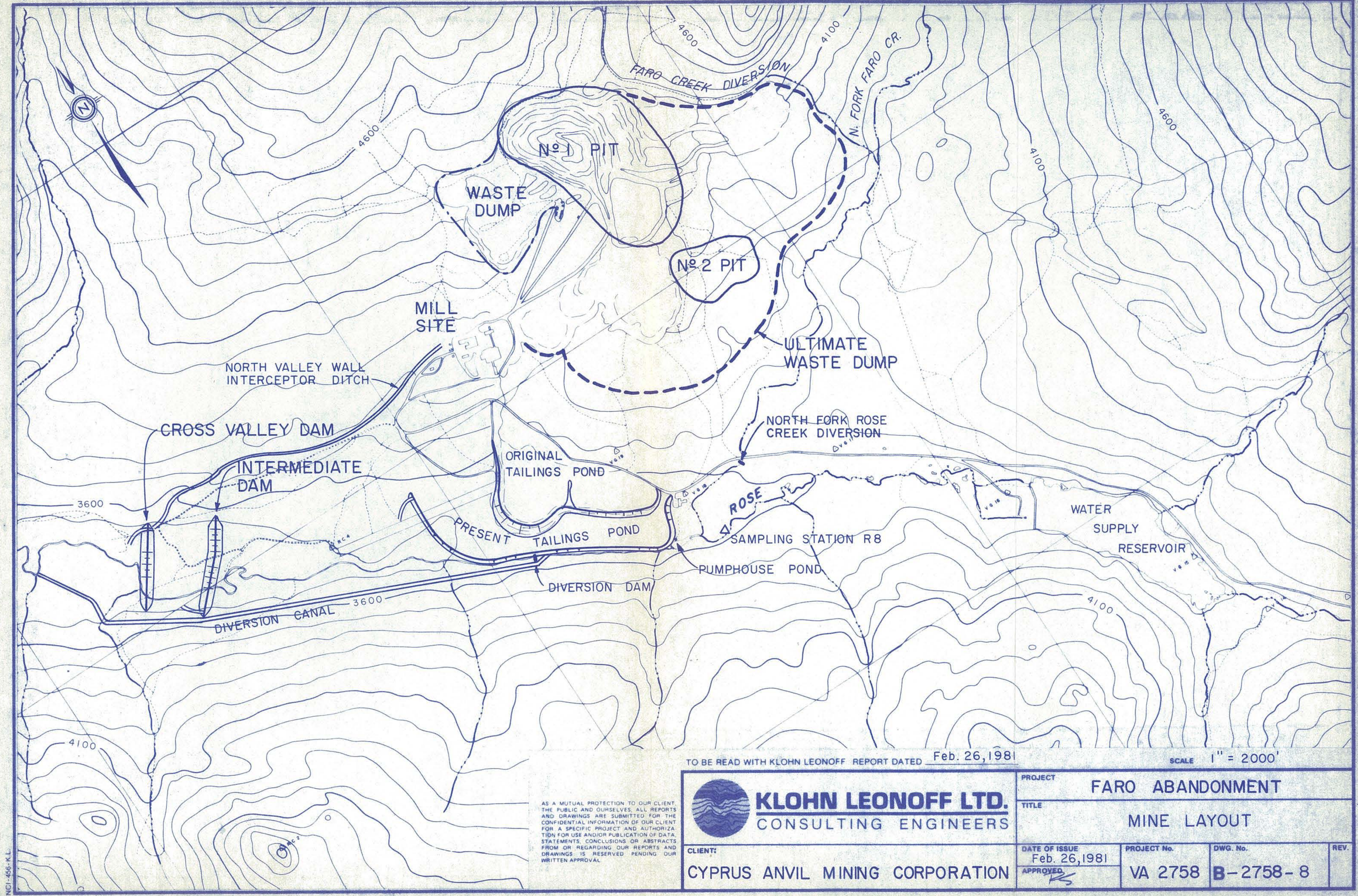

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TITLE: MINE LAYOUT

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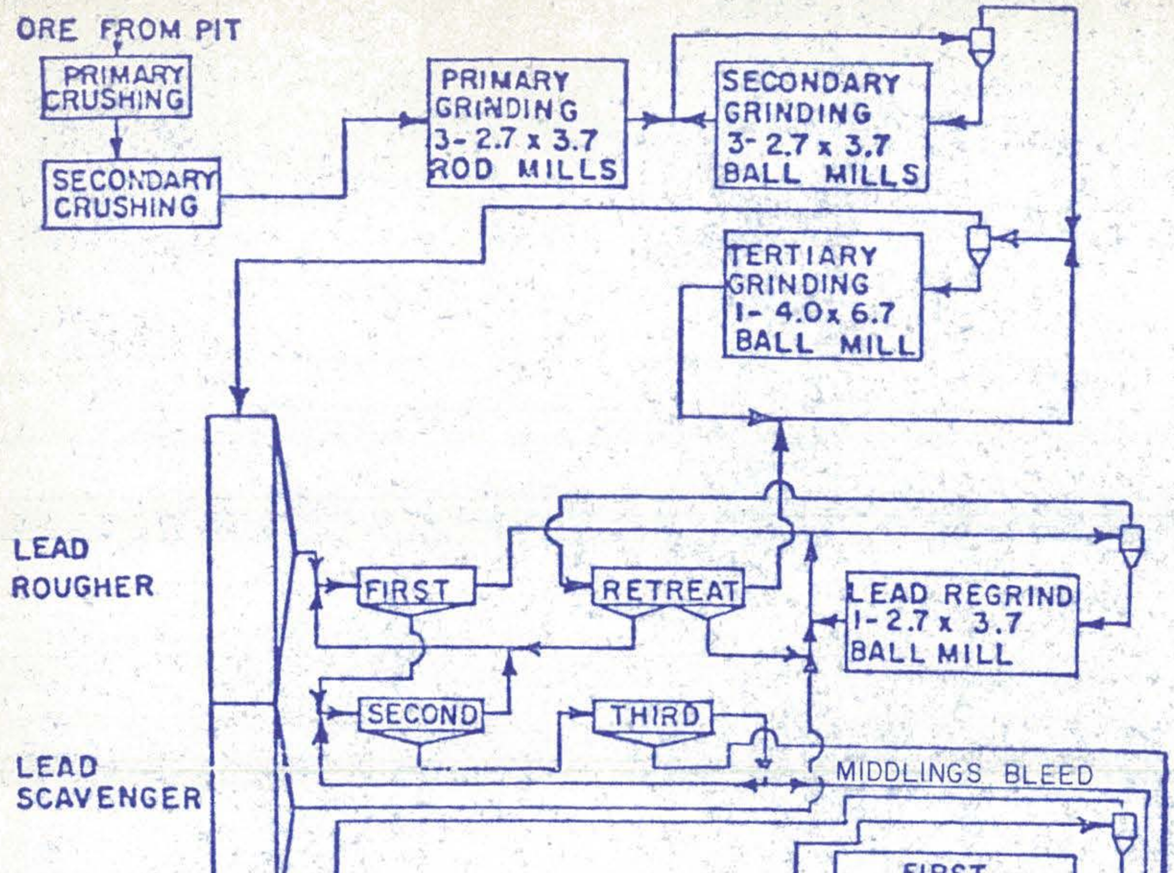

REFERENCE : FROM WALLINGER

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PROJECT: FARO ABANDONMENT

TITLE: MILL CIRCUIT

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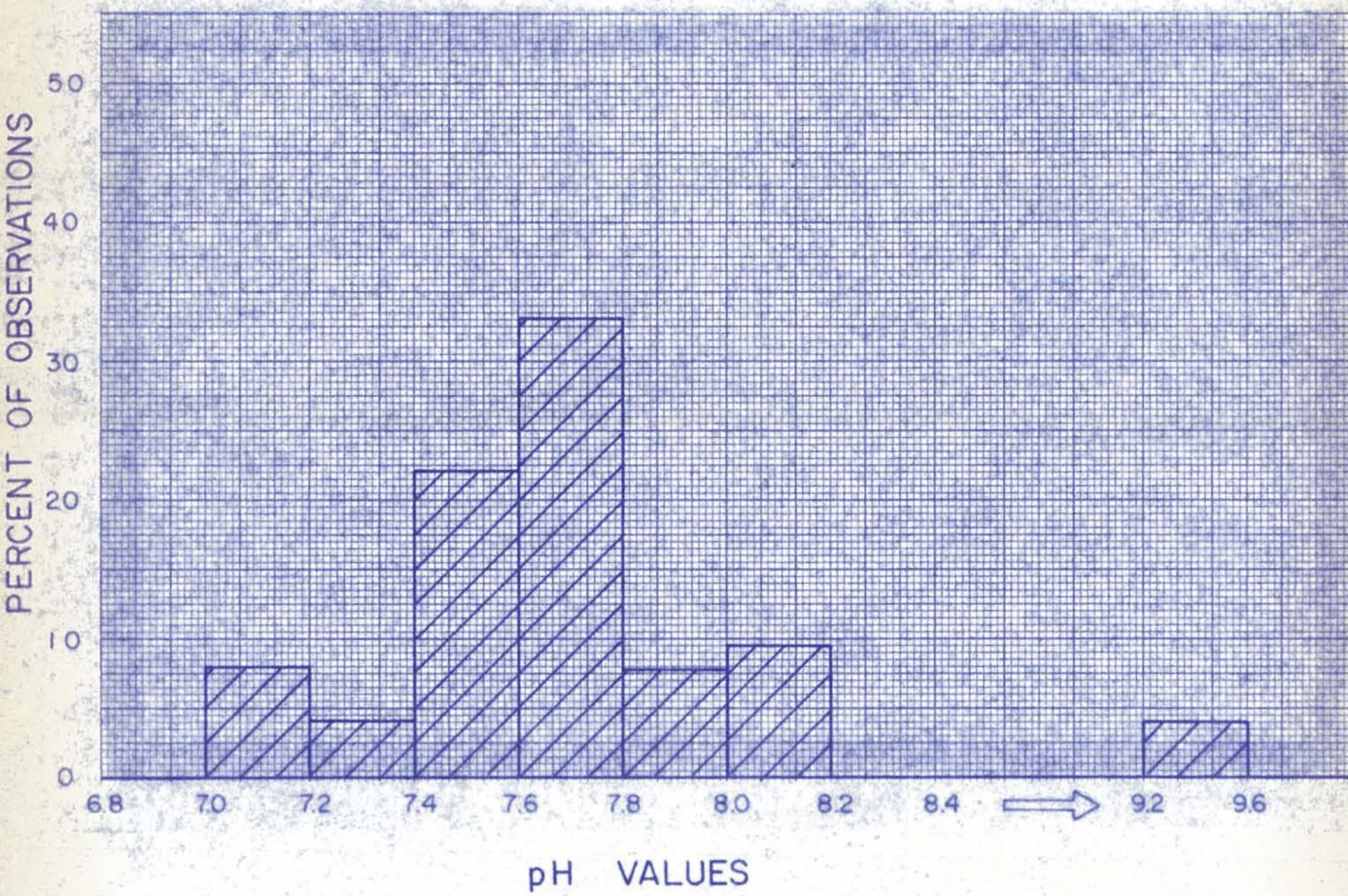

NUMBER OF OBSERVATIONS = 26
MEAN pH = 7.78

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PROJECT: FARO ABANDONMENT

TITLE: HISTOGRAM OF pH VALUES
STATION R8,
ROSE CREEK (1974 - 1980)

CLIENT: CYPRUS ANVIL MINING CORPORATION

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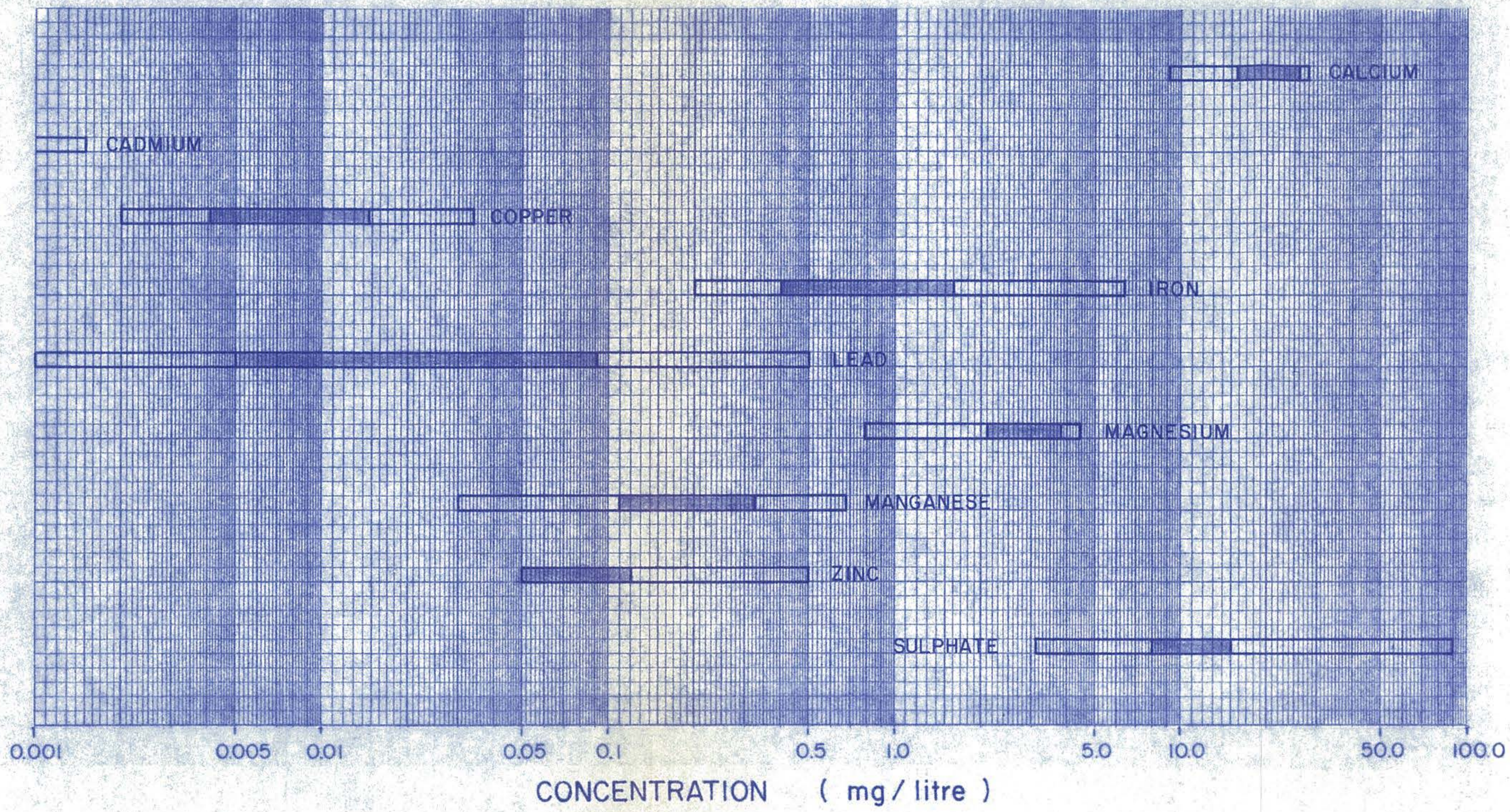

NOTE

SHADED REGION = 95 % CONFIDENCE INTERVAL OF ARITHMETIC MEAN

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PROJECT	FARO ABANDONMENT
TITLE	CONCENTRATION RANGES OF IMPORTANT CONSTITUENTS, STATION R8, ROSE CREEK
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DATE OF ISSUE	Feb. 26, 1981
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PROJECT No.	VA 2758
DWG. No.	B-2758-11
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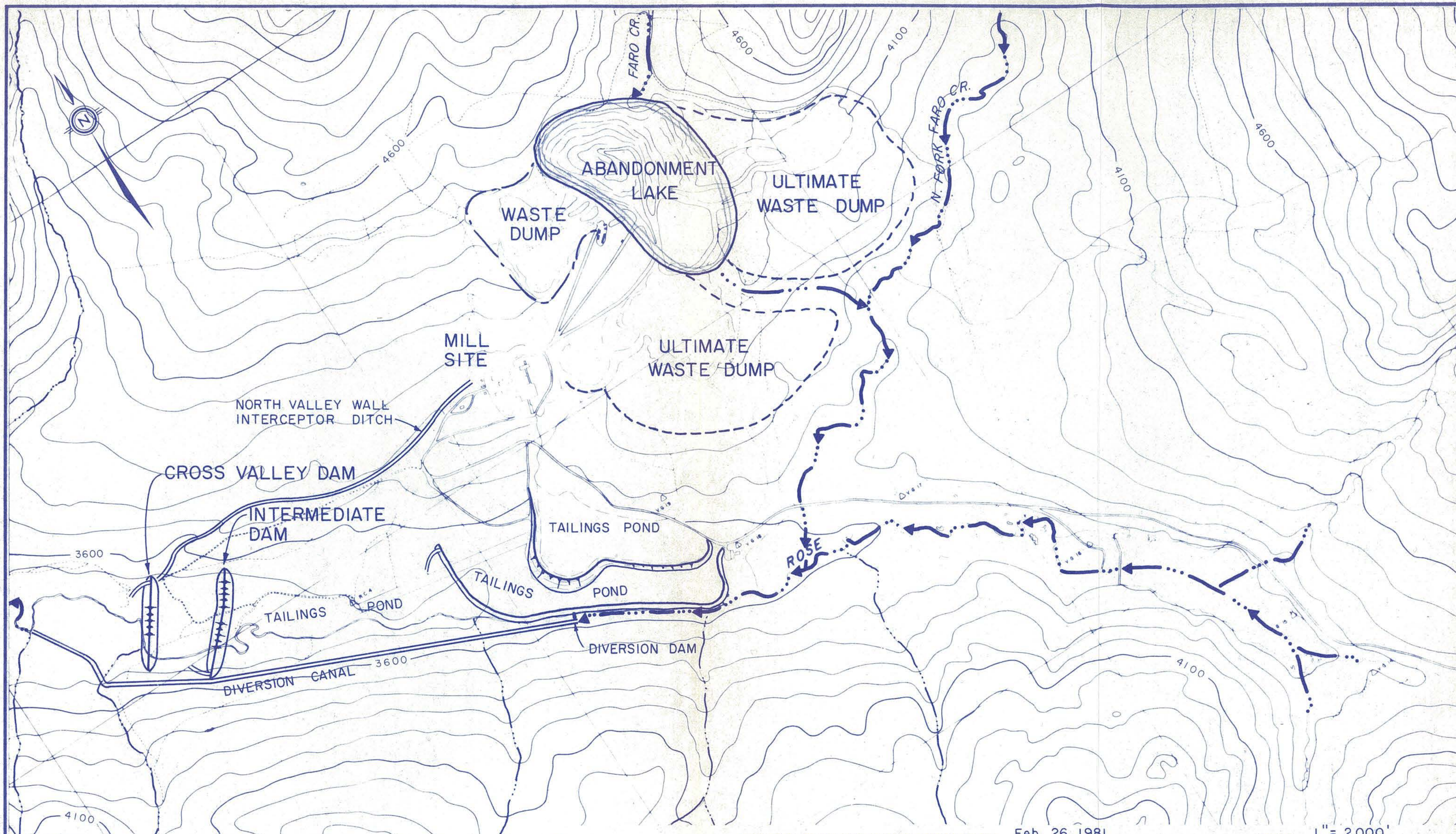

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PROJECT	FARO ABANDONMENT
TITLE	SCHEME I DIVERSION CANAL
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PROJECT No.	VA 2758
DWG. No.	B-2758-12
REV.	

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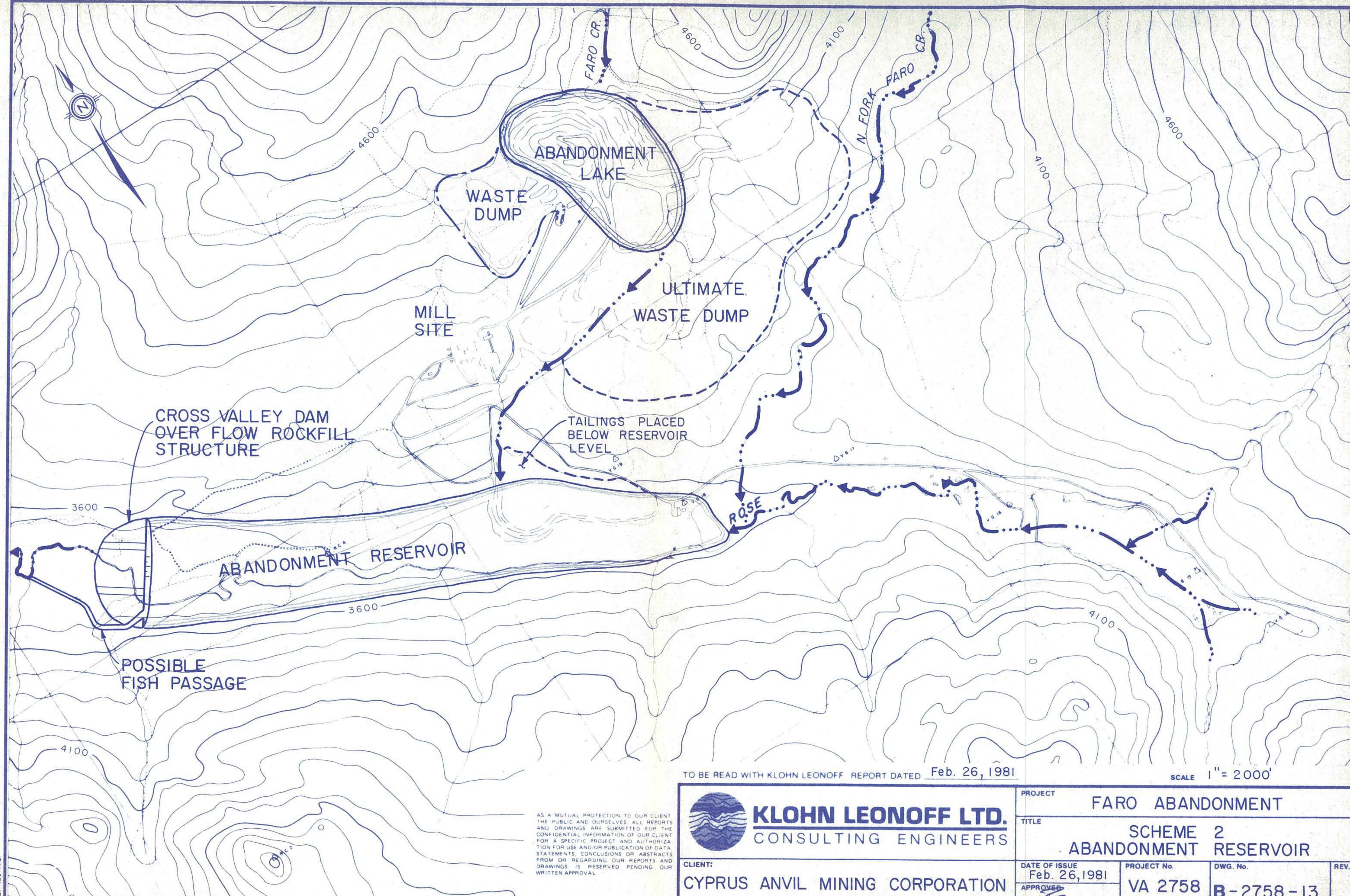

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PROJECT: FARO ABANDONMENT

TITLE: SCHEME 2 ABANDONMENT RESERVOIR

CLIENT: CYPRUS ANVIL MINING CORPORATION

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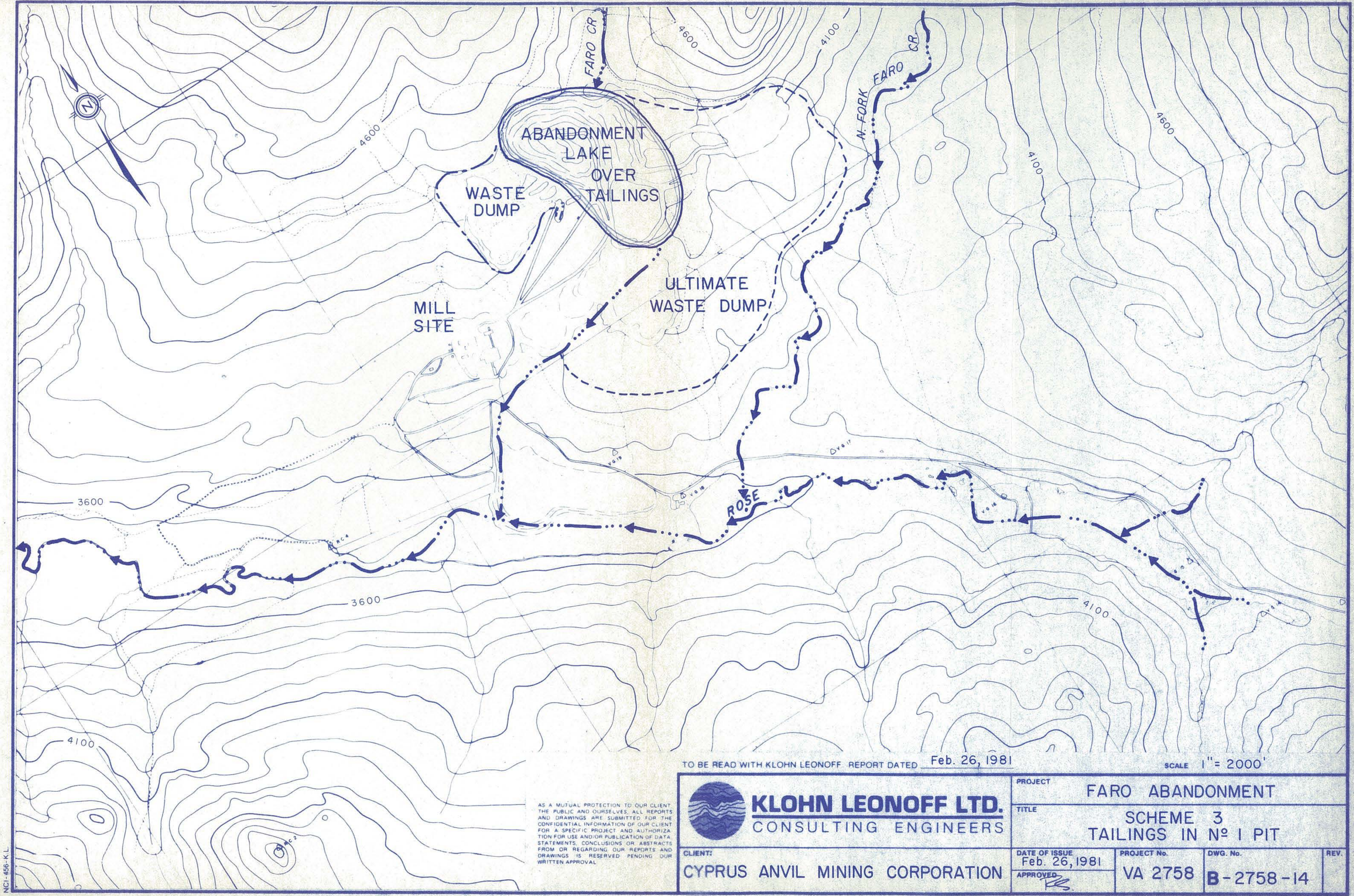

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PROJECT: FARO ABANDONMENT

TITLE: SCHEME 3 TAILINGS IN Nº 1 PIT

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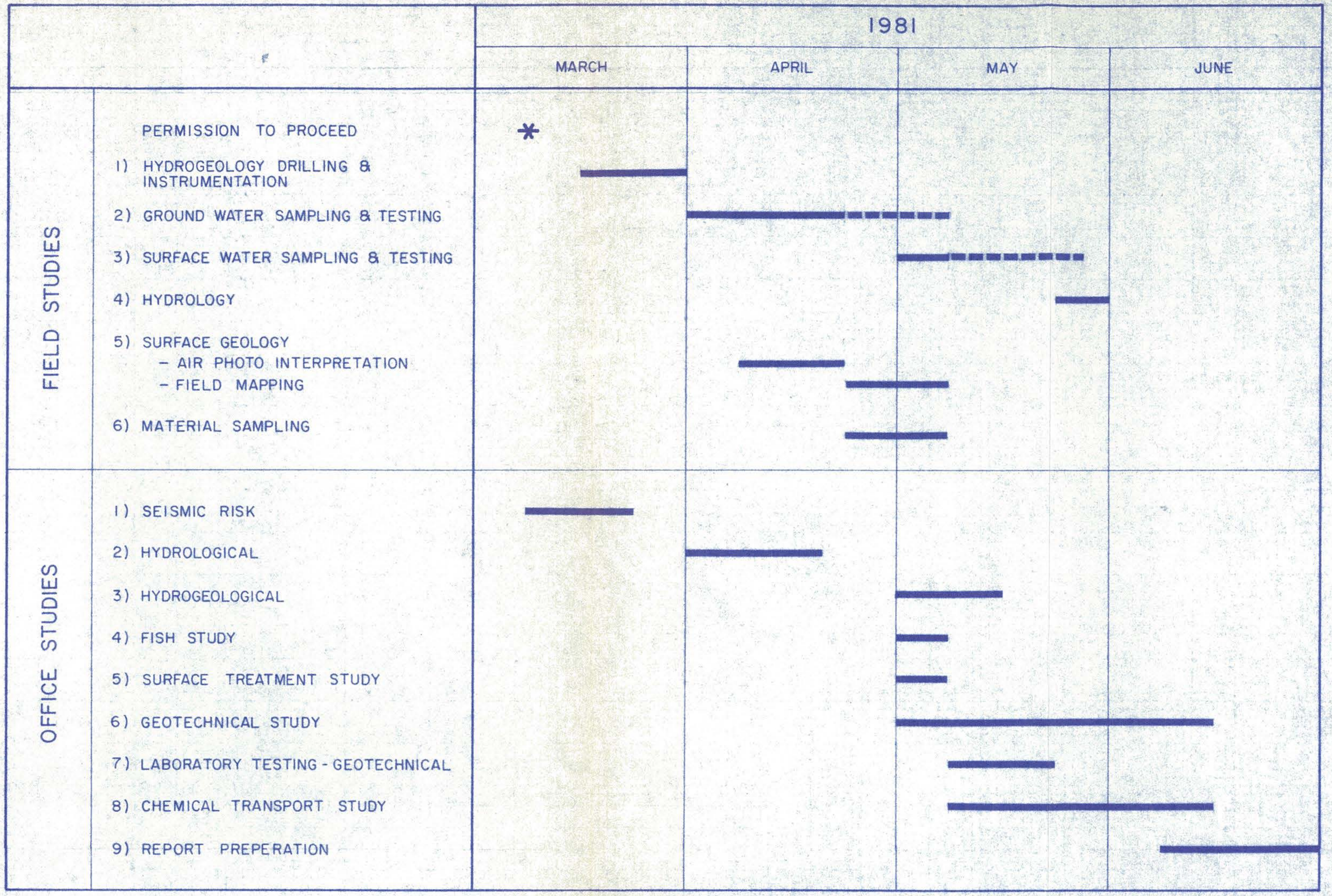

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PROJECT: FARO ABANDONMENT

TITLE: SCHEDULE OF WORK

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