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Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

REPORT NO. 2 TO
CURRAGH RESOURCES CORPORATION
RE
PROPOSED ROCK DRAIN
NORTH FORK OF ROSE CREEK
FARO, YUKON

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TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1

2.0 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS 2

3.0 ROCK DRAINS 4

4.0 ROCK DRAIN - NORTH FORK OF ROSE CREEK 6
  4.1 Creek Crossing 6
  4.2 Rate of Discharge 6
  4.3 Rock Available for Development of the Drain 7
  4.4 Method of Development of Rock Drain 8
  4.5 Capacity of the Rock Drain 9

5.0 STABILITY 11

APPENDIX A - Discussion of Concerns That Have Been Expressed Regarding the Long Term Performance of Rock Drains

LIST OF FIGURES

Figure 1 - Geographical Location of Site

Figure 2 - Plan Showing Proposed Rock Fill Causeway Across North Fork of Rose Creek

Figure 3 - Sections - North Fork Crossing

Figure 4 - Approximate Flood Frequency Curve - North Fork of Rose Creek

Figure 5 - Discharge Curve, North Fork of Rose Creek for the Interval May 10th to June 6th, 1975.

Figure 6 - Approximate Storage Volume on Upstream Side of Rock Fill vs Height Above Stream Bed Level

Figure 7 - Estimated Rate of Discharge Through Rock Drain vs Depth of Pool at Inlet to Drain

Figure 8 - Estimated Pond Surface Level vs Recurrence Interval Discharge

1.0 INTRODUCTION

Curragh Resources Corporation are currently putting the former Cyprus Anvil mining property back into production. The property is a lead zinc deposit located north of Faro, Y.T. The geographical location of the mine is indicated on Figure 1.

As part of the mine planning studies, Curragh are investigating alternative schemes for providing access between the concentrator and the Vangorda ore deposit, which is located east of the present open pit. One of the schemes being investigated would entail development of a rockfill causeway across the north fork of Rose Creek to provide road access to the future Vangorda Pit.

Extension of the rockfill causeway across the North Fork drainage course would interupt the natural creek flows. Golder Associates have been requested to investigate the practicality of conducting the creek flows via a rock drain at the base of the causeway. The rock drain would consist of coarse fragments of waste rock, and the discharge in the north fork of Rose Creek would be conducted from the upstream to the downstream limits of the rockfill via the void spaces between the rock fragments comprising the drain.

The Cyprus Anvil mining records and drawings are in Imperial units, and Curragh Resources continue to use the Imperial system of measurement. Discharge records are in S.I. units. Both Imperial and S.I. units of measurement are used in this report as appropriate.

2.0 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

2.1 Transmission of the surface discharge in the north fork of Rose Creek through a rock drain at the base of the proposed rockfill causeway is considered to be feasible. The rock drain will comprise coarse rock fragments that separate on the face of the advancing causeway fill below the active dumping crest, and come to rest at the toe.

2.2 Calcium-silicate rock (CaSi) is suitable for development of the rock drain. The schistose-type waste rock is not suitable, and must not be incorporated within the rock drain.

The recommended minimum width of the drain is 70 m (230 ft), centered on the north fork drainage course. Approximately 1.5 million tons of calcium-silicate rock will be required to advance the face of the causeway fill the required 70 m to form the rock drain.

2.3 Downward migration of fine rock fragments from the upper region toward the base of the waste rock fill is not expected to result in reduction of the through-flow capacity of the rock drain over time.

2.4 During periods of high discharge, a pool will develop above the inlet end of the rock drain. This pool will serve as a temporary settling pond which will trap both bedload and suspended solids. Solids which remain in suspension and which enter the rock drain can be expected to remain in suspension and to be swept through the drain. Sedimentation within the drain is not expected to result in a reduction of through-flow capacity over time.

2.5 The calcium-silicate rock is hard and durable. Reduction in the through-flow capacity of the rock drain is not expected to occur as a result of weathering and degredation of the calcium-silicate rock fragments over time.

2.6 Glaciation, i.e. the formation of ice within the rock drain during the winter months could occur, and could result in a temporary reduction in the through-flow capacity of the drain. We expect that the discharge of water through the drain during the subsequent summer months will result in melting of seasonal ice, and that ice will not accumulate within the drain from year to year.

Although glaciation may result in a temporary reduction in through-flow capacity, complete blockage of the drain would not occur. Nevertheless, the volume of potential storage on the upstream side of the causeway fill is sufficiently large to store the 100-year discharge event with the water surface remaining some 70 to 80 ft below causeway crest level.

2.7 On abandonment, an emergency overflow spillway will be excavated in the crest of the causeway fill, and a spillway channel will be constructed to conduct emergency flows to the bottom of the drainage course on the downstream side of the causeway fill. The design of the emergency overflow spillway and the discharge channel is to be addressed by Curragh in the final abandonment plan, and is outside the scope of this report.

2.8 With the end-dumping method proposed for development of the rockfill causeway, the upstream and downstream fill slopes will be inclined at the angle of repose for the waste rock. At this inclination, factors of safety with respect to potential downslope mass movement as a result of shear displacements on potential failure surfaces located at shallow depth blow, and subparallel to the face will remain marginally greater than unity.

During periods of high discharge, when the pool develops above the inlet of the rock drain, seepage pressures will act in a direction into the face of the upstream fill slope, and will compensate for the effect of submergence of the toe. Stability analyses indicate that the pool above the inlet to the rock drain will not have a significant effect on the stability of the upstream fill slope, and that slope can be expected to remain stable.

During periods of high discharge, the seepage pressures at the outlet end of the drain will act in a direction out of the downstream fill slope, and will tend to reduce stability. To provide additional toe support, and to guard against ravelling of the downstream slope, a fillet should be constructed along the downstream toe. Along the outlet of the rock drain this fillet should consist of large monosize fragments of CaSi rock. The surface of the fillet should slope at 3:1 (horizontal to vertical) or flatter and its upper surface should intersect the downstream face of the causeway fill at a height 15 m above the toe.

3.0 ROCK DRAINS

Rock drains are currently being employed in the East Kootenay region of British Columbia to conduct surface flows beneath waste rock dumps. The majority of these rock drains consist of coarse, durable rock fragments contained within the mass of waste rock generated in the course of open pit mine operations.

When waste rock is dumped at the crest of a waste pile, significant segregation of particle sizes occurs as the material rolls and slides down the dump face below the crest where dumping takes place. The largest fragments tend to separate from the mass of dumped waste rock, and to roll down the face. In the course of transit down the face of the dump, these large rock fragments attain both kinetic and rotational energy. As a consequence, they come to rest within a zone which extends a moderate distance beyond the line of intersection of the plane representing the face of the dump and the topographic surface on which the dump is constructed. As a result, a zone of coarse, segregated rock extends beyond the dump toe.

The dump is advanced by the process of gradual accretion of waste rock on the face below the active dumping crest. With progressive advance of the dump face, the zone of coarse segregated rock at the dump toe becomes covered, and constitutes a coarse, pervious drainage blanket over the surface of contact between the base of the dump and its foundation.

If the dump is advanced across a drainage coarse, the bottom of the drainage coarse tends to collect the coarse rock fragments that have separated on the dump face, rolled to the dump toe, and have come to rest within the topographic depression of the drainage course. This zone of coarse, segregated rock within the drainage course can serve as a French drain to conduct surface flows from the upstream to the downstream side of a waste rock dump.

Inspection on the face of active waste rock dumps, as well as grain size analyses of dumps modelled in the laboratory, show that there is a gradual reduction in the size of the rock fragments proceeding from the crest toward the toe of the dump. This reduction in particle sizes, from the top toward the base of the dump serves as a well graded filter which precludes downward migration of fine particles from the upper regions of the dump toward the zone of coarse, segregated rock at the base of the dump. This conclusion is confirmed by the results of grain size analyses for material within a model dump as presented in Appendix A. Consequently, the through-flow capacity of the zone of coarse, segregated rock remains unimpaired as a result of reduction in the size of the void spaces due to accumulation of fine particles originating from the mass of waste rock located above the drain.

4.0 ROCK DRAIN - NORTH FORK OF ROSE CREEK

4.1 Creek Crossing

A plan showing the proposed extension of the rockfill causeway across the north fork of Rose Creek is shown on Figure 2. The causeway would have a crest width of 100 ft at elevation 3,900 ft. The maximum thickness of the rockfill above the bottom of the north fork drainage channel would be approximately 230 ft (70 m). For the proposed rockfill causeway illustrated on Figure 2, the total length of the rock drain between the upstream and downstream toes would be approximately 720 ft. A longitudinal section and two cross sections through the proposed causeway are shown on Figure 3.

4.2 Rate of Discharge

The size of the catchment area of the north fork of Rose Creek above the proposed rock drain is approximately 119 sq. km. For this drainage area, the approximate flood frequency curve in the form of peak discharge versus recurrence interval is shown on Figure 4. The 100-year recurrence interval peak discharge is estimated to be approximately 70 cumecs, and the 200-year peak discharge is estimated to be approximately 87 cumecs.

A plot of discharge versus time for the north fork of Rose Creek as based on field observations during May and June, 1975 is shown on Figure 5. This figure illustrates that in 1975, the time interval during which high discharge rates were recorded was relatively short. During the interval May 24th to June 6th, 1975, the total volume of discharge in the north fork of Rose Creek was approximately 6.4×10^4 m^3. The shape of the discharge curve during the short period of high discharge which in 1975 occurred during the interval June 2nd to June 6th is considered to be characteristic of the shape of the peak discharge curves for this catchment.

4.3 Rock Available for Development of the Drain

The waste rock generated at the existing open pit consists of schistose-type rock, and of calcium silicate (CaSi) rock. The CaSi rock is suitable for development of a rock drain within the bottom of the north fork drainage channel, while the schistose type rock is not suitable.

Two photographs illustrating typical fragments of the CaSi-type rock that have separated on the face of the dump, and have come to rest at the dump toe are illustrated on Photographs 2 and 3. The mean size of these rock fragments is estimated to be approximately 0.5 m.

If the rock drain is developed by end dumping the CaSi rock at causeway crest level, some fragmentation will occur when the rocks that separate from a dumped load have gained significant kinetic energy in the course of transit down the dump face and impact on rock fragments that have already come to rest at the dump toe. Also, some fracturing and size reduction can be expected to occur as a result of the high point-to-point contact stresses that will develop in sustaining loads imposed by weight of the rockfill above the drain. Based on these considerations the effective size of the CaSi rock fragments comprising the drain has been taken as 0.3 m for purposes of the design analyses. This is considered to be a conservative assumption.

4.4 Method of Development of Rock Drain

The proposed rockfill causeway will be constructed in the form of a narrow waste rockfill that would be advanced across the valley of the north fork of Rose Creek. The causeway would be advanced outward from the right valley wall to a position such that the toe of the fill is located 35 m (115 ft) from the centreline of the drainage course. This initial segment of the causeway may consist of schistose-type waste rock.

When the toe of the fill has been advanced to a position 35 m from the center of the drainage course, calcium-silicate rock only should be consigned to the causeway until the face of the causeway has been advanced an incremental distance of 70 m (230 ft), i.e. until the toe of the causeway fill has been advanced to a position 35 m from the axis of the drainage course on the opposite side. The remainder of the causeway fill may consist of schistose-type rock. A longitudinal section, showing the segment of the causeway fill that must consist of CaSi rock, and segments that may consist of schistose-type rock is shown on Figure 3.

Using the procedure described in the preceding paragraph, the rock drain with a width of 70 m will comprise coarse fragments of CaSi rock that separate on the face of the advancing causeway fill, and roll to the toe. Inspection at the toes of waste rock dumps shows a significant reduction in the size of the rock fragments proceeding from the dump toe to modest height above the toe. This reduction in rock size is evident in Photograph No. 2. As a result of this reduction in the size of the rock fragments at modest height above the toe, the vertical dimension of the North Fork rock drain has been assumed to be 3.6 m, and the gross cross-section of the drain is assumed to be 250 sq. m. This assumed cross-sectional area is considered to be conservative, since the smaller CaSi rock fragments located above the assumed upper boundary of the rock drain will also be capable of transmitting modest flows and will contribute to the capacity of the drain.

4.5 Capacity of the Rock Drain

The capacity of a rock drain is governed by the following factors.

i The mean size of the rock fragments comprising the drain

ii The void ratio, i.e. the ratio of the percentage of the gross volume of the drain occupied by void spaces between the rock fragments, to the percentage of the volume that is occupied by solid material

iii The surface roughness of the constituent rock fragments within the drain

iv The hydraulic gradient

v The gross cross-sectional area of the drain

Factors i, ii, and iii above remain essentially fixed. Fluctuations in the rate of discharge through the rock drain will be governed primarily by the hydraulic gradient, and to a lesser degree by the area of the wetted cross section.

The gradient along the north fork drainage channel is approximately 1.3%. Hydraulic gradients within the drain greater than 1.3% will depend on development of a pool on the upstream side of the rockfill causeway, and attendant increases in piezometric level above the upstream end of the drain. A plot showing the estimated rate of discharge through the drain versus the depth of the pool above the inlet end of the drain is shown on Figure 7. The available storage volume on the upstream side of the causeway versus the depth of the pool above the toe of the fill at the inlet end of the drain is shown on Figure 6.

Flood routing calculations were carried out by Ker Priestman Associates Ltd to obtain an estimate of the height to which the pool surface could be expected to rise for various return interval discharge events. These flood routing calculations are based on the discharge capacity of the rock drain as shown on Figure 7, the storage volume curve in accordance with Figure 6, peak stream discharge in accordance with Figure 4, and an assumed rise and decay of stream discharge with respect to time in accordance with the shape of the observed discharge curves shown on Figure 5. The results of the flood routing analyses are presented in graphical form on Figure 8. The analyses indicate that for the mean annual discharge event, the pool at the inlet end of the rock drain would reach a maximum depth of approximately 11 m. For the 100-year discharge event, the anticipated maximum depth of the pool is 40 m, some 30 m (100 ft) below the crest of the causeway fill.

Various scenarios have been postulated by others suggesting that the through-flow capacity of a rock drain might diminish with time. These scenarios, which we believe not to be valid, are discussed in Appendix A.

Glaciation within the rock drain during the winter months is a scenario that has not been raised by others, but which is a factor that must be considered for the north fork rock drain. As discussed in Appendix A, glaciation could result in a temporary reduction in the through-flow capacity of the drain. However, we do not expect that ice would accumulate from season to season, or that glaciation could result in blockage of the drain during any single season. Nevertheless, we have examined an unlikely scenario which assumes that the drain becomes blocked by ice during the winter preceding the 100-year discharge event. As indicated on Figure 6, the 100-year discharge event could be retained within a pool having a surface level approximately 46 m above the toe of the fill at the inlet end of the drain. This level is approximately 25 m (82 ft) below the elevation of the crest of the proposed causeway.

5.0 STABILITY

As indicated previously, the proposed causeway across the north fork of Rose Creek would be developed by end dumping waste rock from the crest at elevation 3900 ft. With this method of development, the advancing face, as well as the side slopes of the causeway fill will remain at the angle of repose for the waste rock. At any time when a slope comprising granular materials is at the angle of repose, the factor of safety with respect to potential downslope mass movement as a result of shear displacements on potential failure surfaces located approximately parallel to, and at shallow depth below the face is always only marginally greater than unity. This is the stability condition that prevails at any rockfill that is developed by end dumping from the crest. Factors of safety with respect to potential failure as a result of shear displacements along the dump/foundation surface of contact are governed to a significant degree by the inclination of the foundation. In the case of the proposed North Fork causeway fill, the foundation is essentially level in a direction parallel to the fall-line on the sides of the causeway, and factors of safety involving this potential failure mode are adequate.

In some cases, the calculated factors of safety of the upstream slopes of earth dams are lower for intermediate reservoir levels, than for the case of the water surface at the toe, or for full reservoir conditions. With this in mind, stability analyses were carried out to check the stability of the upstream face of the causeway fill for the assumed pool surface at levels intermediate between the toe of the fill and anticipated maximum pond surface level corresponding to the 100-year flood event.

For the conditions of ponding above the inlet to the rock drain, the direction of the seepage presures will be into the slope, and these seepage pressures serve to improve stability, and to compensate for the reduction in shearing resistance attendent with submergence of the toe region of the slope. The results of the stability analyses indicate that the factors of safety of the slope on the upstream side of the causeway fill will be virturally unaffected by the pool above the inlet to the rock drain.

At the toe of the fill on the downstream side of the causeway where the water will issue form the rock drain, the seepage pressures act in a direction out of the slope, and will have the effect of reducing stability in this region. Since the slope will have a factor of safety only marginally greater than unity for the condition of zero discharge from the rock drain, any reduction in the factor of safey can be expected to result in movement within the toe region of the fill, and in sloughing on the face, with the potential for deposition of slide debris over the outlet of the rock drain. Such development could be expected to impede discharge from the drain, and to exacerbate stability conditions at the toe.

To guard against this eventually, we recommend that additional toe support be provided along the downstream toe of the causeway fill. This toe support would consist of a fillet consisting of CaSi rocks of the largest practicable size. The objective is to provide a zone which has the maximum practicable conductivity, and which will remain stable when subjected to the discharge conditions at the outlet end of the rock drain. The surface of the fillet should slope not steeper than 3:1 (horizontal to vertical), and it should intersect the downstream slope of the causeway fill at a level 15 m above the base.

Part of the fillet along the downstream toe will be formed in the course of construction of the causeway. This segment of the fillet will consist of large rock fragments that attain considerable kinetic and rotational energy during transit down the face, and come to rest beyond the line of intersection of the plane representing the downstream side slope of the causeway fill with the foundation. The supplementary materials required to complete the fillet should consist of large monosize fragments of CaSi rock approximately 1 m or larger in size, and devoid of smaller size rock. We expect that these large rocks could be garnered from the toe regions of existing or future dumps. It will be necessary to develop a suitable method for recovering these rocks. Past experience has shown that front end loaders are generally not suitable, since it is impracticable to scoop up the large rocks while excluding smaller rocks and other materials.

Yours very truly,

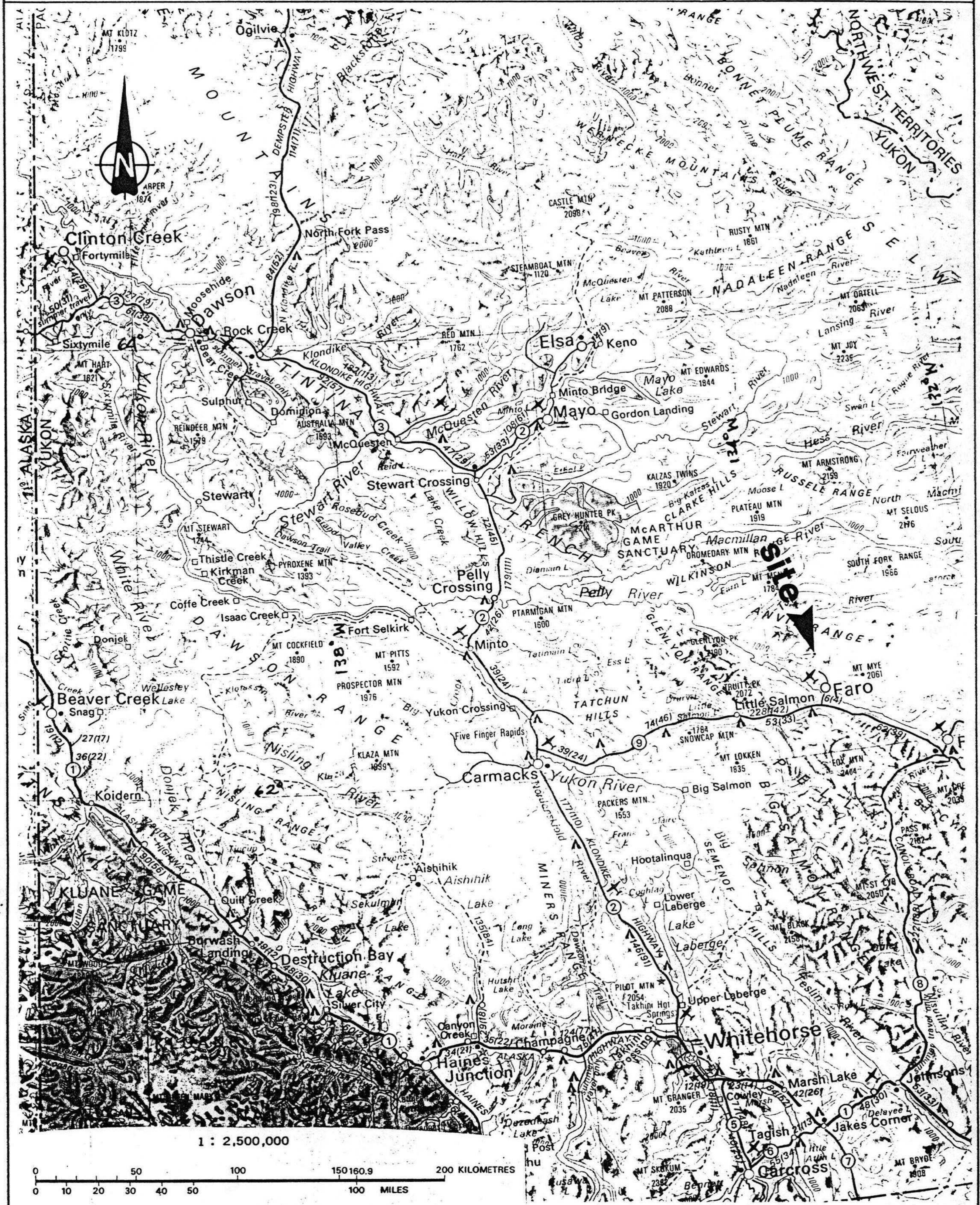
GOLDER ASSOCIATES

D.B. Campbell, P. Eng.

DBC/gg
862-1093

GEOGRAPHICAL LOCATION OF SITE

Figure **1**



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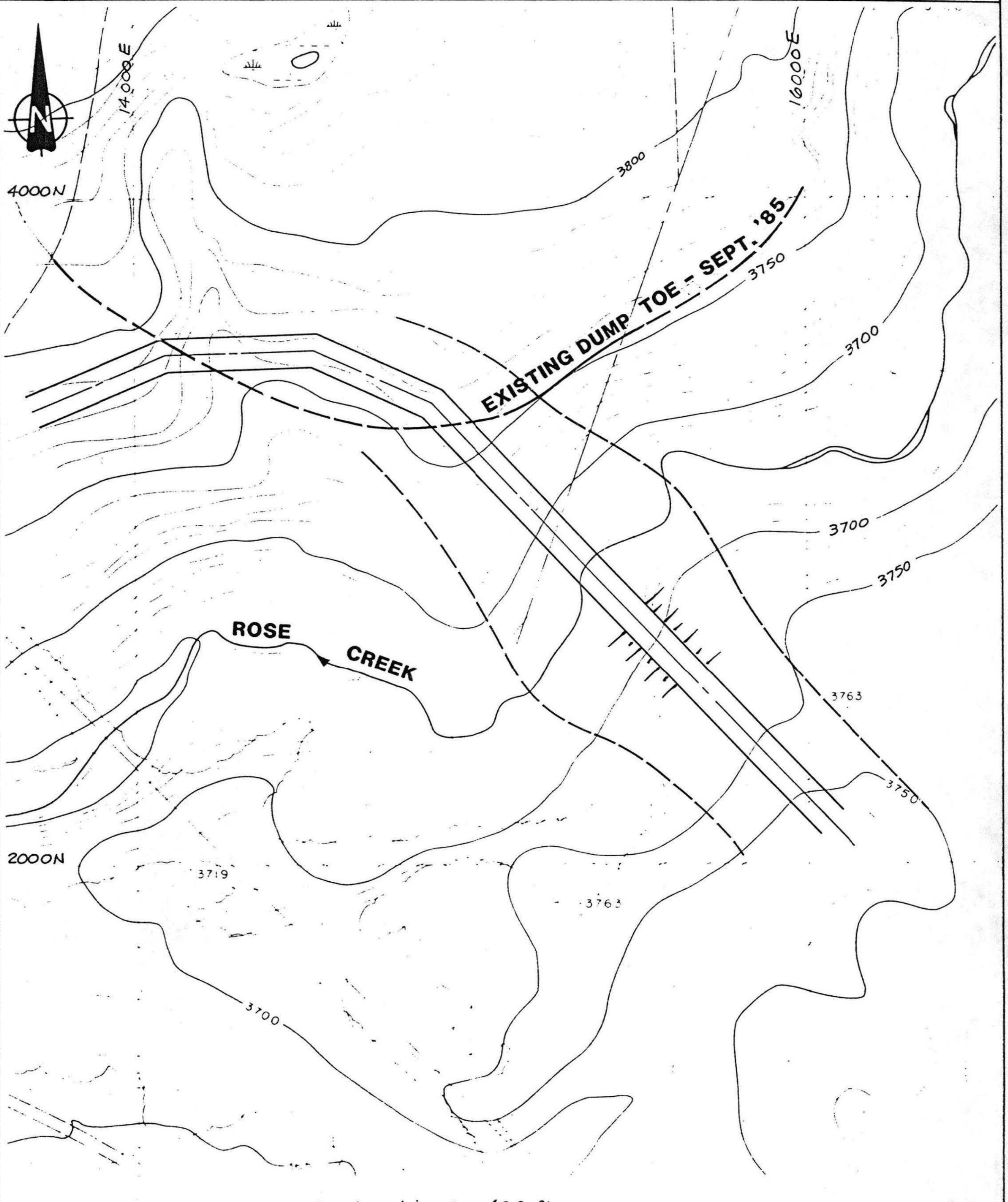
PLAN SHOWING PROPOSED ROCK FILL CAUSEWAY
ACROSS NORTH FORK OF ROSE CREEK

Figure **2**



Scale 1 in. to 400 ft.

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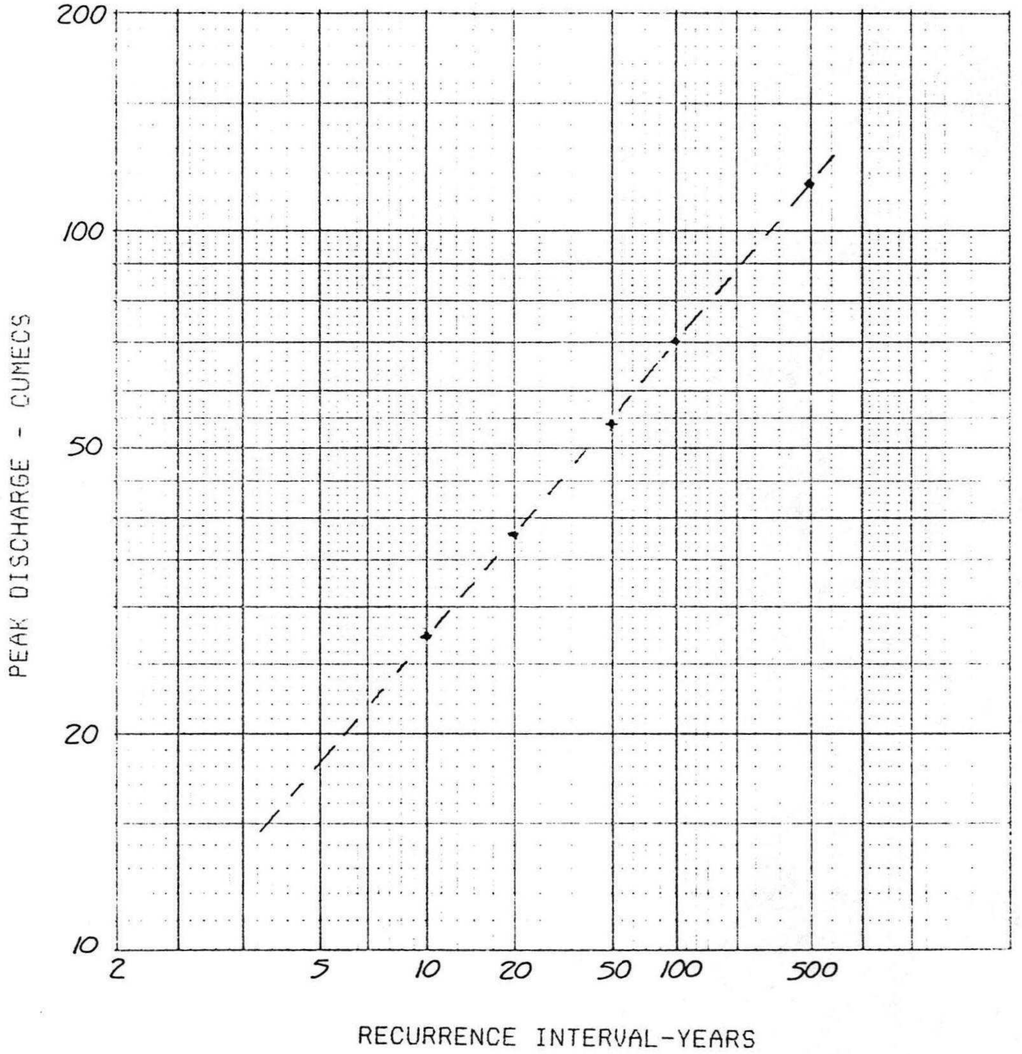
APPROXIMATE FLOOD FREQUENCY CURVE-
NORTH FORK OF ROSE CREEK.

Figure **4**



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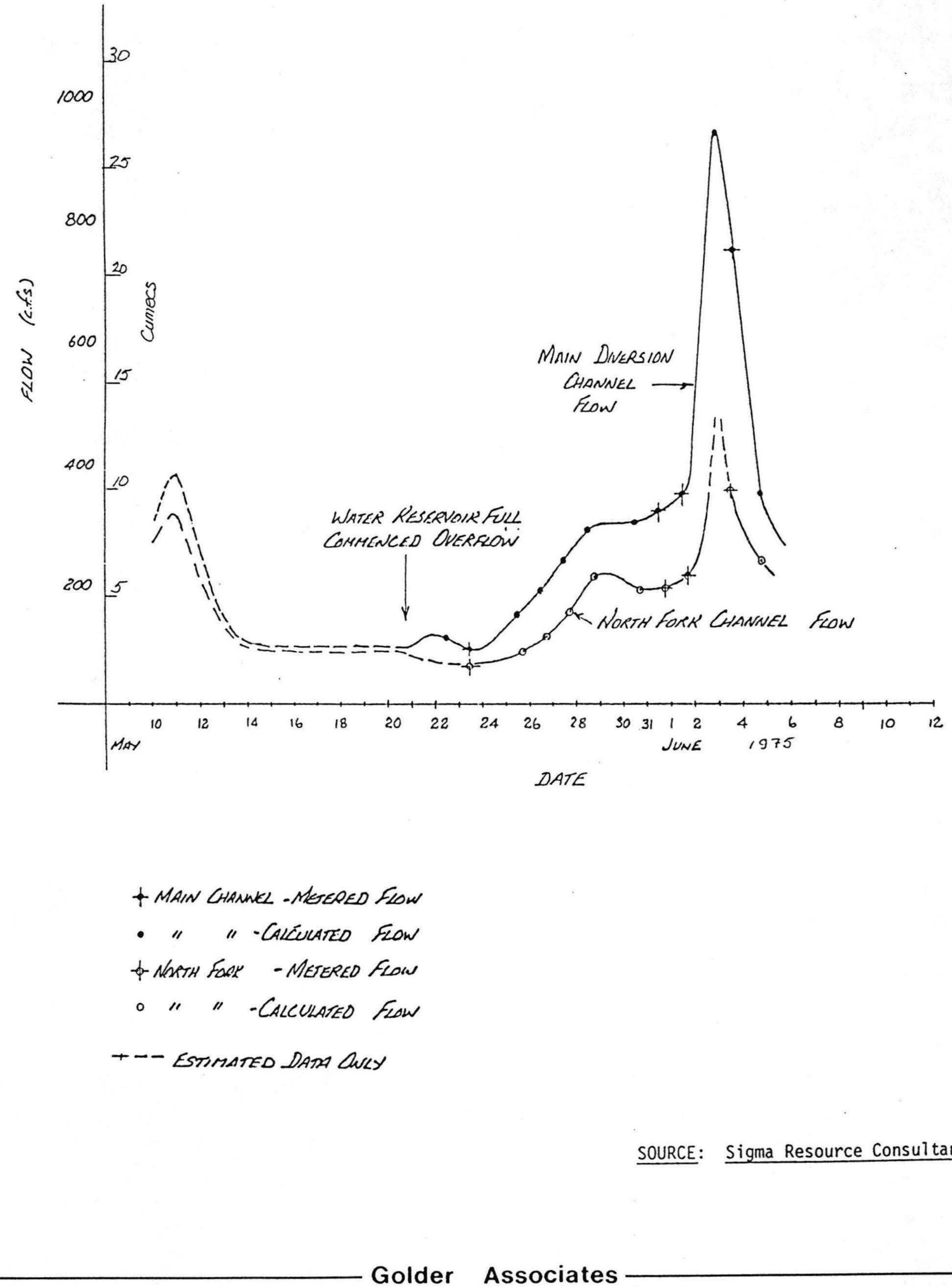
DISCHARGE CURVE, NORTH FORK OF ROSE CREEK FOR THE INTERVAL 10 MAY TO 6 JUNE 1975

Figure **5**



SOURCE: Sigma Resource Consultants Ltd.

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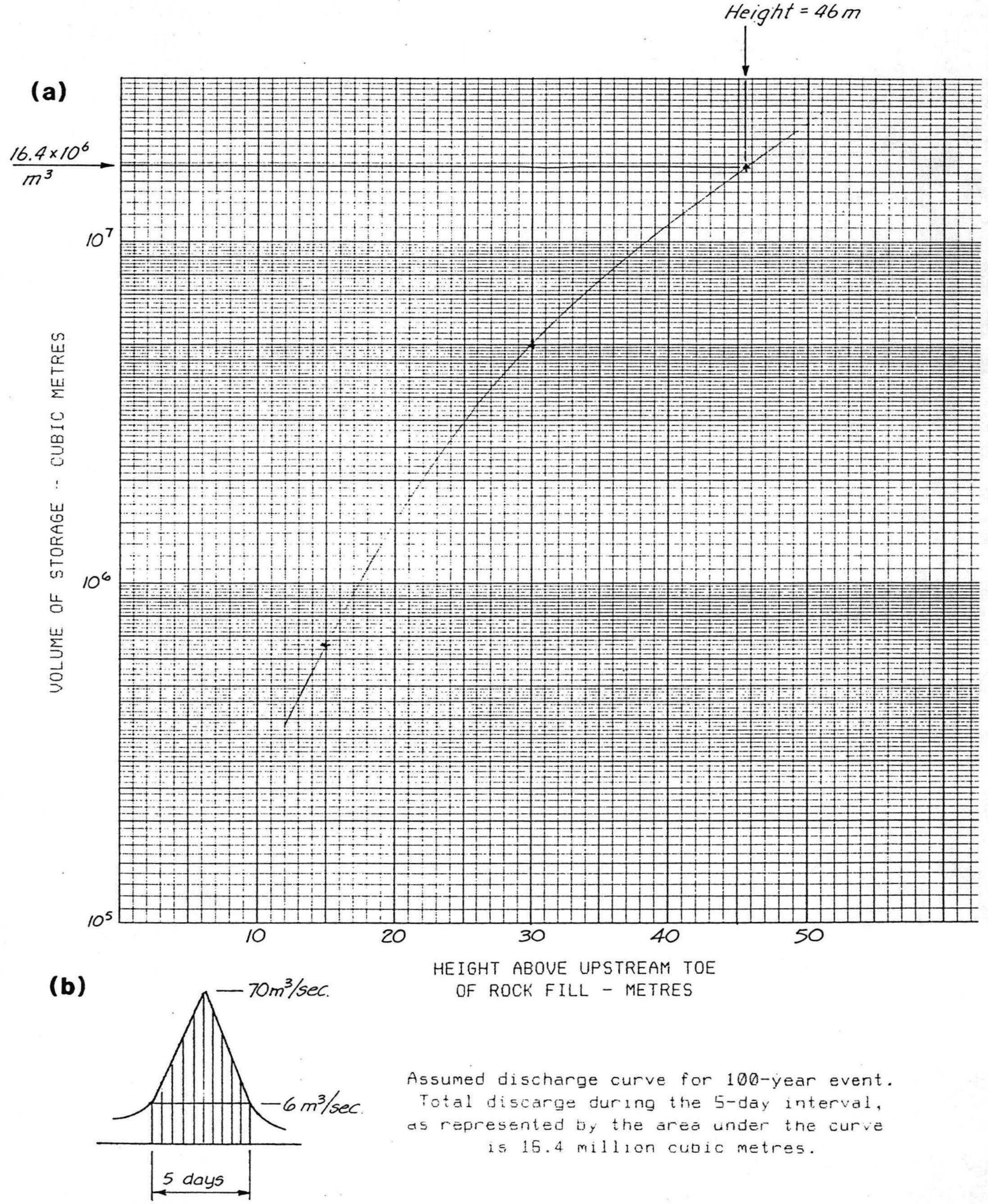
APPROXIMATE STORAGE VOLUME ON UPSTREAM SIDE OF ROCK FILL VS HEIGHT ABOVE STREAM BED LEVEL.

Figure 6



Assumed discharge curve for 100-year event. Total discarge during the 5-day interval, as represented by the area under the curve is 16.4 million cubic metres.

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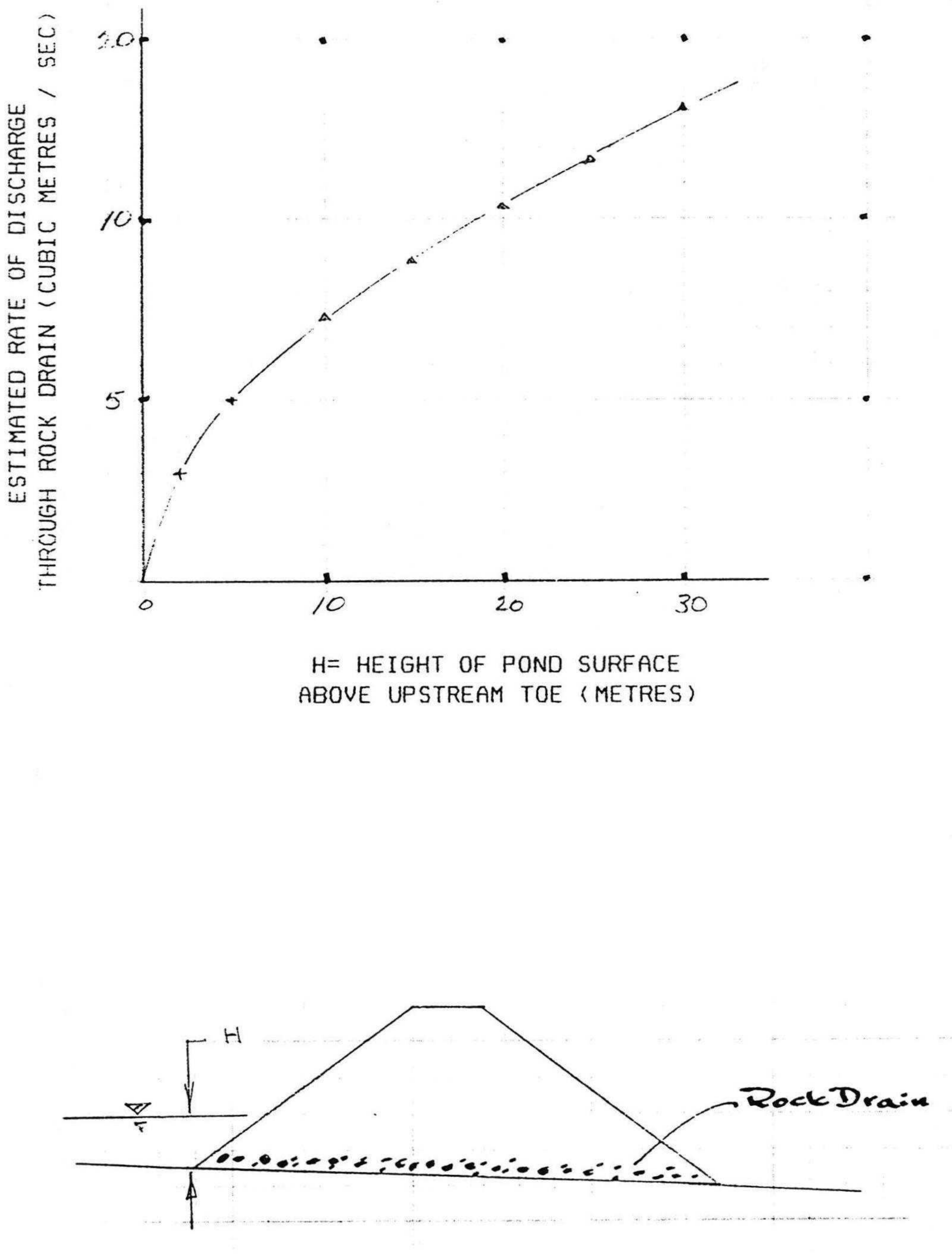
ESTIMATED RATE OF DISCHARGE THROUGH ROCK DRAIN VS DEPTH OF POOL AT INLET TO DRAIN

Figure 7



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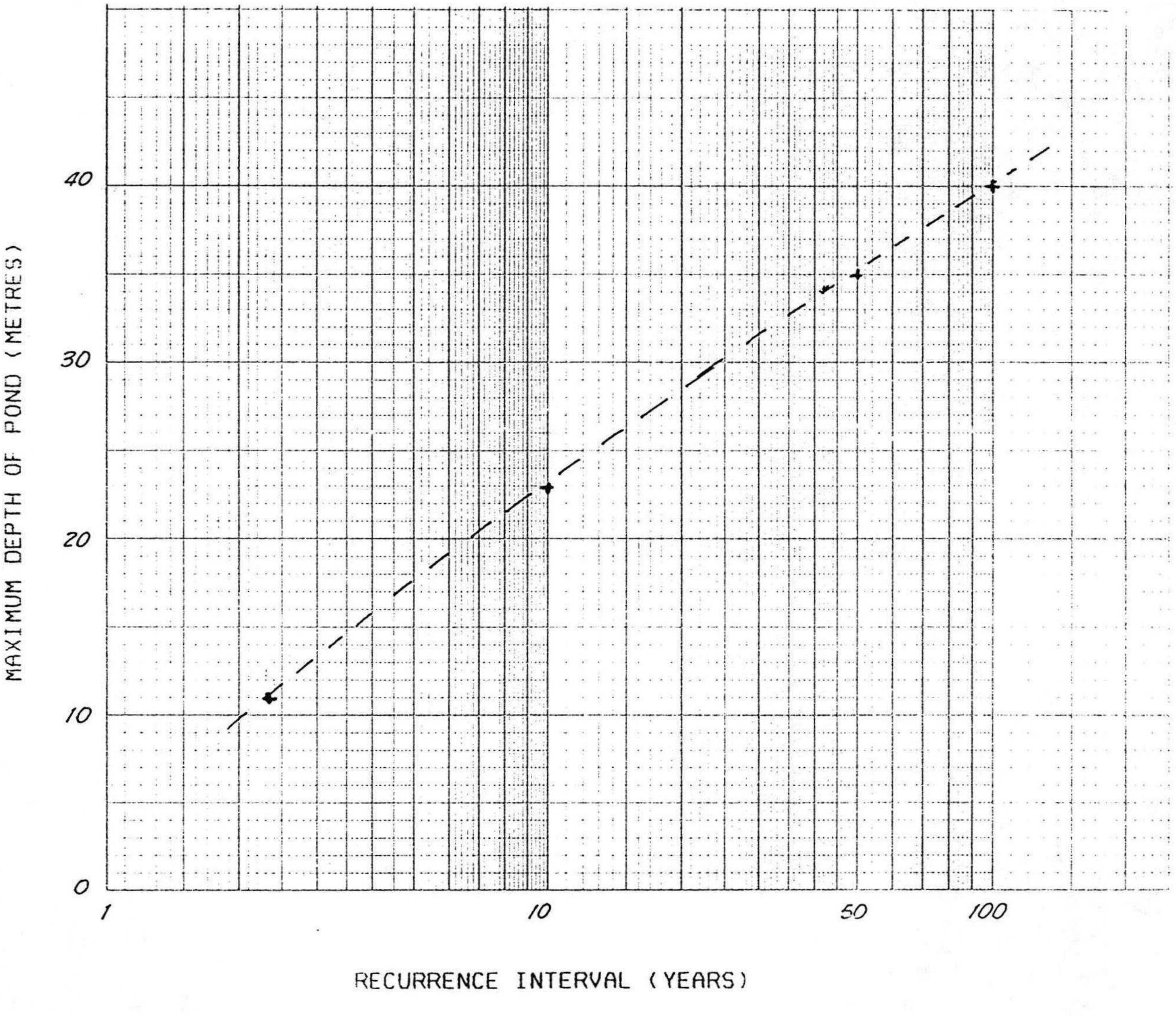
ESTIMATED POND SURFACE LEVEL VS RECURRENCE INTERVAL DISCHARGE

Figure **8**



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The proposed rock fill causeway will cross the north fork of Rose Creek at approximately this location.

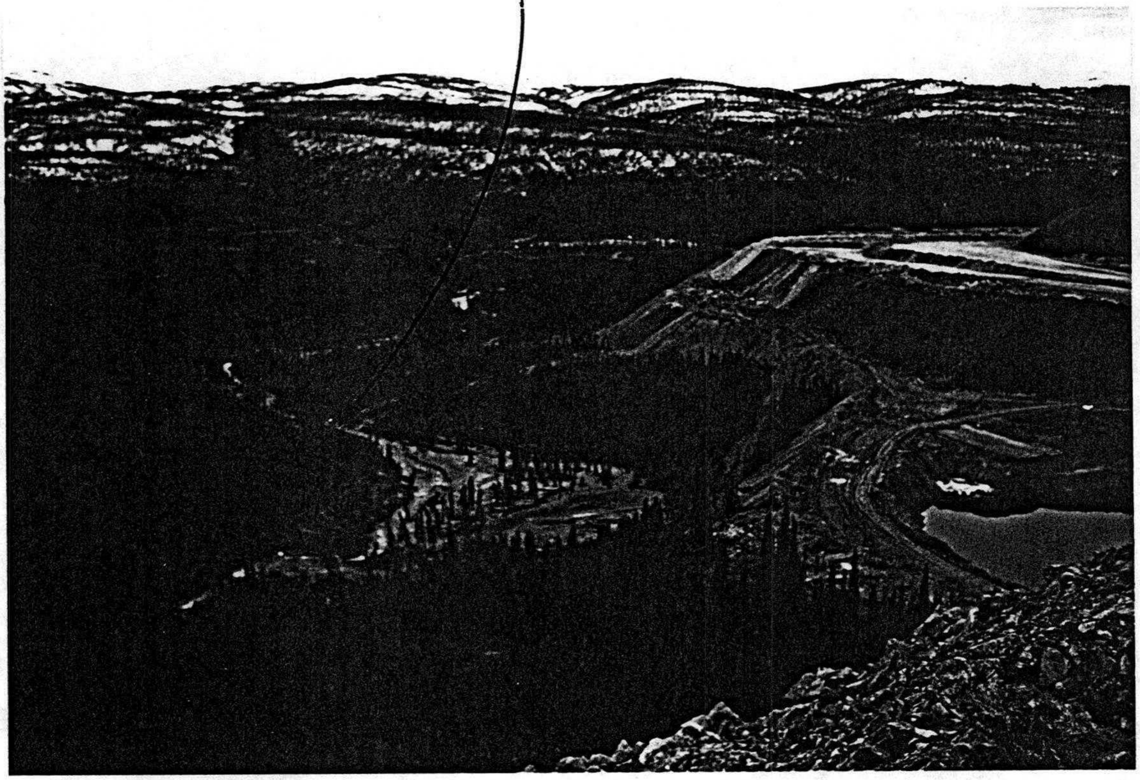
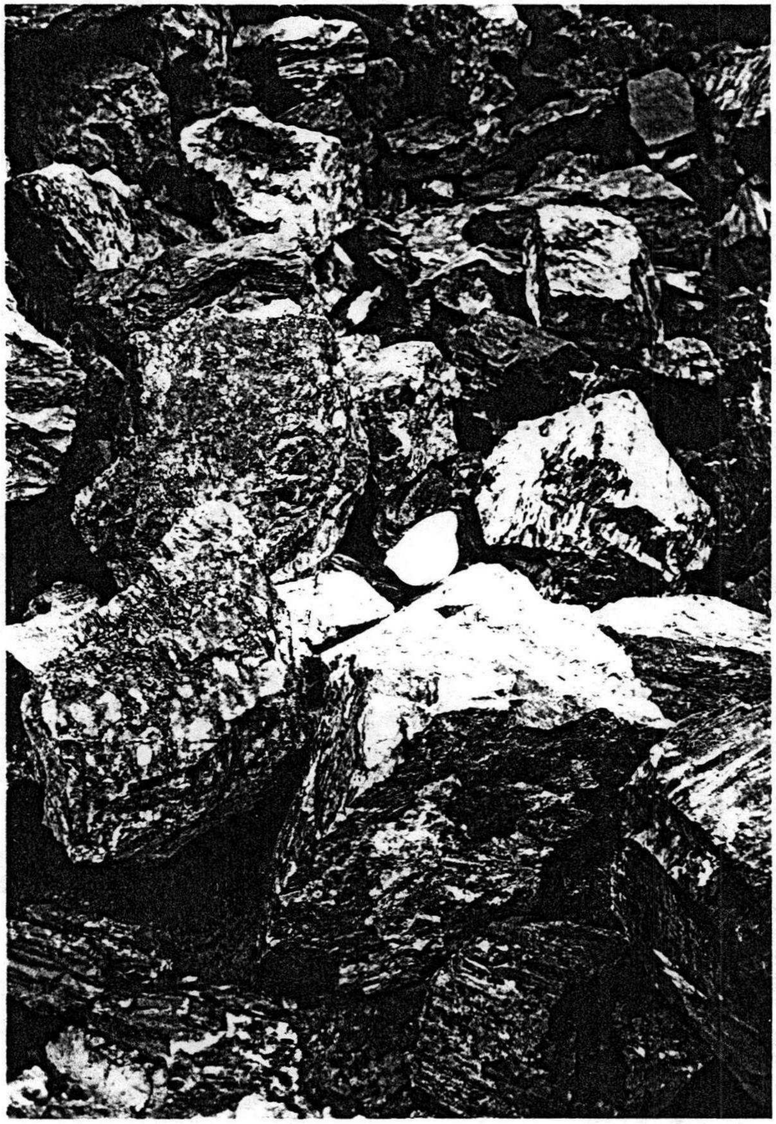


PHOTO NO.1
LOOKING TOWARD THE SOUTHWEST, SHOWING THE LIMIT OF THE PRESENT WASTE ROCK DUMP, AND THE NORTH FORK OF ROSE CREEK TO THE LEFT OF THE DUMP TOE. THE POINT WHERE THE CREEK APPEARS FARTHEST FROM THE DUMP TOE IN THIS PHOTO, IS AT COORDINATE LOCATION N3250, E16250 APROXIMATELY.



PHOTOS 2 & 3

EXAMPLES OF LARGE FRAGMENTS OF CALCIUM-SILICATE (CaSi) ROCK THAT HAVE SEPARATED ON THE DUMP FACE, AND HAVE COME TO REST AT THE TOE. THE MEAN PARTICLE SIZE OF THESE FRAGMETS IS ESTIMATED TO BE APPROXIMATELY 0.5 METRES. CaSi ROCK IS SUITABLE FOR DEVELOPMENT OF A ROCK DRAIN, WHEREAS SCHISTOSE-TYPE WASTE ROCK IS NOT SUITABLE

The rock drain concept for conducting surface flows beneath waste rock dumps is relatively new. Golder Associates provided design recommendations for the first rock drain developed at a mining project in British Columbia. This rock drain is located at Fording Coal's property in southeast British Columbia, and conducts the surface flows in Swift Creek through the base of a rockfill causeway that was required to provide truck access on the opposite side of the drainage course where space was available for expansion of a waste rock dump.

The Swift Creek rock drain at the Fording Coal property was developed in 1981. The drain itself consists of coarse fragments of waste rock that segregated on the face of the advancing dump, rolled to the dump toe, and collected within the bottom of the drainage course. Before the rockfill causeway was advanced across the drainage course, instrumentation was installed to permit measurement of piezometric levels at selected points along the axis of the drain, and detailed surface measurements were made to establish the topographic ground profiles which form the lower boundary of the rock drain cross-sections. These data, together with measured rates of discharge through the drain permit assessment of the rate of discharge through the drain per unit area of wetted cross-section. The data also provide a means of assessing whether the through-flow capacity of the rock drain decreases with time.

In 1981, the rock drain was a new concept, and no precedent data were available. Members of the regulatory agencies postulated a number of scenarios that they thought could be responsible for impairment of the performance of the rock drain over time. These scenarios which are addressed in this appendix included:

- Deposition of sediment within the rock drain

- Downward migration of fines within the dump, and deposition of these fines within the rock drain
- Degradation of the coarse rock fragments over time

These postulated scenarios as they apply to the Rose Creek rock drain, and to rock drains in general, are discussed following. Also discussed is the potential for ice accumulation within the drain, a scenario that has not previously been raised.

Sedimentation

Although detailed field measurements of sediment transport in the north fork of Rose Creek have not been made, it is reasonable to expect that during periods of high flow, the discharge in the north fork of Rose Creek is accompanied by bed load transport along the bottom of the creek channel, as well as transport of suspended sediments.

Head is required to 'drive' the water through the drain. As the rate of discharge in the North Fork drainage increases during the initial stages of a discharge event, a pool will develop adjacent to the upstream face of the rockfill. The difference in elevation between the pool surface above the inlet to the drain, and the point at which discharge emerges at the downstream toe represents the head loss through the drain, and this difference in head provides the energy to overcome the head loss. The relationship between the depth of the pond above the inlet end of the rock drain and the estimated rate of discharge through the north fork rock drain is shown on Figure 7 of the main text.

The estimated rate of discharge through the drain versus upstream pond depth, together with the hydrograph on Figure 4, and the storage volume curve on Figure 6 were utilized in flood routing calculations to estimate the depth of the pool that would develop adjacent to the upstream face of the causeway fill for various return period discharge events. The flood routing calculations were made by Ker Priestman and Associates employing an in-house computer program developed at their Victoria office. The results of these flood routing studies are presented in graphical form on Figure 8 which shows a plot of expected pool depth above the inlet end of the drain versus flood recurrence interval plotted on a log scale.

The presence of the temporary pool on the upstream side of the causeway fill provides protection against the entry and deposition of sediment within the drain that could result in a reduction of the through-flow capacity of the drain over time. This is demonstrated by making a comparison between the size of the particles that remain in suspension and which could enter the upstream end of the rock drain, with the size of particles subject to incipient scour corresponding to the average velocity of flow through the voids comprising the rock drain. Only those particles of a size smaller then the incipient scour-size particle would enter the drain; larger sized particles would settle out in the pond and would not enter the drain. The method of analysis is illustrated by the flow chart presented on Figure A2, and the results of the analyses are discussed following.

For the 10-year flood event, the maximum depth of the pool above the inlet end of the rock drain is estimated to be approximately 23 m. Considering the volume of water contained in this pool together with the maximum instantaneous discharge, the indicated retention time is approximately 23.7 hours*. The maximum settling time for the incipient scour

*Retention time is taken as pool volume divided by rate of stream discharge.

size particle is approximately 0.25 hours. Thus, the retention time is approximately two orders of magnitude greater than the maximum settling time for the incipient scour-size particle. The size of the particle that could settle from the surface to the bottom of the pool during the retention time has an effective diameter approximately 1/10 of the effective diameter of the incipient scour-size particle.

Similarly, if the mean annual flood is considered, the retention time in the pool is approximately 30 times longer than the maximum settling time for the incipient scour-size particle. The size of the particle that could settle a vertical distance equivalent to the full depth of the pool during the retention time is approximately 1/5 of the size of the particle corresponding to incipient scour.

Admittedly, there will be a discrepancy in the times at which peak discharge occurs and the time at which pool level is reached. However, these analyses indicate that the discrepancies between retention time and settling times for particles having an effective diameter equal to the incipient scour velocity are sufficiently large to conclude that particles which enter the drain will not settle, but will remain in suspension, and will be swept through the drain. The pool that will develop at the inlet end of the rock drain during a discharge event will provide protection against sedimentation that could impair through-flow capacity of the drain over time.

Downward Particle Migration Within the Dump

Downward migration of particles within the mass of dumped waste rock, and accumulation of these particles within the drain is one of the scenarios that have been postulated to result in potential reduction of the through-flow capacity of a rock drain.

The proposed rockfill causeway across the north fork of Rose Creek will be developed by truck dumping at the crest. The face of the causeway will be advanced through the process of gradual accretion of material on the advancing causeway face below the active dumping crest. This is the method by which waste rock dumps are commonly developed.

When a dump is developed by end dumping at the crest, the fine fraction of the waste rock fragments tend to segregate and accumulate within the upper region of the dump. The coarsest fraction of the rock fragments tend to separate from the mass of waste rock dumped at the crest. These large fragments roll down the dump face which remains at the angle of repose, and the coarse fragments collect at the toe. In this manner a zone of coarse fragments of calcium silicate rock will form the North Fork rock drain.

Field examinations on the faces of waste rock dumps show a trend of gradual reduction in mean particle size proceeding from the dump toe toward the dump crest. This gradual reduction in particle size constitutes a well graded filter which precludes downward migration of fines from the upper region of a dump toward its base. We are of the opinion that downward migration of particles within a dump is not a factor that results in a reduction in the through-flow capacity of a rock drain. This conclusion, which is based on the results of field observations, is confirmed by modelling studies in the laboratory.

In the laboratory studies, a model waste dump with a height of approximately 600 mm was developed using well graded 10 mm minus sand and gravel. In this laboratory model, the ratio of the maximum particle size to the vertical dimension of the model dump was approximately 60. This ratio of maximum particle size to dump height for the model is approximately the same as the ratio of maximum particle size to dump height for the proposed causeway across the north fork of Rose Creek.

The model dump in the laboratory was developed by depositing the material at the dump crest, and permitting the material to roll and slide down the dump face which remained at the angle of repose. After the dump face had been advanced a distance of approximately 800 mm, samples were recovered from a vertical segment extending from the dump platform to the base of the dump. This vertical column was subdivided into six segments each having a vertical height of 100 mm. Grain size analyses were then carried out on the material contained within each of the segments from the vertical column. The results of these grain size analyses are presented in graphical form on Figure A1. The grain size curves show that the material within the vertical column becomes progressively coarser proceeding from the top toward the bottom of the dump. Inspection of the grain size distribution for material contained within each segment as represented by the curves on Figure A1 shows that downward migration of particles within the dump is precluded.

Based on the results of our examinations of dump faces in the field, together with the results of grain size analyses on material contained within a vertical column extending from the top to the base of the laboratory model, we are confident that downward migration of particles from the upper regions of the causeway fill into the rock drain is not a factor that would result in a reduction in the through-flow capacity of the rock drain over time.

Particle Degradation

If degradation of the coarse rock fragments comprising a drain were to occur over time, this could be expected to result in a reduction in the through-flow capacity of the rock drain.

Waste rock generated in the course of the open pit mining at the Curragh property consists of schistose-type rock, and of calcium silicate (CaSi). Examinations on the faces of existing waste rock dumps at the Curragh property, as well as within the region beyond the toes of these dumps, show that the schistose-type rock is subject to breakdown and reduction in particle size. The CaSi rock on the other hand is very hard, and does not show evidence of degradation and weathering when exposed on the dump face, or in the region of the dump toe. For this reason, as the dump toe is advanced across the bottom of the north fork drainage course, the materials consigned to the rockfill causeway should consist of CaSi rock only, so that the rock drain will comprise only calcium-silicate rock fragments. We do not expect that the CaSi rock fragments comprising the drain will degrade over time. Consequently, the through-flow capacity of the rock drain is not expected to diminish with time as a result of degradation of the constituent rock fragments.

Potential Freezing

Although potential freezing and accumulation of ice within a rock drain is not a scenario that to date has been raised by members of regulatory agencies responsible for approval of proposed rock drains, potential freezing and ice accumulation in the North Fork rock drain is a factor that we believe could result in temporary reduction in the through-flow capacity of the drain.

It is reasonable to expect that during cold winter periods, when winds are negligible, cold air flows down the local drainage courses in the form of density currents. The extension of the rockfill causeway across the north fork of Rose Creek would represent an obstruction to the convection air currents within the north fork valley. With the rock fill causeway in place, cold air could be expected to 'pool' within the depression on the upstream side of the rockfill, and part of this cold air could be expected to seep through the rock drain.

The accumulation of ice within the culvert that conducts the North Fork creek flows beneath the access roadway between Faro townsite and the mine illustrates that low base flows continue to discharge within the north fork of Rose Creek during most of the winter. This base discharge through the rock drain, together with the flow of cold ambient air through the drain could result in accumulation of ice and could result in a temporary reduction in the discharge capacity of the drain. However, the formation of the water pool above the inlet end of the rock drain during a discharge event provides protection against ice accumulation from year to year as explained following.

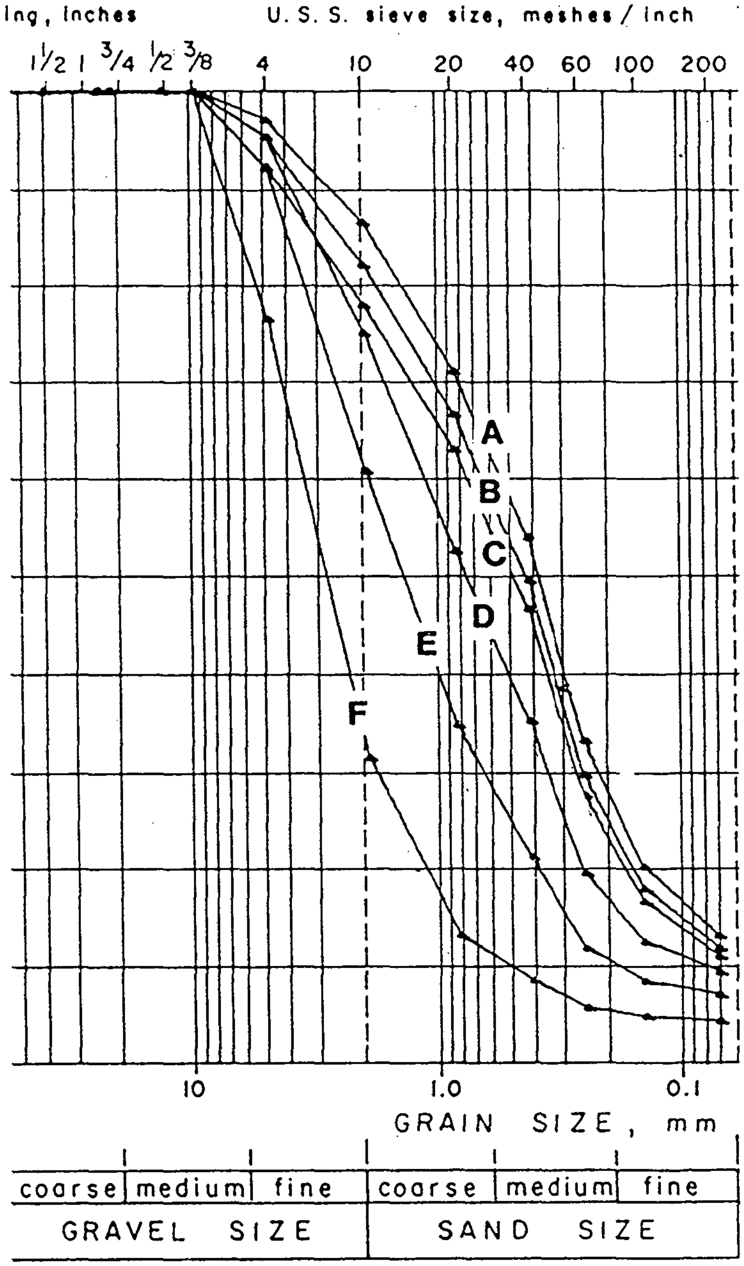
The density of water is temperature dependent, and is at maximum density at a temperature of 4° C. A plot of density versus temperature over the temperature range 0 to 10° C is shown on Figure A4. Maximum discharge in the North Fork of Rose Creek can be expected to occur at the time of spring breakup. At this time, the temperature of the surface discharge in the north fork of Rose Creek can be expected to range between 0° C and a temperature slightly higher than 0° C. Water which enters the pool at temperatures slightly higher than 0° C can be expected to gravitate to the lowest part of the pool, which is coincident with the inlet end of the drain. Thus, the water that discharges through the drain can be expected to be at a temperature slightly above 0° C, and will transfer heat to the drain, resulting in melting of ice. During the summer season, water temperatures can be expected to increase, with the result that melting of ice that may have accumulated during the previous winter season will continue. We do not expect that build up of ice within the drain would increase gradually with time. The volume of ice that might accumulate within the drain during a single winter season, and the degree to which the through-flow capacity of the drain might be impaired at the time of spring breakup cannot be predicted. However, the curve of storage volume versus height above the inlet end of the drain indicates that the storage capacity upstream of the proposed causeway fill is sufficiently large to impound all of the discharge resulting from a 100-year discharge event. We conclude that temporary accumulation of ice within the rock drain does not pose a threat that the pool would rise to a level that would overtop the rockfill causeway.

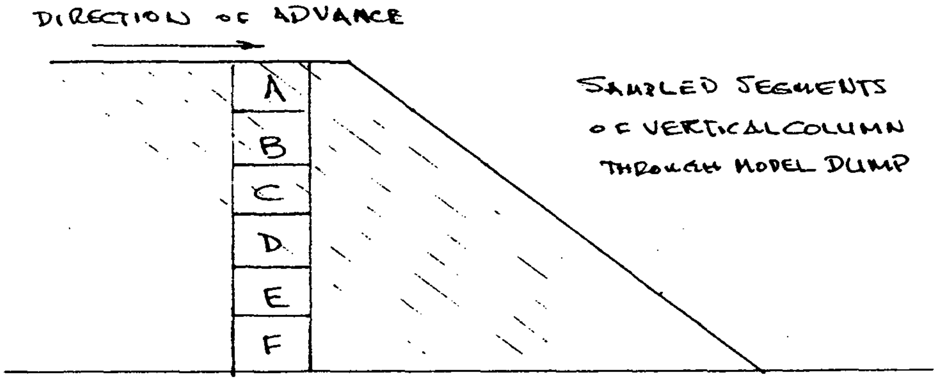
Conclusions

Based on the analyses and reasoning as described briefly in this appendix, we are of the opinion that the capacity of the drain will not be impaired by accumulation of sediment within the drain, by downward migration of fine rock fragments within the dump, or by degradation of the rock fragments comprising the drain. We are also of the opinion that although seasonal ice may accumulate within the drain during a single winter season, the temperature of the water flowing through the drain during the subsequent summer will cause melting of seasonal ice, and will preclude build up of ice from season to season.

GRAIN SIZE DISTRIBUTION WITHIN A MODEL DUMP

Figure A-1





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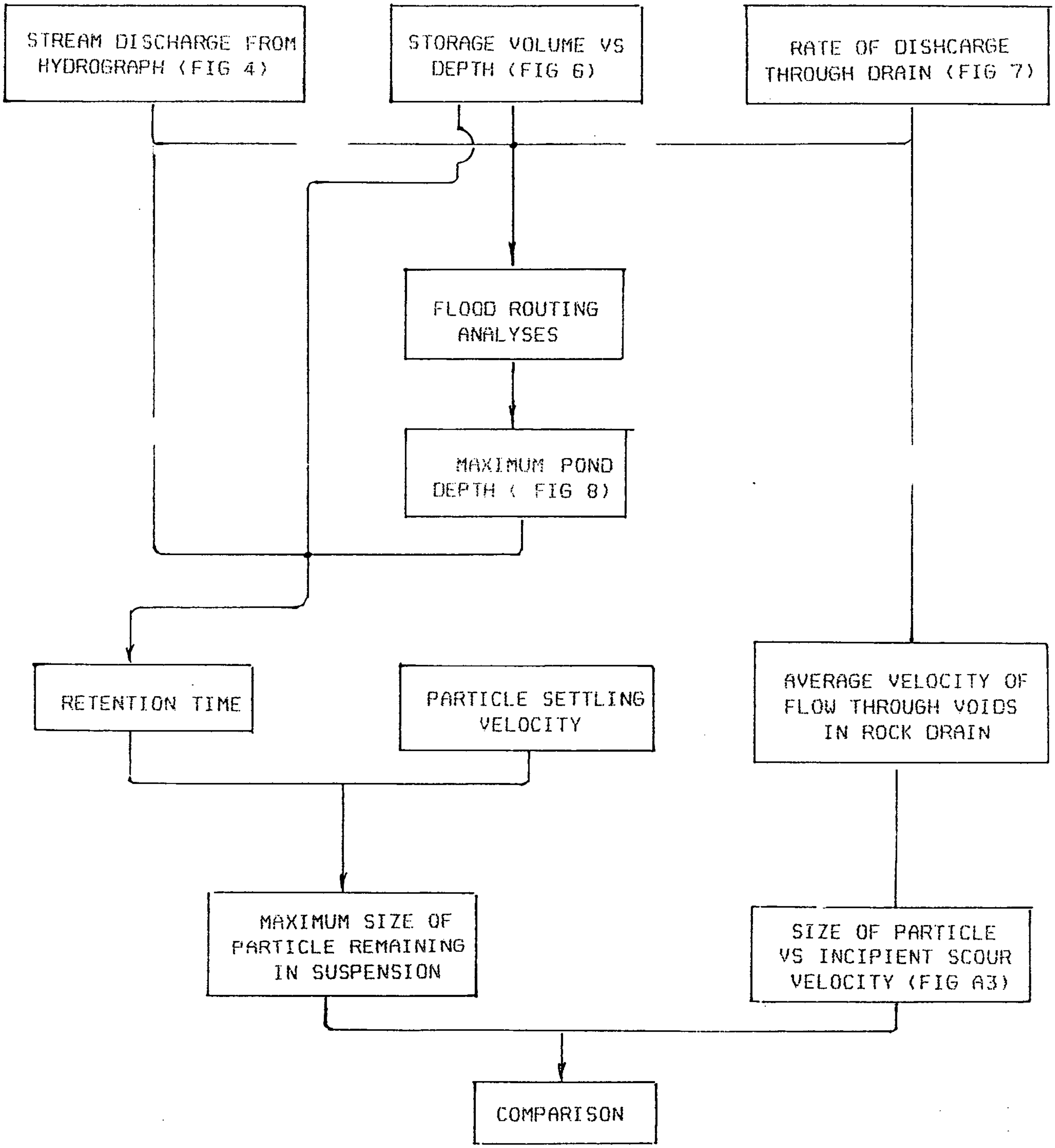
ANALYSES FOR POTENTIAL SEDIMENTATION WITHIN ROCK DRAIN

Figure A-2



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RELATIONSHIP BETWEEN PARTICLE SIZE AND INCIPIENT SCOUR VELOCITY

Figure A-3

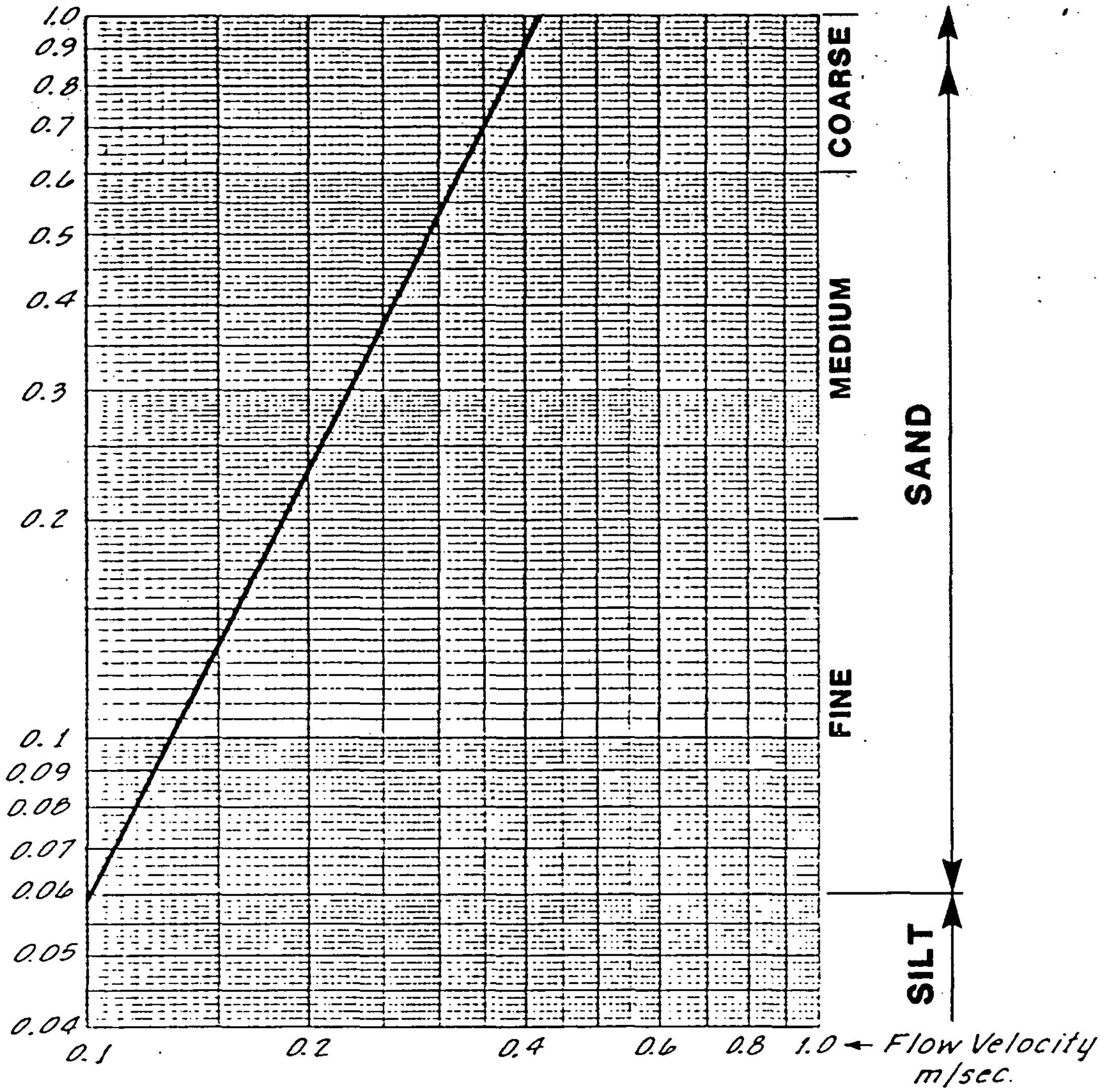


Chart based on...

$$V_c = \left(\frac{8B}{F}\ g\ (S-1)\ d_e\right)^{\frac{1}{2}}$$

B = Shield's critical shear stress parameter = 0.04

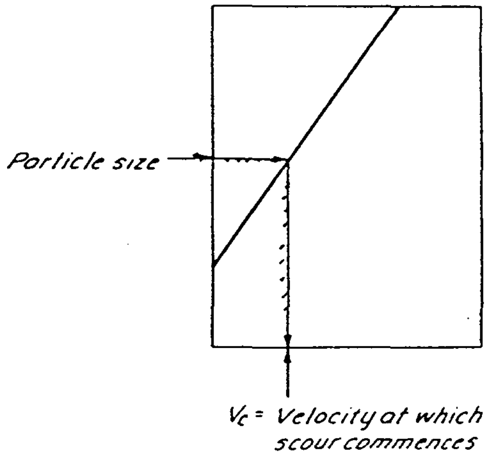
F = Darcy-Weisbach friction factor taken as 0.03

g = acceleration due to gravity

d_e = Effective particle diameter

S = Specific gravity taken as 2.65

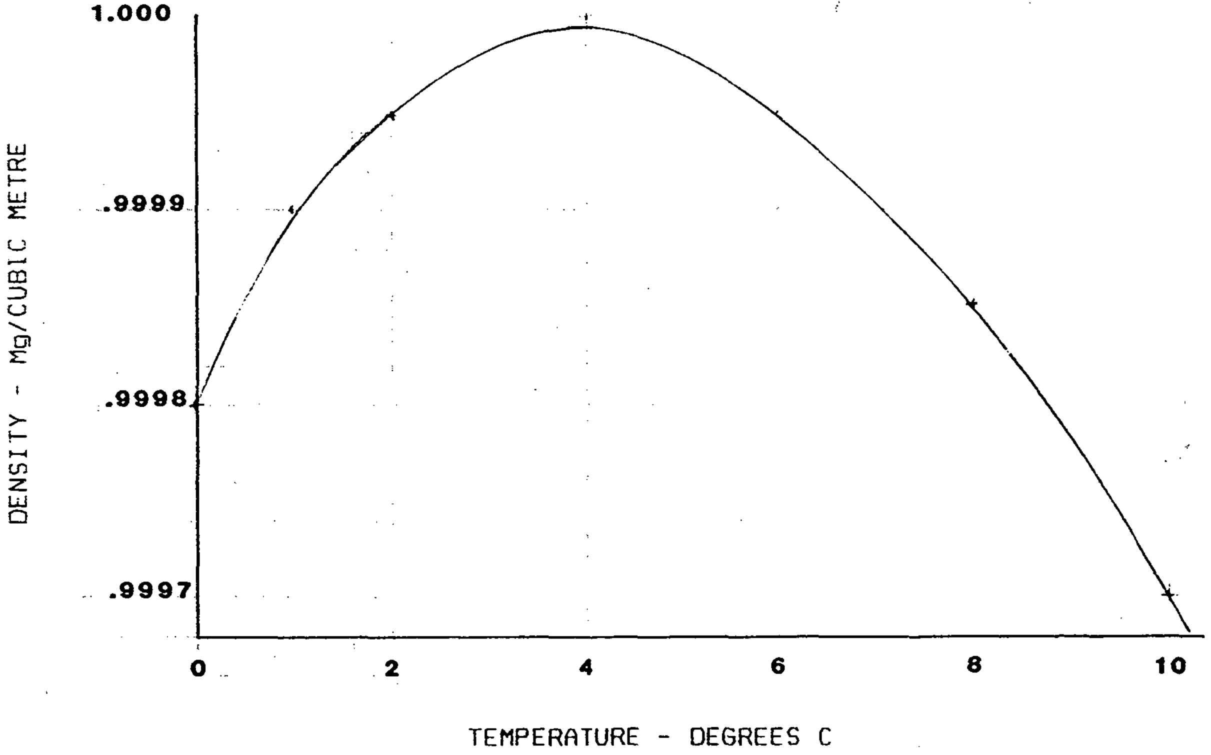
V_c = Velocity at which scour commences



PROJECT NO. 862-1093 DRAWN .... REVIEWED .... DATE Aug. '86

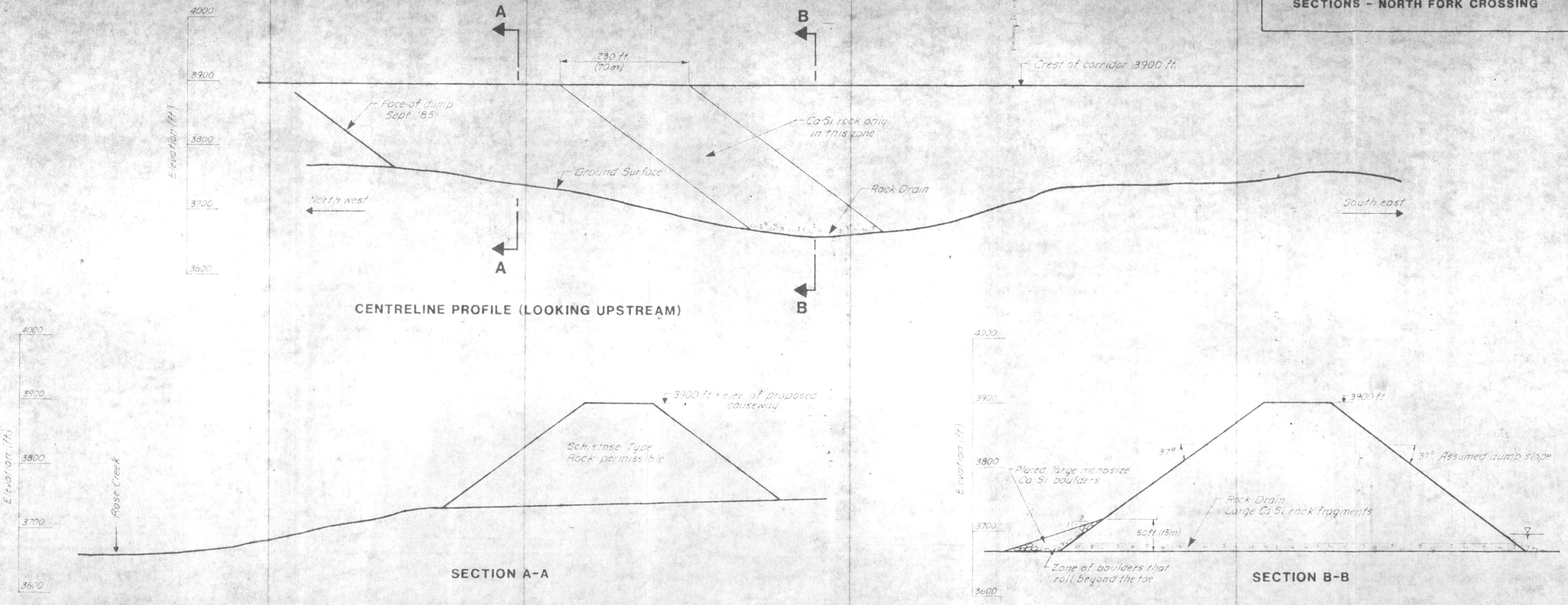
RELATIONSHIP BETWEEN
DENSITY OF WATER AND TEMPERATURE

Figure **A-4**



PROJECT NO. 862-1093 DRAWN .... REVIEWED .... DATE Aug. '86

SECTIONS - NORTH FORK CROSSING Figure **3**



SCALE 1 in. to 100 ft.

Golder Associates

Drawn: G.P.
Reviewed:
Date: Aug. 86