Golder Associates Ltd.
CONSULTING ENGINEERS

CURRAGH RESOURCES INC.
FARO MINE
DOWN VALLEY TAILINGS PROJECT
CROSS VALLEY DAM
TOE BERM DESIGN REPORT

Faro Yukon

Distribution: 6 Copies - Curragh Resources Inc.
Faro, Yukon Territory

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Calgary, Alberta

June, 1990

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Golder Associates Ltd.
CONSULTING ENGINEERS

15 June, 1990 Ref. No. 892-2410

Curragh Resources Inc.
P.O. Box 1000
Faro, Yukon
Y0B 1K0

<u>Attention: Mr. Jack Bowers, Engineering</u>

RE: CROSS VALLEY DAM TOE BERM

Dear Sir:

We have prepared the following design recommendations report concerning berming of the downstream toe of the Cross Valley Dam. Curragh committed to the project during Water Board hearings in September, 1989 at Whitehorse.

The purpose of the berm is to provide some confinement to the area of toe seepage without frustrating its free drainage to exit channels. These objectives are satisfied by using a zoned section comprised of processed and pit run granular materials which are sized to satisfy common filter criteria and required flow capacity.

The processed materials quantities have been minimized by electing to separate the length of the berm into three sections. Whereas the central section will be drained by the existing culvert which has a weir plate across its inlet, the other sections will require new installations.

We appreciate the assistance that Curragh has provided in preparation of this design and would note that construction drawings and related specifications are in the final stages of preparation. We look forward to being involved in construction of this project.

Yours very truly,
GOLDER ASSOCIATES LTD.

PROFESSIONAL ENGINEER
H.G. GILCHRIST
YUKON TERRITORIES

H.G. Gilchrist, P.Eng.
Principal

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1.0 INTRODUCTION

Golder Associates Ltd. is pleased to submit this report which outlines design details related to intended construction of a loaded toe drain on the Cross Valley Dam at Faro Mine, Yukon, Canada. The Cross Valley Dam is located in the Rose Creek Valley and forms part of the Down Valley Tailings Containment Project. The site location is shown on Figures 1 and 2. The purpose of the construction is to increase vertical stress over the immediate toe area of the dam while permitting a ready drainage path for the emerging seepage.

2.0 EXISTING CONDITIONS

The existing conditions at the Cross Valley Dam (CVD) were interpreted from the following sources:

- The 1980 design report by Golder Associates Ltd. entitled 'FINAL DESIGN RECOMMENDATIONS FOR THE DOWN VALLEY TAILINGS DISPOSAL PROJECT'.
- The 1982 "as built" report by Golder Associates Ltd. entitled 'DOWN VALLEY TAILINGS CONTAINMENT PROJECT, 1980-81 CONSTRUCTION'.
- Records of Test Pits and Boreholes and laboratory testing results on the field materials.
- Records of instrumentation readings at the site.
- Photographs of the site and the 'Annual Inspection Reports' for the CVD.

2.1 Geometry

The geometry of the CVD was inferred from the 'as built' sections prepared during and after construction and the topographic survey carried out by Yukon Engineering Services in September 1989. A typical existing cross-section of the CVD toe drain area is shown on Figure 3. In the 1981 `as built' sections, the top elevation of the downstream filter (Class X) at the toe of the dam ranges from 1049.0 m to 1053.0 m to conform to the natural ground surface contours.

2.2 In Situ Materials

Downstream Filter

The downstream filter of the dam was constructed using Class X borrow material. Several grain size analyses were conducted for this material during construction. Figure 4 shows the envelope of the test results from construction testing on Class X material. The 1982 'as built' report notes, however, that these test results are not necessarily representative of the overall conditions of the Class X material in place. Rather, these tests "often represent materials which were marginal and testing was performed to confirm visual judgements".

Foundation

The foundation of the CVD is described in the original design report as consisting of "mainly sand and gravel but also there are extensive lenses of frozen, non-organic fine sands and silts". Figure 5 shows a summary of 33 laboratory grain size tests which were performed on the foundation materials. The majority of test results fall within the shaded area in Figure 5 (i.e. Sandy GRAVELS to Silty SANDS). However, a few of the test results plotted in the Clayey SILT to Sandy SILT gradation. These test results are consistent with the original interpretation of foundation conditions.

2.3 Seepage Conditions

The seepage underneath, around and through the dam is monitored regularly via three v-notch weirs installed in the existing downstream drainage ditch. These weirs are located at approximate stations 0+220 and 0+560 (these stations refer to horizontal chainage along the crest of the CVD in metres). The third weir is located at the culvert outlet and measures the total flow which exits through the ditch. Table 1 below shows the peak flows which have been measured through these weirs between 1983 and 1989.

Table 1
Flow Through Weirs

Weir No.	Location	Peak Flow (igpm)
W2	N. Abut. Sta 0+220	280
W3	Culvert Outlet	1,800
W6	S. Abut. Sta 0+560	230

The peak total flow measured in 1986 was approximately 1,800 igpm. These flows were measured while the CVD pond was kept at or near the full supply level of approximately 1063.5 m.

The following assumptions were made with regard to flows for design purposes.

- The minimum flow through a section is 200 igpm.
- The north and south drainage sections contribute equally in terms of flow per unit length of toe drain. The total flow exits through the single culvert located at approximate station 0+430.
- The peak flow is 1,800 igpm.

Figure 6 shows graphically the inferred distribution of flow along the drainage ditch as referenced to the horizontal chainages along the CVD crest.

3.0 DESIGN CONSIDERATIONS

3.1 Design Concept

Curragh Resources Inc. committed to construction of the toe drain during Water Board hearings in September, 1989. It was felt that a toe drain was required at the site to provide additional comfort concerning toe area seepage rate. Further benefit of this construction is that it will increase the stability of the dam against sliding through loading of the toe.

A typical cross-section of the design toe drain is presented in Figure 7. It had been decided to design the drain to conform to the existing ground contours and to extend the drain up to an elevation of 1054.0 m. The practical limits for the toe drain are from station 0+185 to 0+610.

A requirement of the toe drain is that it must readily accept seepage flow emerging from the toe area. Due to the variable nature of these soils intermediate filtering materials are required to permit use of a highly pervious drain rock zone.

To reduce the total design flows the toe drain has been separated into three sections using two impervious cutoffs located at approximately stations 0+300 and 0+500. While the existing culvert will drain the central section, two additional culverts and related outlet channels will be needed to carry the flow from the flanking section to the existing drainage channel. This will enable continued monitoring of the seepage flows at three locations along the dam toe at approximate stations of 0+300, 0+400 and 0+500.

Figure 8 presents a sketch of the CVD Toe Drain system as designed.

3.2 Toe Drain Materials

The requirements for the construction materials are 1) that they be coarse enough to pass the design flows with an adequate factor of safety, and 2) that they be properly graded to restrain particle movement while permitting flow to exit from the downstream filter materials and the toe area. Based on testing of the in-situ materials (Figures 4 and 5), three material classes were defined which would act as compatible filters for the foundation and downstream filter materials. These are Class VIIIA (filter sand), Class XIIA (drainage gravel) and Class IVB (drainage rock). The gradation requirements for these materials are shown in Figure 9. A typical cross-section of the designed toe drain using the above material classes is illustrated in Figure 7.

3.3 Area Requirements

The following assumptions were made when considering the flow yield (and therefore the area requirements) for the drainage materials which comprise the toe drain:

- The gradient for flow was taken as equal to the ground slope. This is equal to approximately 1% from station 0+185 to 0+450 and 2.5% from station 0+450 to 0+610.
- Turbulent flow is likely to occur in the Class XIIA and Class IVB materials.
- The permeability of Class XIIA material was taken as 0.1 metres per second.
- The permeability of Class IVB material was taken as 0.4 metres per second.

- The permeability of Class VIIIA material was considered negligible in comparison with the Class XIIA and Class IVB materials.
- The distribution of flow along the alignment of the drain as shown on Figure 10. Note that this figure takes into account the two impervious cutoffs at approximate stations 0+300 and 0+500.

For turbulent flow, the flow may be calculated by the following equation:

$$Q = K * i^n * A \text{ (After Hough, 1957)}^{1} \qquad ...1$$

Where Q = Flow in cu.m/s

K = Combined Permeability in m/s

i = Hydraulic gradient

n = Power function (Value of 0.65)

A = Area in sq.m

Figure 7 shows a typical toe drain cross-section used for the flow calculations and Figure 10 shows the inferred flows in the toe drain taking into account the impervious cutoff at stations 0+300 and 0+500.

A minimum factor of safety of 3.0 was used with regard to the flow capacity of the drain. The factor of safety has been summarized for the toe drain design with regard to expected vs. design flows on Figure 11.

[1] Hough, B.K., Basic Soils Engineering, The Ronald Press Company, New York. 1957.

4.0 DESIGN DETAILS

4.1 Geometry

The general geometry shown in Figure 7 was used for the design. The following points summarize some of the important aspects of the drain cross-section geometry.

- The thickness of the filter sand (Class VIIIA) shall be a minimum of 0.3 m.
- The thickness of the drainage gravel (Class XIIA) shall be a minimum of 0.6 m.
- The area of drainage rock (Class IVB) shall be determined based on requirements for geometric purposes and for flow area.
- The top of the toe drain shall be approximately at the same elevation as the top of the downstream filter. Fill required to bring the drain up to this elevation, but not required for drainage may consist of Class VIII/VIIIA material. A minimum 0.6 m thickness of Class VIII/VIIIA material should be placed over the drain for long term protection of the drain.
- Impervious cutoffs shall be constructed at approximate stations 0+300 and 0+500. A culvert shall be installed across the toe access road upstream from each of these locations. A ditch shall be excavated from the culvert outlets to drain into the existing drainage channel.
- A geotextile separator shall be placed between the material placed as the impervious cutoff and surrounding drain and filter materials. Also a geotextile separator shall be placed between the Class VIII random fill and the Class IVB drain rock. The geotextile shall comprise Exxon GTF 2000 or equivalent.

A profile along the toe drain centreline showing the design thickness of the respective classes of material is presented in Figure 11.

4.2 Ditch Preparation and Excavation

Prior to placing fill, the ditch should be prepared by removing organic materials from the base area of the toe drain with the least possible disturbance to the existing ground conditions.

In order to obtain the required area for the toe drain construction, it will be necessary to widen the existing ditch from approximately station 0+200 to 0+525 m. The design toe drain invert is to be the same as the existing ditch invert except between approximately stations 0+405 to 0+475 m where the invert should be slightly deepened to promote smooth drainage and reduce ponding in this area.

The calculated ditch excavation volume is approximately 3000 cubic metres (excluding contingencies).

4.3 Fill Specifications

The fill materials for use in construction shall be referred to as Class IVB drain rock, Class VI impervious fill, Class VIII random fill, Class VIIIA filter sand and Class XIIA drainage gravel. All fill materials shall be clean earth materials, free of organic and other deleterious inclusions.

Class IVB drain rock material shall conform to the following gradation limits when in place:

Particle Size	Minimum Percent by Weight Passing	Maximum Percent by Weight Passing
500 mm	100	100
400 mm	50	100
300 mm	0	100
200 mm	0	40
150 mm	0	2

To determine the effective size of cobbles from 150 mm to 500 mm, the following formula shall be used:

$$D_e = \frac{(L^2 + D^2 + W^2)^{1/2}}{3} \qquad \ldots 2$$

Where D_e is the effective diameter and L, D and W are the mutually perpendicular principal particle dimensions measured in millimetres.

The Class VI impervious fill shall conform to the following gradation limits when in place:

U.S. Standard Sieve Size	Minimum Percent by Weight Passing	Maximum Percent by Weight Passing
40 mm	85	100
20 mm	85	100
2.5 mm	57	85
315 μm	35	65
80 μm	20	50

Class VIII random fill shall be within the following gradation limits when in place:

U.S. Standard Sieve Size	Minimum Percent by Weight Passing	Maximum Percent by Weight Passing
150 mm	70	100
75 mm	52	100
40 mm	40	95
5 mm	15	70
315 μm	0	35
80 μm	0	20

The Class VIIIA filter sand shall be within the following gradation limits when in place:

U.S. Standard Sieve Size	Minimum Percent by Weight Passing	Maximum Percent by Weight Passing
100 mm	100	100
40 mm	60	100
20 mm	45	100
10 mm	30	80
5 mm	15	55
630 μm	0	28
315 μm	0	20
80 μm	0	5

Class XIIA drainage gravel shall be within the following gradation limits when in place:

U.S. Standard Sieve Size	Minimum Percent by Weight Passing	Maximum Percent by Weight Passing
150 mm	100	100
100 mm	70	100
75 mm	50	100
50 mm	15	80
40 mm	0	65
20 mm	0	32
10 mm	0	2

Equation 2 shall be used to determine the effective size of cobbles from 75 mm to 150 mm.

4.4 Culverts and Drainage Ditches

Culverts shall be installed across the existing Toe Access Road at approximate stations 0+290 and 0+510 as shown in Figure 8. The outlet invert elevations for the culverts shall be 1047.5 m and pipe invert grade shall not be less than one percent.

The culverts shall comprise 600 mm nominal diameter corrugated steel pipe placed in prepared trenches. The trenches shall be overexcavated 150 mm with a minimum width of 3 metres and sideslopes no steeper than 1H:1V. The overexcavation in the bottom of the trench shall be replaced with a 150 mm thick lift of native material compacted to a minimum 100 percent Standard Proctor maximum dry density.

After placement of the culvert the trench shall be backfilled with native materials to a minimum 98 percent Standard Proctor maximum dry density in lifts not exceeding 200 to 300 mm thick.

Drainage ditches shall be excavated from the outlet of the culverts to drain into the existing drainage course as shown on Figure 8. The drainage ditches shall be graded to meet the invert of the existing drainage course. The ditches shall be a minimum 1 m wide at the base with sideslopes no steeper than 2H:1V, excavated in natural soils.

5.0 BORROW SOURCES

Borrow for construction of the toe drain may be taken from Borrow Area 'K' which is within 2 km of the site. Test pits in this area indicate that sufficient quantities of material are available for construction of the toe drain. Borrow was obtained from this pit during the 1990 construction season. Based on the results of limited laboratory testing of samples it is expected that the in situ material will require screening to obtain the desired gradation for the Class IVB and Class XIIA materials.

6.0 RECOMMENDED CONSTRUCTION PROCEDURES

It is recommended that the construction of the toe berm be carried out from upstream to downstream. In this way the possibility of contamination of the filter materials during construction will be minimized. It is expected that the culverts will be installed early in the construction sequence along with the drainage ditches which tie in with the existing drainage channel. The materials excavated during construction of the drainage ditches and installation of the culverts may be useable as random fill.

7.0 QUANTITIES

Quantity estimates are presented on Table 2. The quantities are preliminary only and based on existing topographic information.

TABLE 2
QUANTITY ESTIMATES
CROSS VALLEY DAM TOE DRAIN
FARO MINE, YUKON

DESCRIPTION		APPROXIMATE IN-PLACE QUANTITY
1.	Ditch Widening	1,500 m^3
2.	Drainage Ditches	2,500 m^3
3.	Culverts	20 m
4.	Fill, Class IV B	2,400 m^3
5.	Fill, Class XII A	4,100 m^3
6.	Fill, Class VI	500 m^3
7.	Fill, Class VIII	2,200 m^3
8.	Fill, Class VIII A	4,000 m^3
9.	Geotextile	3,600 m^2

NOTE:

(1) The quantities reported herein do not include contingency

(2) Where raw materials are to be screened to produce specification material, loose stockpiles of product should have 20 percent larger volume than the quantities given above.

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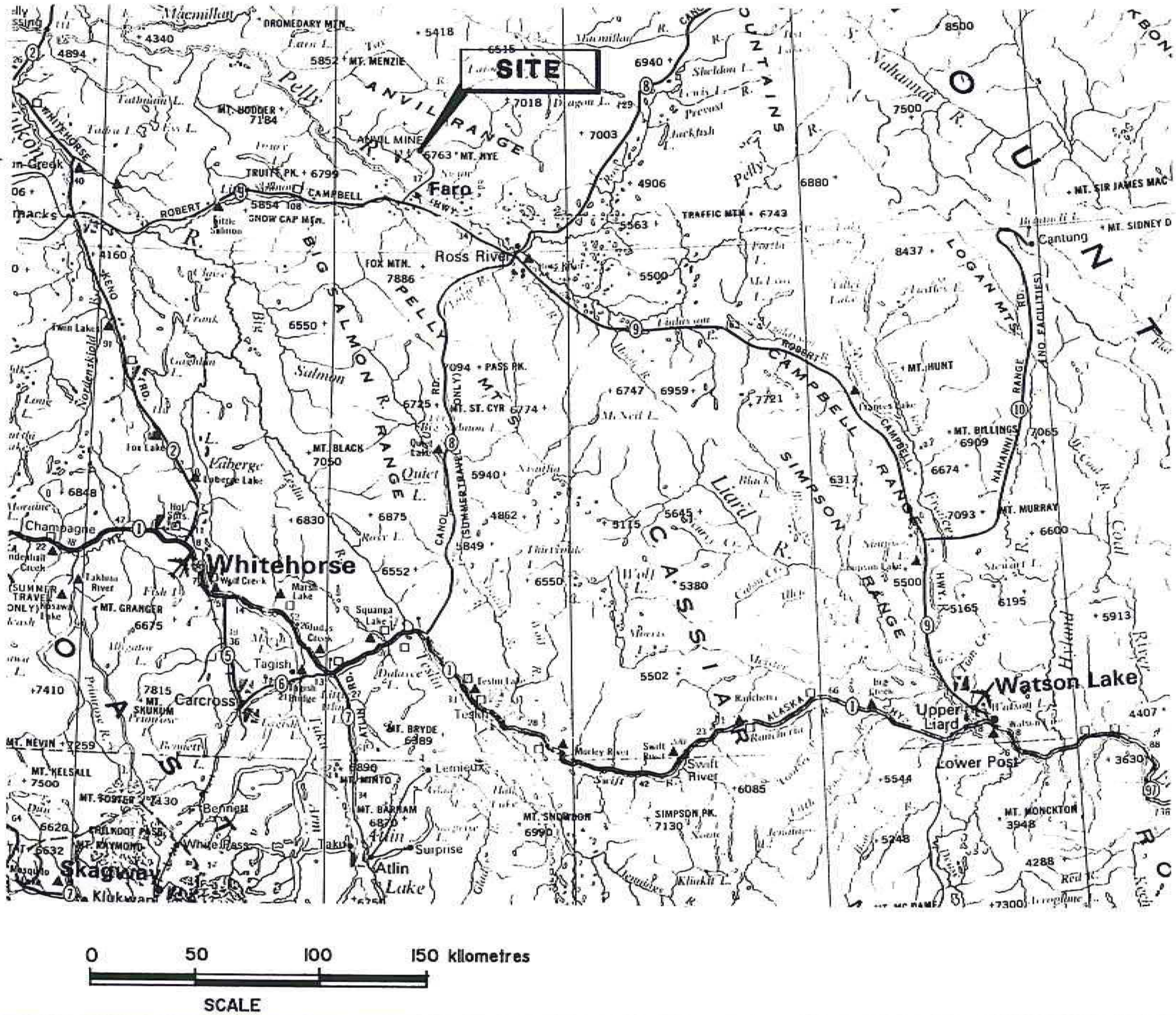

SITE LOCATION PLAN

Figure 1

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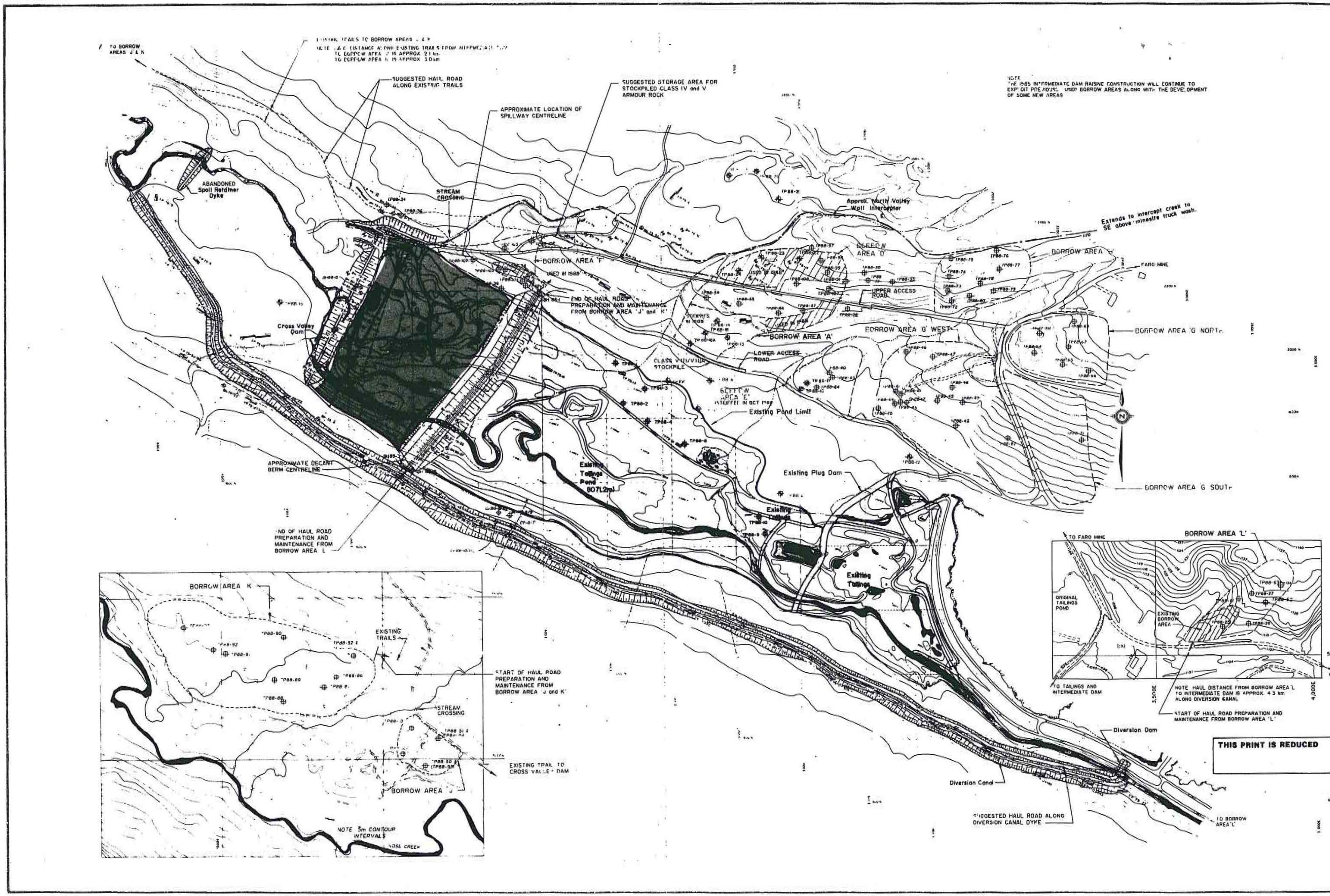

TO BORROW AREAS J & K
SUGGESTED HAUL ROAD ALONG EXISTING TRAILS
APPROXIMATE LOCATION OF SPILLWAY CENTRELINE
SUGGESTED STORAGE AREA FOR STOCKPILED CLASS IV and V ARMOUR ROCK
THE 1989 INTERMEDIATE DAM RAISING CONSTRUCTION WILL CONTINUE TO EXPLOIT PREVIOUSLY USED BORROW AREAS ALONG WITH THE DEVELOPMENT OF SOME NEW AREAS
ABANDONED Spoil Retainer Dyke
STREAM CROSSING
Approx. North Valley Wall Interceptor
Extends to intercept creek to SE above minesite truck wash.
BORROW AREA 'F'
USED IN 1988
BORROW AREA 'D'
BORROW AREA 'H'
FARO MINE
UPPER ACCESS ROAD
END OF HAUL ROAD PREPARATION AND MAINTENANCE FROM BORROW AREA 'J' and 'K'
Cross Valley Dam
BORROW AREA 'A'
BORROW AREA 'G' WEST
BORROW AREA 'G' NORTH
CLASS VII/VIII STOCKPILE
LOWER ACCESS ROAD
BORROW AREA 'E'
Existing Pond Limit
APPROXIMATE DECANT BERM CENTRELINE
Existing Tailings Pond (1071.2m)
Existing Plug Dam
BORROW AREA 'G' SOUTH
Existing Tailings
END OF HAUL ROAD PREPARATION AND MAINTENANCE FROM BORROW AREA 'L'
BORROW AREA 'K'
EXISTING TRAILS
START OF HAUL ROAD PREPARATION AND MAINTENANCE FROM BORROW AREA 'J' and 'K'
STREAM CROSSING
EXISTING TRAIL TO CROSS VALLEY DAM
BORROW AREA 'J'
NOTE 3m CONTOUR INTERVALS
ROSE CREEK
BORROW AREA 'L'
TO FARO MINE
ORIGINAL TAILINGS POND
EXISTING BORROW AREA
TO TAILINGS AND INTERMEDIATE DAM
NOTE: HAUL DISTANCE FROM BORROW AREA 'L' TO INTERMEDIATE DAM IS APPROX. 4.3 km ALONG DIVERSION CANAL
START OF HAUL ROAD PREPARATION AND MAINTENANCE FROM BORROW AREA 'L'
Diversion Dam
THIS PRINT IS REDUCED
Diversion Canal
SUGGESTED HAUL ROAD ALONG DIVERSION CANAL DYKE
TO BORROW AREA 'L'

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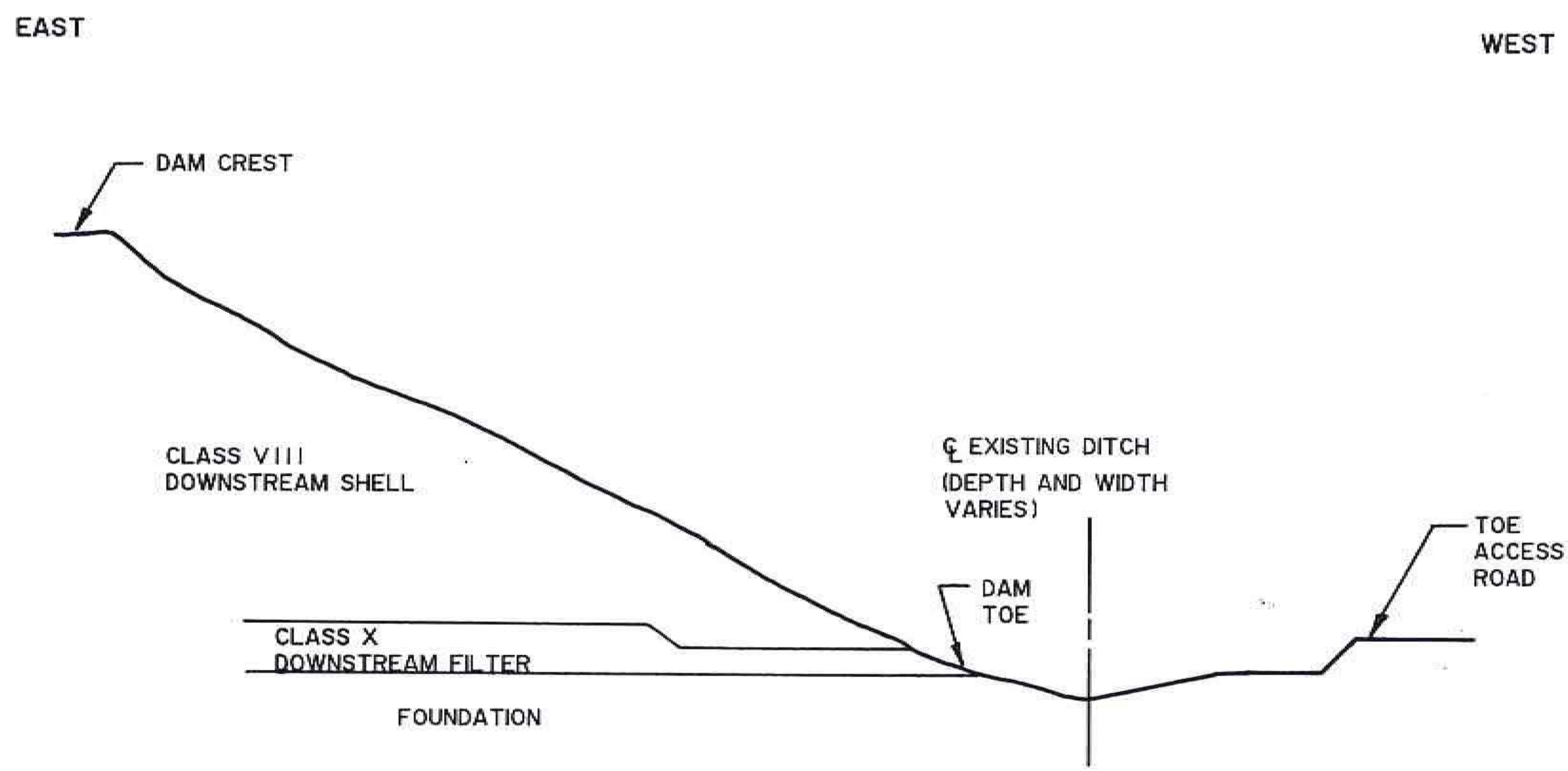

NOT TO SCALE

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TYPICAL CROSS-SECTION OF CROSS VALLEY DAM, DOWNSTREAM TOE

Figure 3

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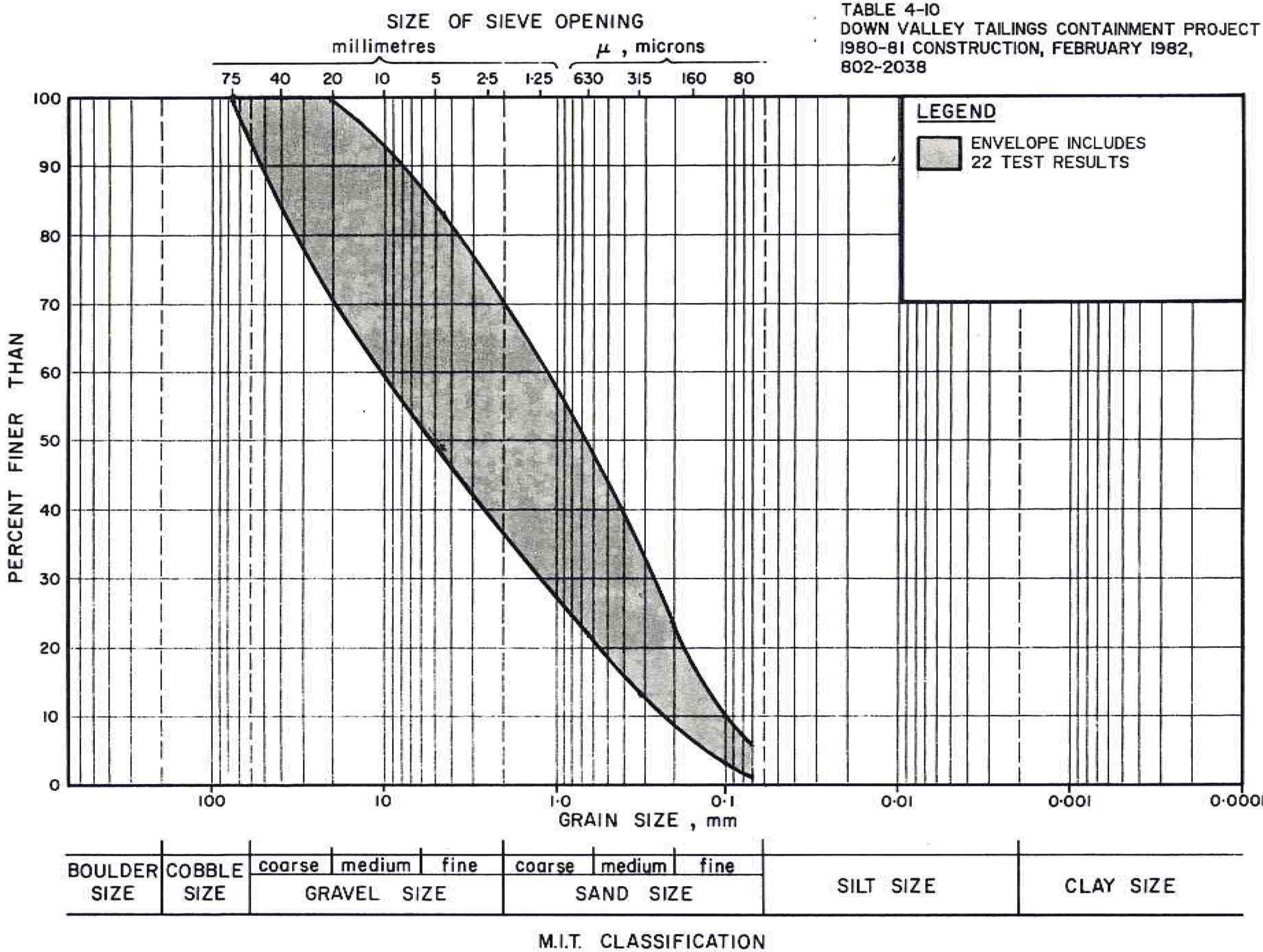
REFERENCE:

TABLE 4-10
DOWN VALLEY TAILINGS CONTAINMENT PROJECT
1980-81 CONSTRUCTION, FEBRUARY 1982,
802-2038



RESULTS OF CONSTRUCTION TESTING ON CLASS X MATERIAL (DOWNSTREAM FILTER)

Figure 4

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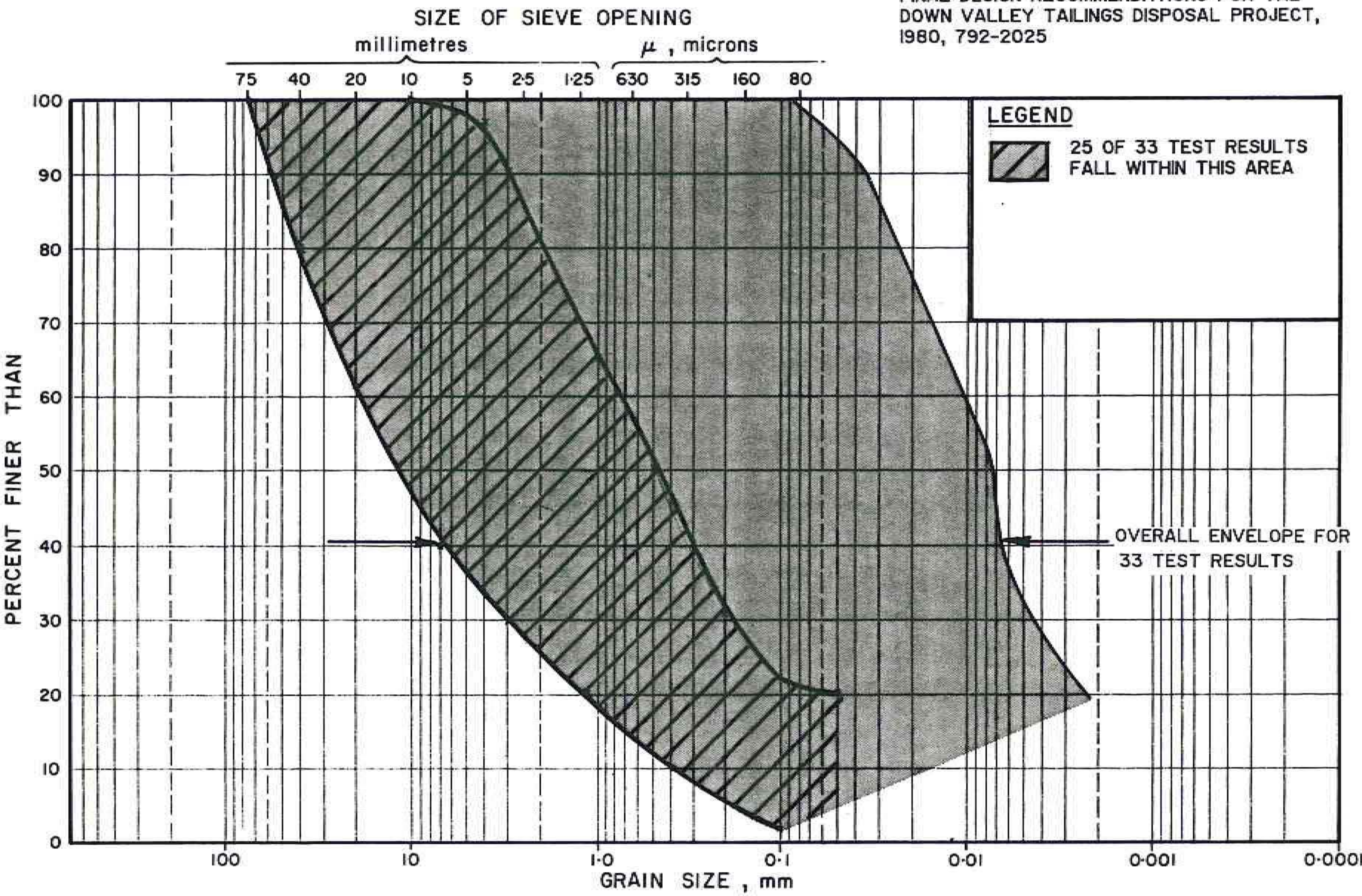
REFERENCE

FINAL DESIGN RECOMMENDATIONS FOR THE DOWN VALLEY TAILINGS DISPOSAL PROJECT, 1980, 792-2025



BOULDER SIZE	COBBLE SIZE	coarse	medium	fine	coarse	medium	fine	SILT SIZE	CLAY SIZE
		GRAVEL SIZE			SAND SIZE				

M.I.T. CLASSIFICATION

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FOUNDATION MATERIALS AT CROSS VALLEY DAM
1979 - 1980 LABORATORY TESTING SUMMARY

Figure 5

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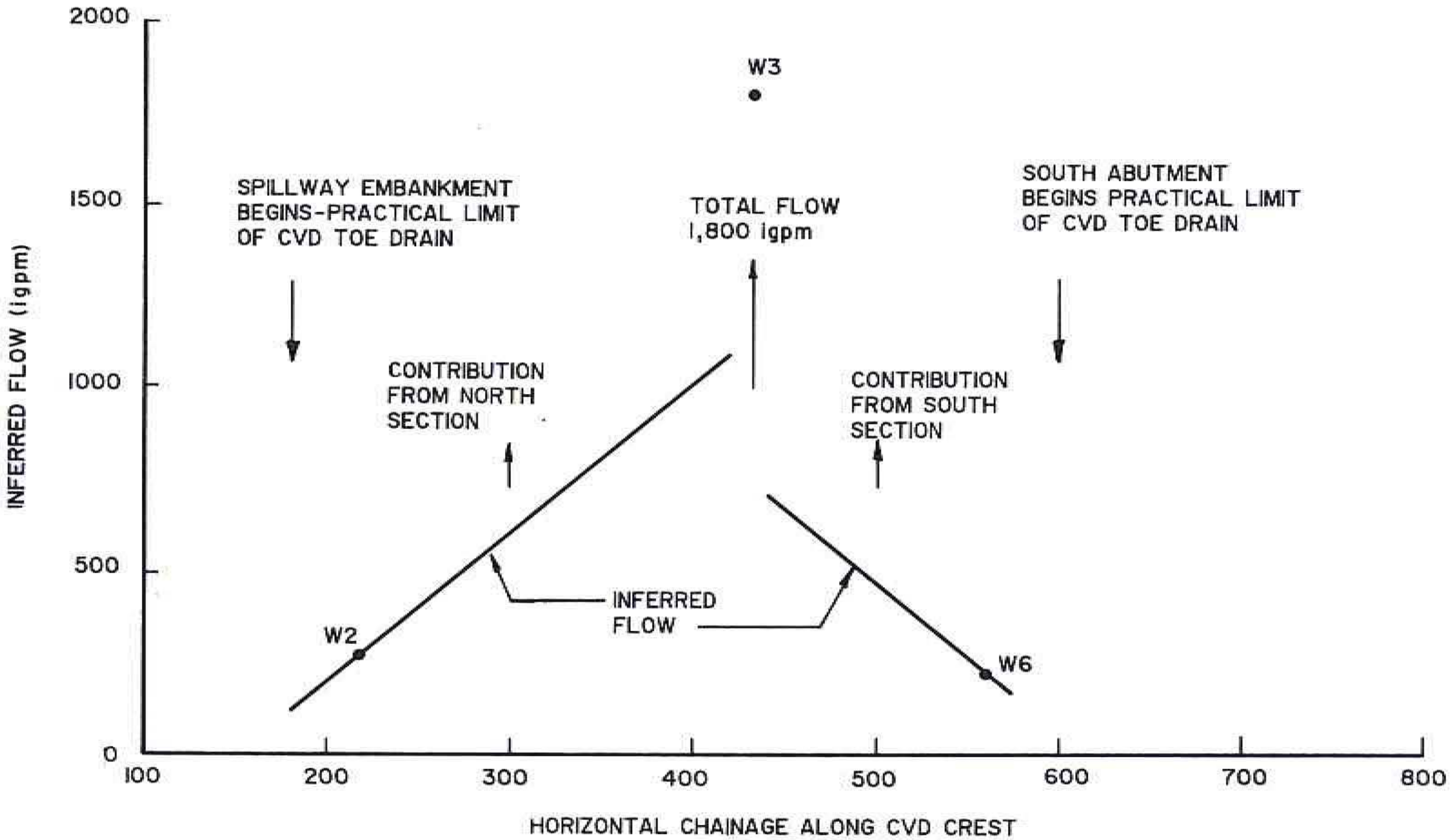

LEGEND

- ● INDICATES MEASURED FLOW AT WEIR LOCATION

INFERRED FLOWS IN DRAINAGE DITCH

Figure 6

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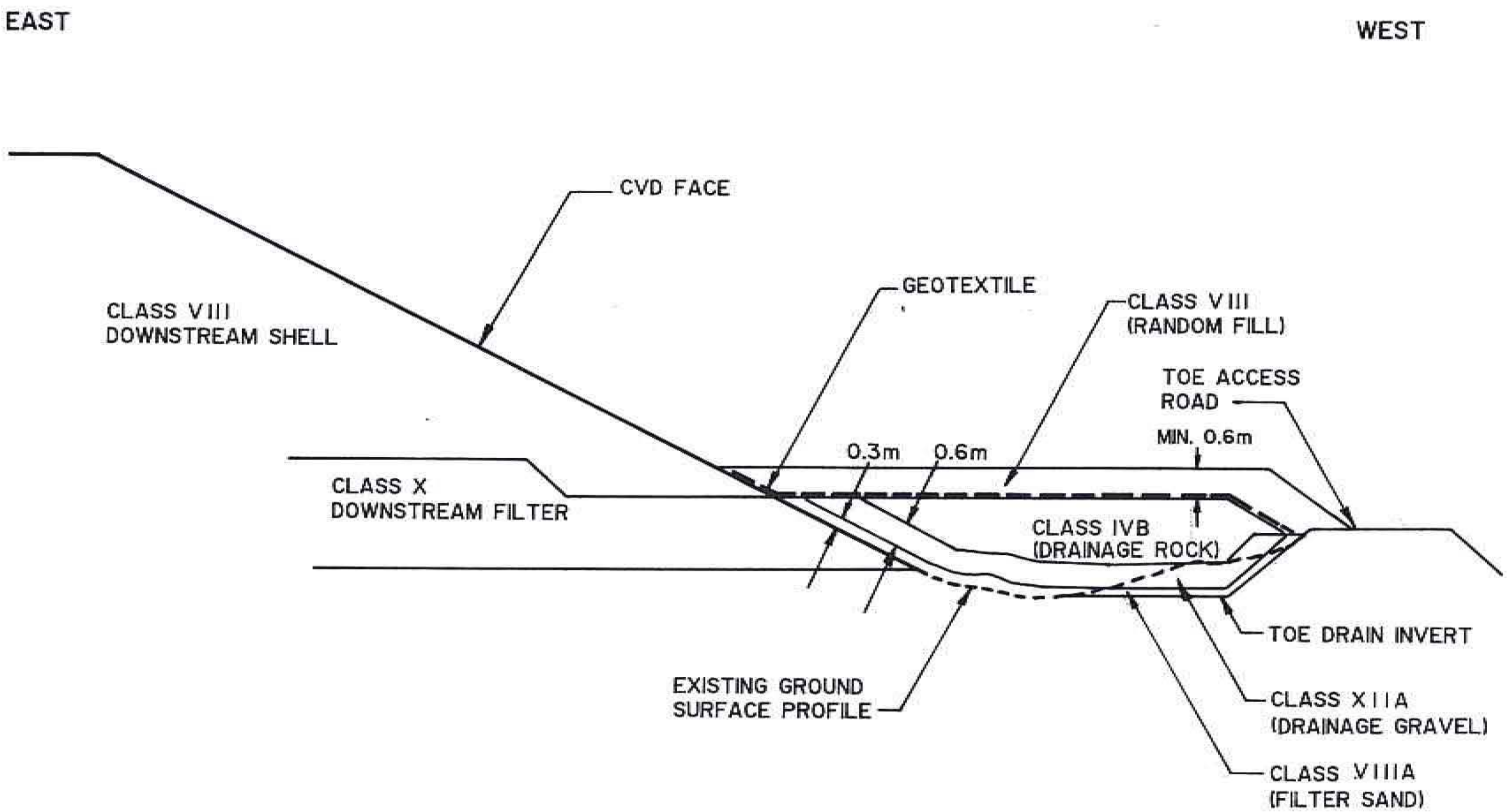

TYPICAL CROSS-SECTION OF TOE DRAIN

Figure 7

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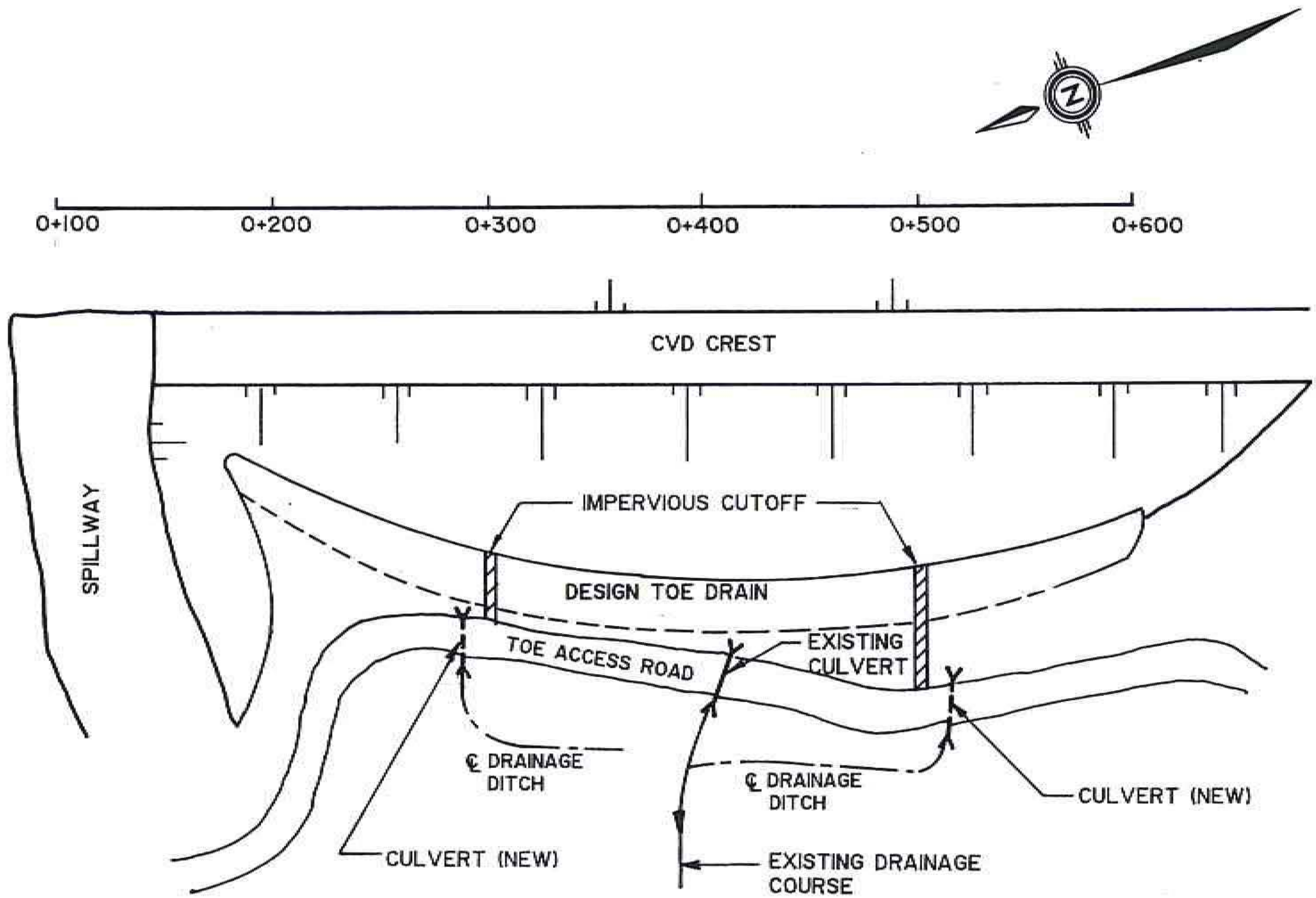

NOT TO SCALE

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PLAN VIEW OF TOE DRAIN AND ASSOCIATED DRAINAGE WORKS

Figure 8

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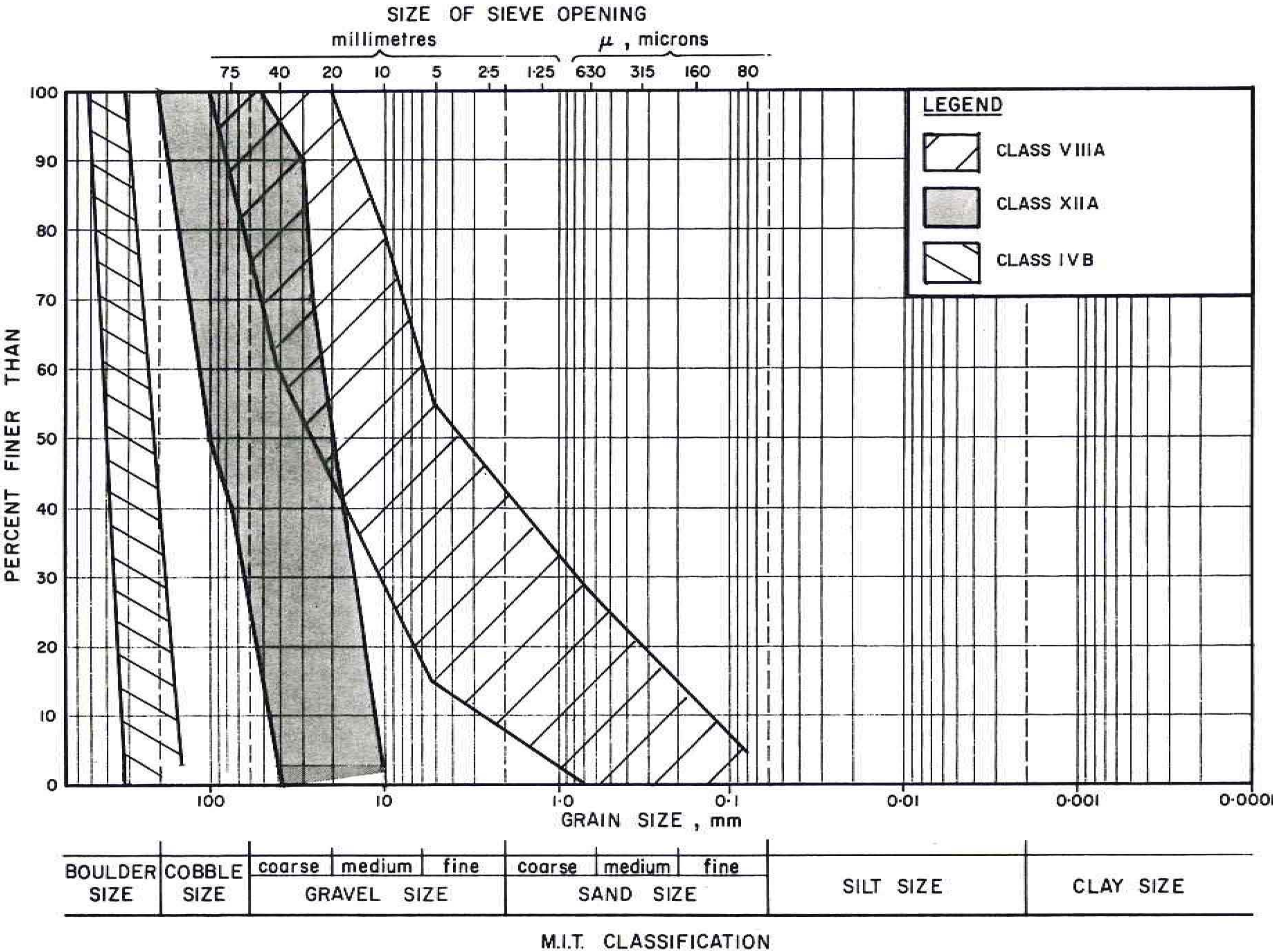

GRADATION REQUIREMENTS FOR DRAIN CONSTRUCTION MATERIALS

Figure 9

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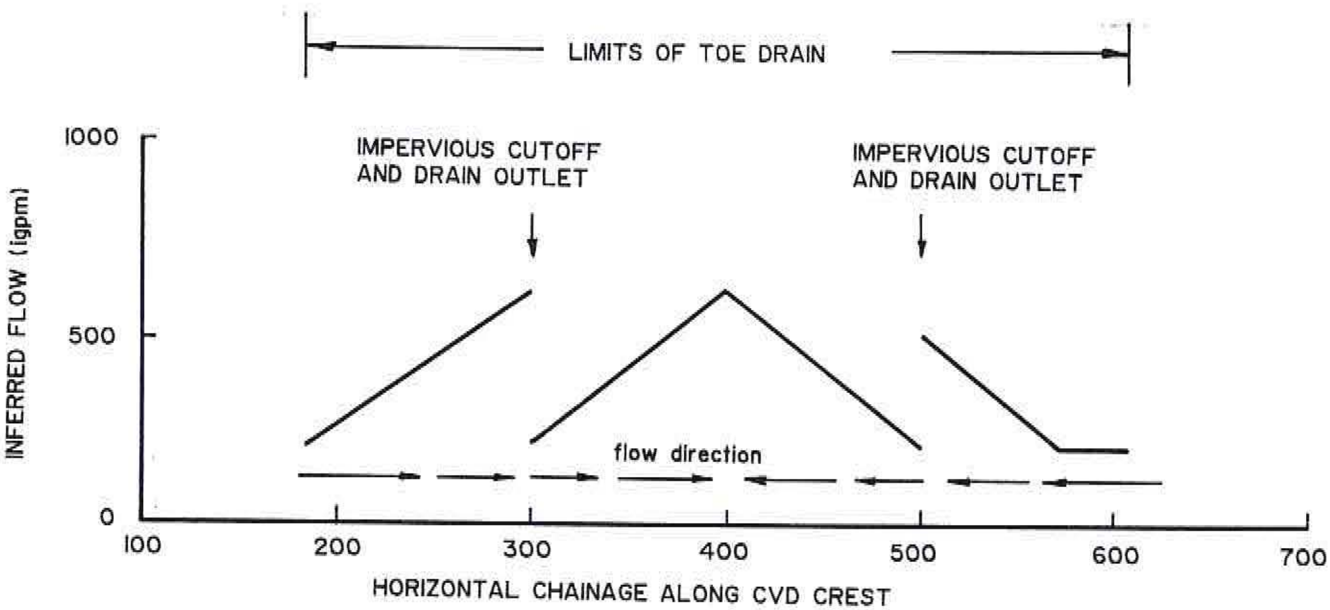
INFERRED FLOWS IN TOE DRAIN

Figure 10



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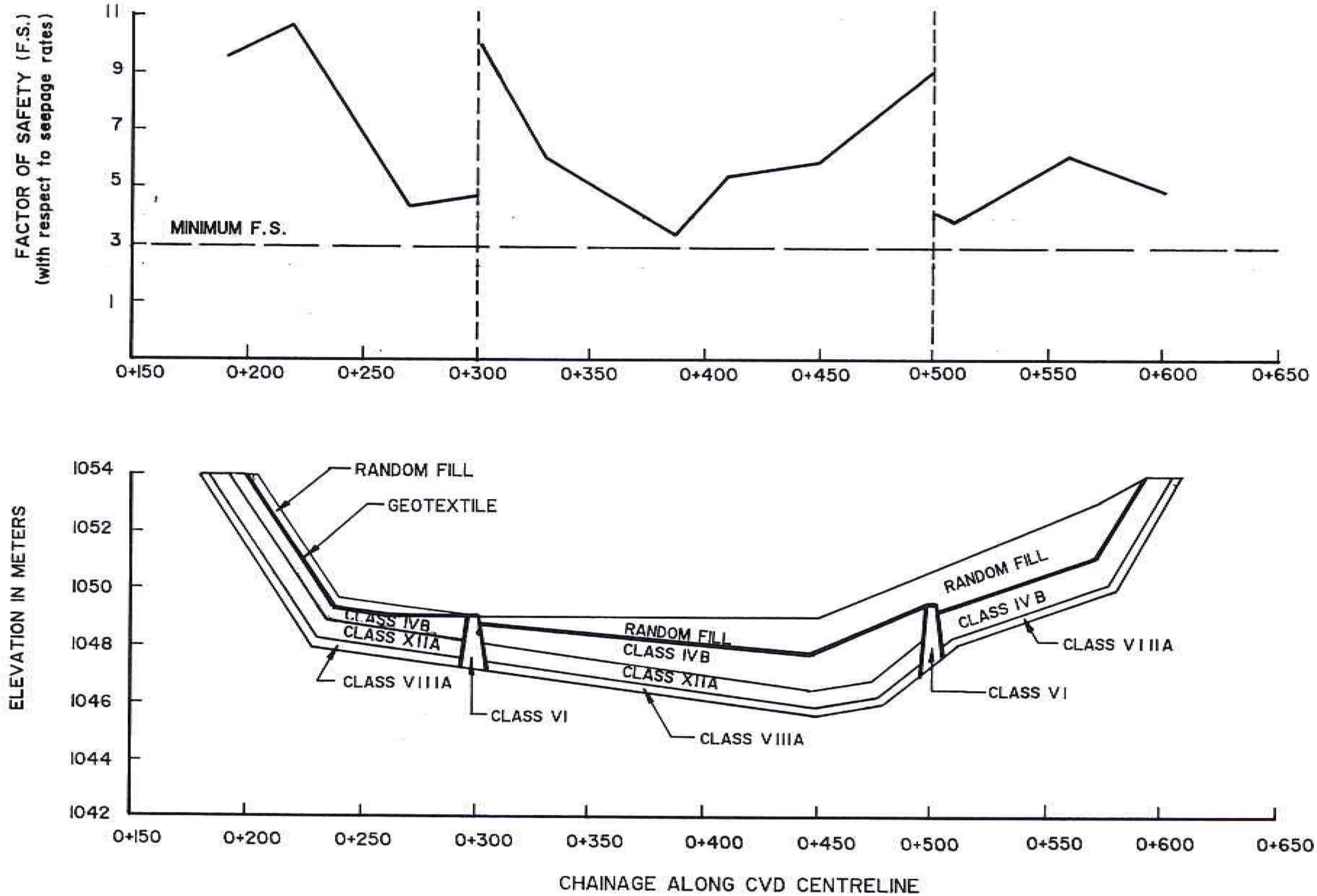

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SECTION THROUGH TOE DRAIN (LOOKING UPSTREAM) WITH ASSOCIATED FACTOR OF SAFETY WITH RESPECT TO SEEPAGE RATES

Figure 11