020379

DEVELOPMENT OF AN ABANDONMENT PLAN FOR FARO TAILINGS IMPOUNDMENT

Dr A. MacG Robertson
17th February, 1987.
~~11th March, 1987~~

TWO STUDIES:

REPORT 60601: EVALUATION OF ALTERNATIVE ABANDONMENT MEASURES FOR FARO MINE TAILINGS
REPORT 60602: ABANDONMENT PLAN DEVELOPMENT PROGRAM.

RELEVANT FACTORS:

1. EXISTING DEPOSITS AND STRUCTURES ARE A FAIT ACCOMPLI (REFER FIGURE 1.1).
2. TWO PRIMARY CONCERNS:
   (i) STABILITY OF ROSE CREEK
   (ii) ACID GENERATION.
3. FISCAL CAPABILITY OF CURRAGH RESOURCES
4. EVOLUTION IN CONTROL TECHNOLOGY

ADDITION

5. ACID GENERATION IS AN EVOLUTIONARY PROCESS — WE HAVE SOME TIME
6. ERRORS IN PREDICTIVE MODELLING
   (i) MODEL INACCURACY
   (ii) INPUT DATA INACCURACY

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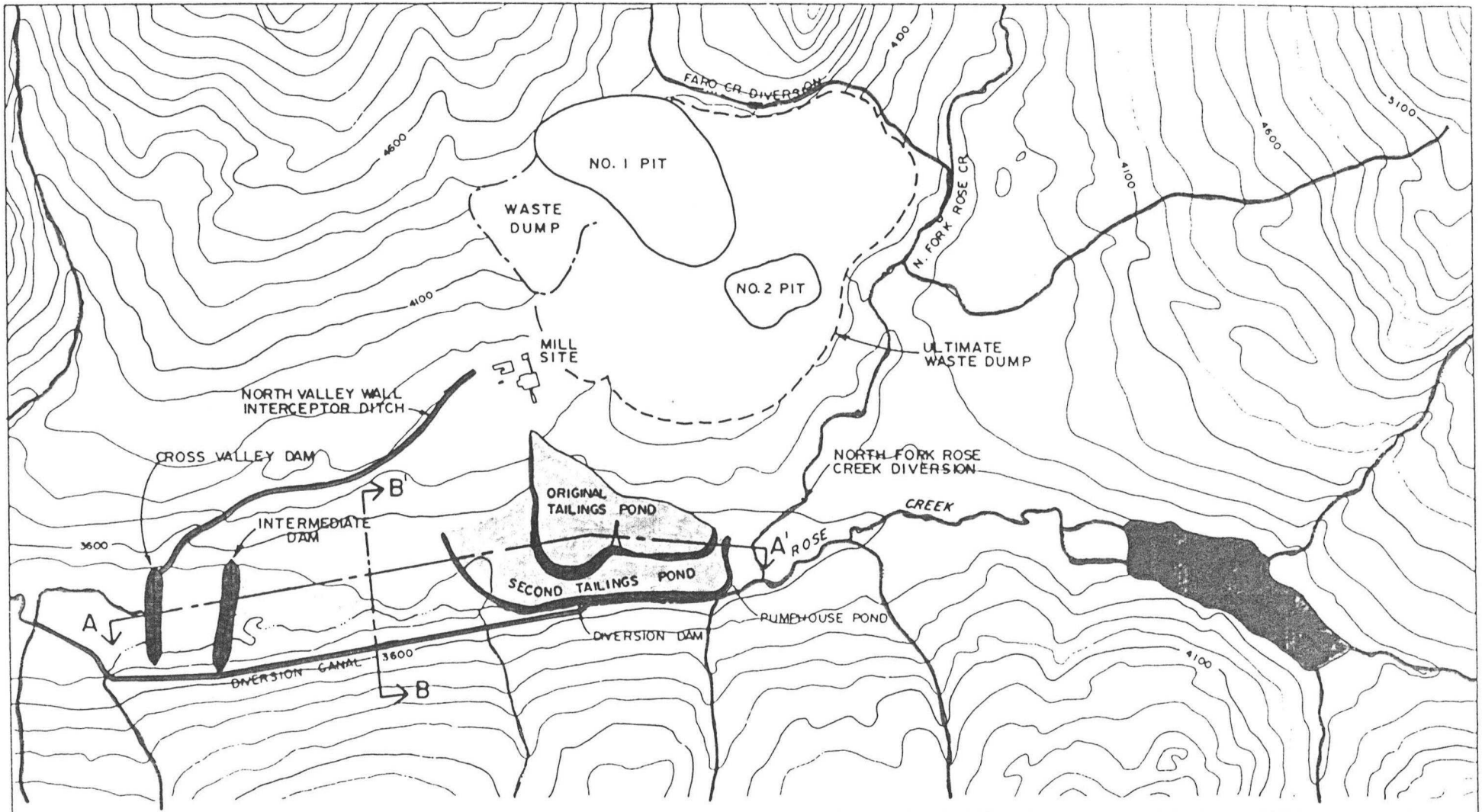

CURRAGH RESOURCES

FARO ABANDONMENT PLAN EVALUATION

FARO MINE LAYOUT

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DATE

PROJ NO

APPROVED

NO

1.1

REVIEW OF NEED FOR PHYSICAL AND CHEMICAL STABILIZATION OF FARO TAILINGS

TAILINGS SOLIDS:

PROVIDED THEY ARE NOT TAKEN UP IN SUSPENSION (EROSION + SOLUTION) AND TRANSPORTED INTO + DOWN ROSE CREEK, THE TAILINGS SOLIDS ARE NOT A CAUSE OF MATERIAL ENVIRONMENTAL IMPACT.

- EROSION PROTECTION IS REQUIRED TO PREVENT PARTICULATE SUSPENSION
- UNLESS CHEMICALLY ALTERED THE SOLUBILITY OF THE SOLIDS IS LOW AND SOLUTION IS NOT A MATERIAL SOURCE OF CONTAMINANTS

TAILINGS WATER

- SURFACE DISCHARGES ARE PREVENTED BY DAMS
- SEEPAGE OF CHEMICALLY UNALTERED TAILINGS WATER HAS BEEN DEMONSTRATED BY BOTH FIELD OBSERVATIONS AND MODELLING TO BE EFFECTIVLY BUFFERED AND DILLUTED ALONG THE SEEPAGE PATH TO YIELD ACCEPTABLE CONTAMINANT CONCENTRATIONS IN ROSE CREEK.

CHEMICAL ALTERATION

- CHEMICAL ALTERATION, PRIMARILY OXIDATION, RESULTS IN LARGE INCREASES IN THE CONTAMINANTS TAKEN INTO SOLUTION (NOTEABLY Zn, Cu, Fe) AND, UNLESS CONTROLLED, WOULD RESULT IN AN UNACCEPTABLE ENVIRONMENTAL IMPACT ON THE WATER QUALITY IN ROSE CREEK.
  - CONTROL OF OXIDATION OR OXIDATION PRODUCTS IS REQUIRED TO PREVENT UNACCEPTABLE SOLUBLE CONTAMINANT DISCHARGES.

REVIEW OF EROSION PROTECTION METHODS

1. TAILINGS SURFACE

   EROSION PREVENTION BY COVERS

   - WATER
   - RIP RAP
   - SOIL (WITH VEGETATION OR RIP RAP)
   - VEGETATION (WITH SOIL)

2. CREEK CHANELS / SPILL WAYS
   - BEDROCK CHANELS
   - RIP RAP
   - CONCRETE
   - ENERGY DISSIPATORS

3. DISRUPTIVE FORCES
   - EROSION
   - WEATHERING
   - FROST ACTION
   - BIOTIC ACTIVITY
   - BLOCKAGE
     - sediment
     - Glaciation
     - Vegetation
     - Debris

4. REQUIREMENT FOR LONG TERM MAINTENANCE

   BASED ON OUR EXPERIENCE AND A TWO YEAR ($300,000) STUDY FOR CANMET ON THE LONG TERM STABILITY OF TAILINGS IMPOUNDMENTS, IT IS OUR OPINION THAT A MINIMAL LEVEL OF MAINTENANCE WILL BE NECESSARY FOR <u>ALL</u> ABANDONMENT PLANS

REVIEW OF ACID GENERATION

ACID GENERATION

ACID GENERATION IS CONTROLLED BY THE FOLLOWING:-

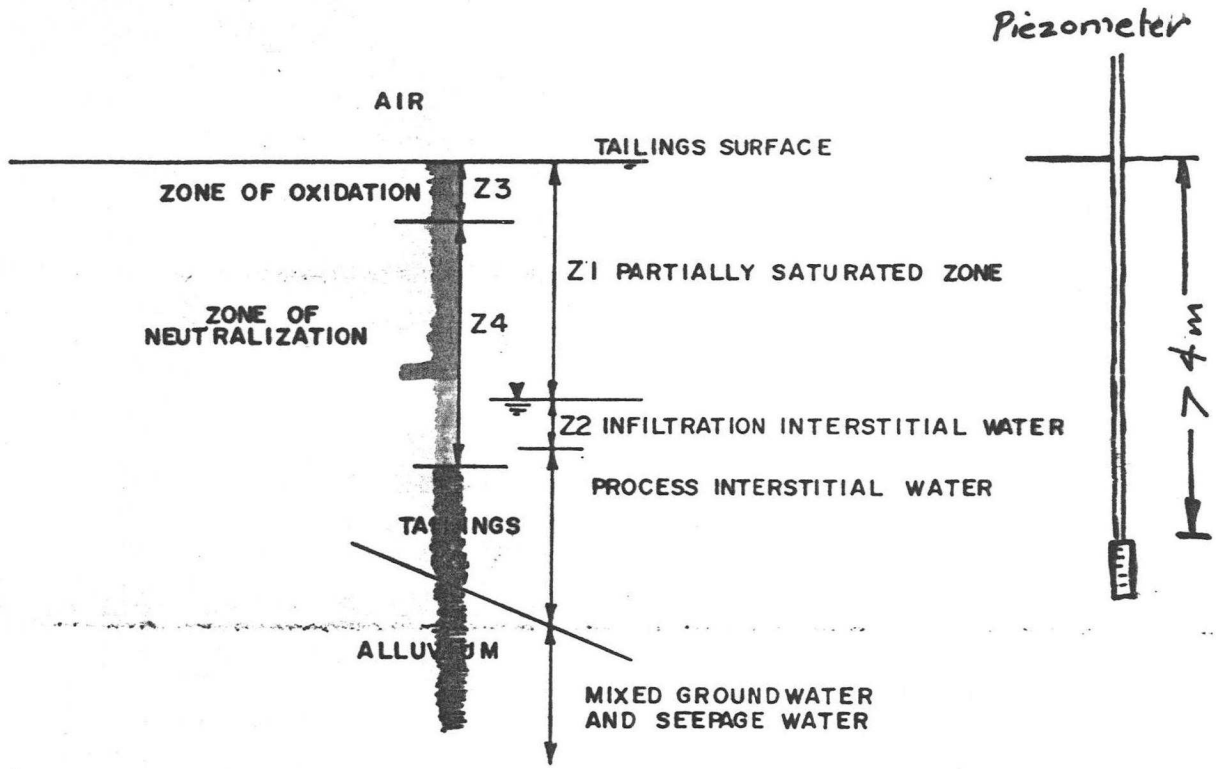
- PRESENCE OF REACTIVE SULPHIDES
- " " OXYGEN
- " " WATER
- " " ACID GENERATING BACTERIA
- TEMPERATURE

ACID GENERATION IN THE TAILINGS AT FARO

REFER FIGURE 1.10
" " 5.1
" " 6.1

CONCLUSIONS:-

- NO ACID GENERATING BACTERIA - CHEMICAL OXIDATION ONLY
- MAJORITY OF OXIDATION NEAR SURFACE
- PENETRATION OF ZONE OF NEUTRALIZATION ABOUT 2 m AFTER 4 YEARS.
  i.e. MIGRATION RATE ABOUT 0.5 m/year.



CURRAGH RESOURCES	DATE
FARO ABANDONMENT PLAN EVALUATION BASIC WATER QUALITY MODEL FOR TAILINGS COLUMN	PROJ. NO. APPROVED NO 1.10
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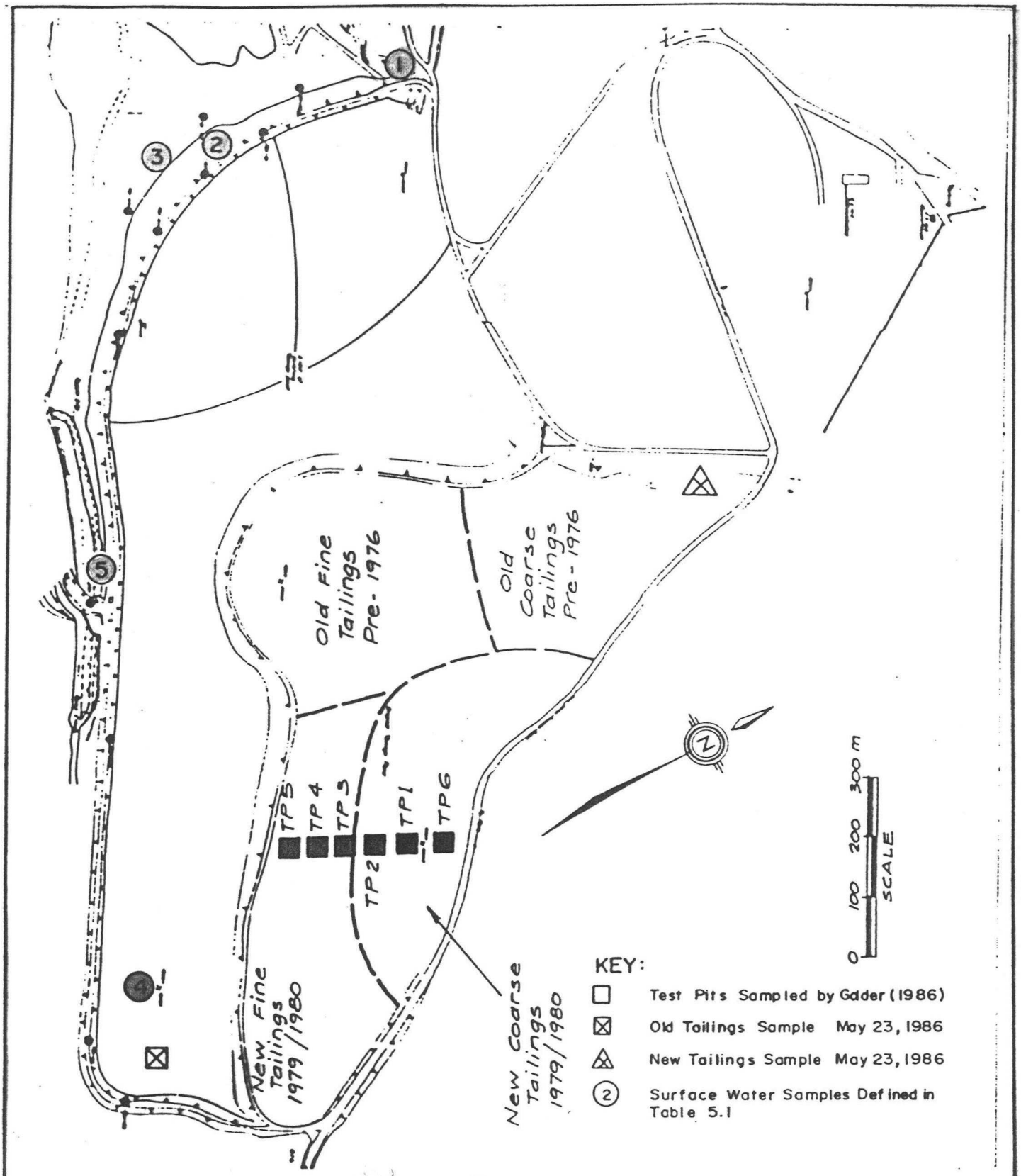

CURRAGH RESOURCES

DATE

PROJ. NO.

APPROVED

SITE PLAN AND TEST PIT LOCATIONS

NO. 5.1

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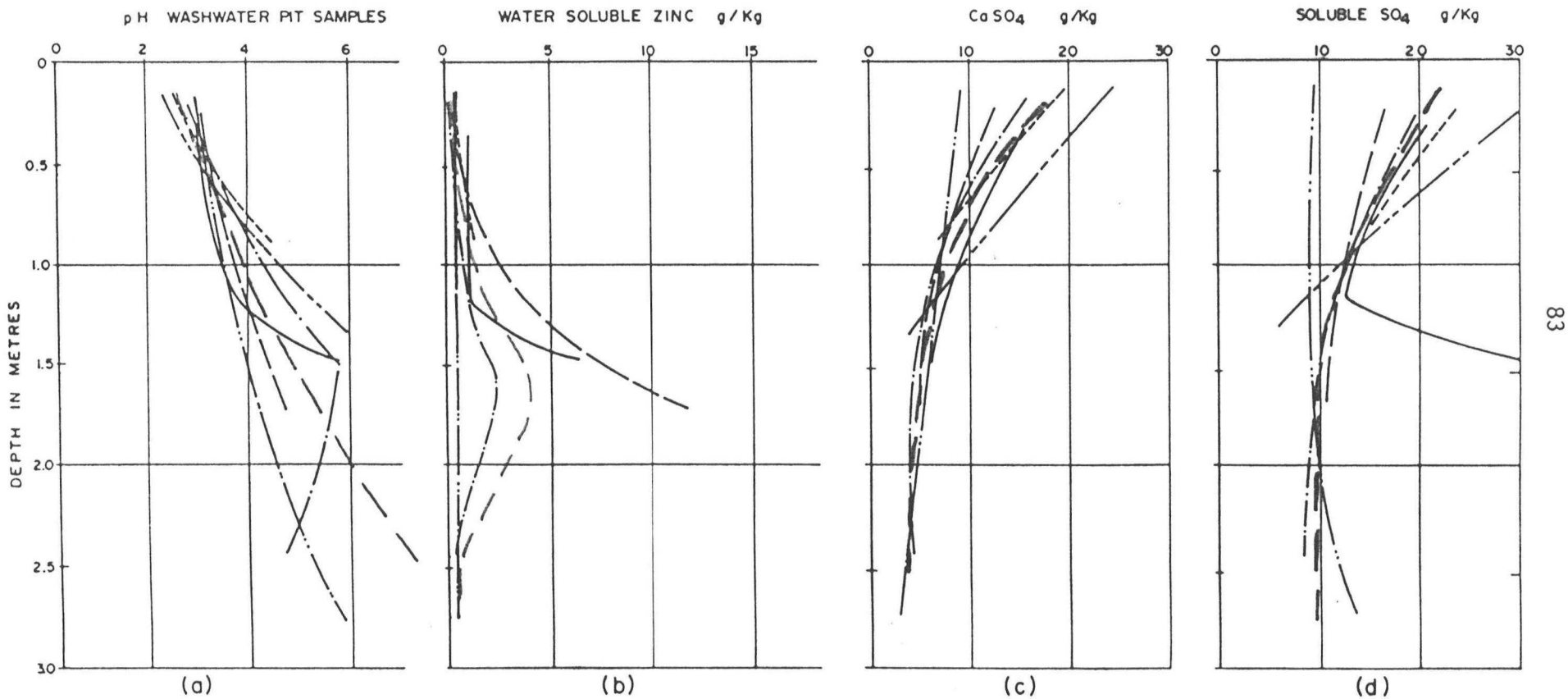


Figure 6.1 pH AND SALT CONCENTRATION PROFILES IN TAILINGS DETERMINED FROM SAMPLES FROM TEST PITS EXCAVATED BY GOLDER ASSOCIATES IN 1985

REVIEW OF ACID PRODUCTS MIGRATION

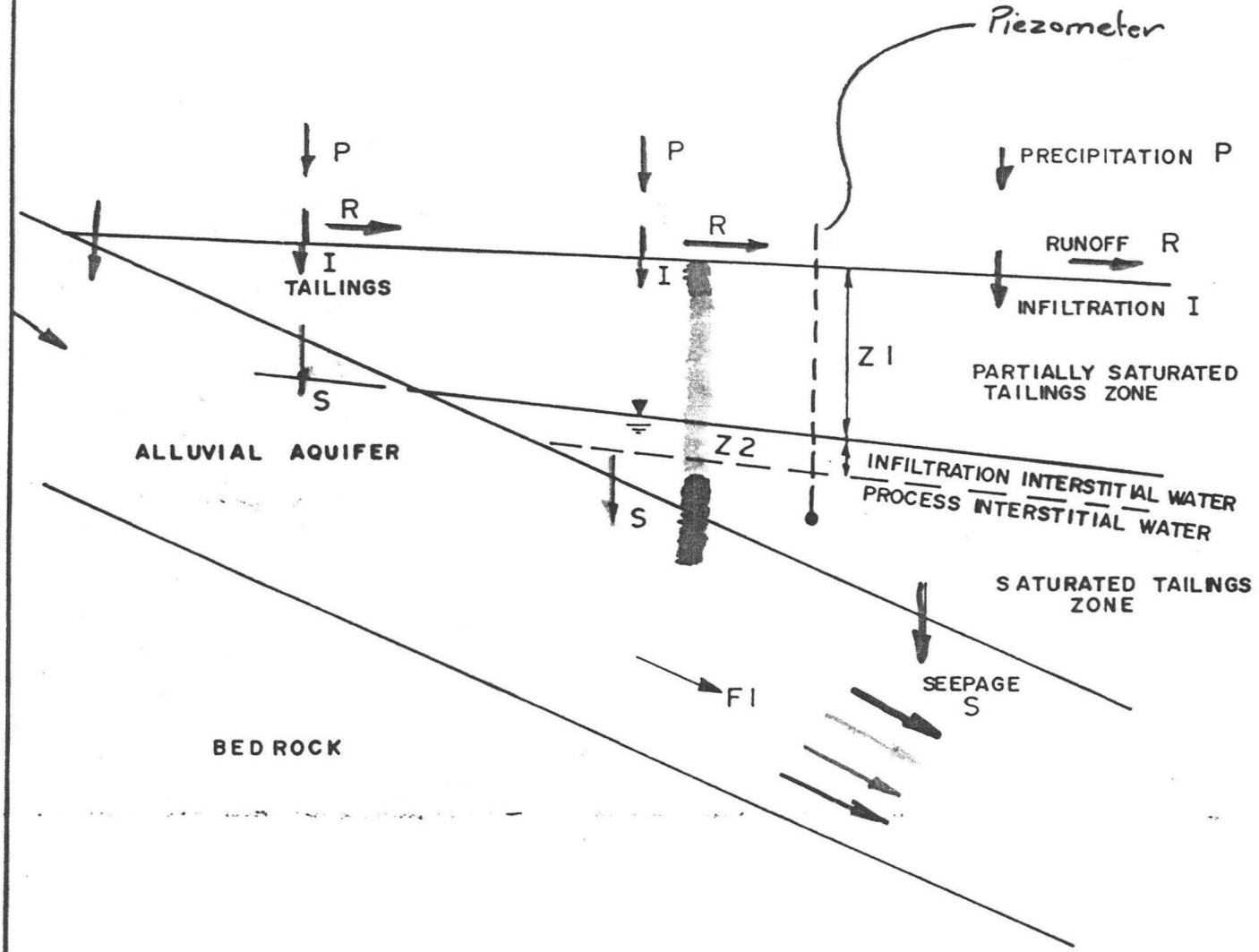
REFER FIGURE 1.9
REFER FIGURE 1.8

- INFILTRATION WATER PASSES THROUGH THE TAILINGS COLUMN THROUGH THE FOLLOWING ZONES
  - (i) OXIDATION ZONE (UPPER FEW DECIMETERS)
  - (ii) NEUTRALIZATION ZONE (DOWN TO 2 m)
- INFILTRATION COLLECTS ABOVE THE INTERSTITIAL TAILINGS WATER, DISPLACING IT DOWNWARDS
- ALL SEEPAGE FRONTS MOVE DOWNWARDS WITH TIME
- CONTAMINANT LOADING TO THE ALLUVIAL AQUIFER INCREASES WITH TIME
- CURRENT MONITORING INDICATES: (SEE FIGURE 7.1)
  - NEUTRALIZATION ZONE HAS NOT YET REACHED THE PIEZOMETERS
  - GROUNDWATER QUALITY AT OBSERVATION WELLS HAVE NOT BEEN SIGNIFICANTLY IMPACTED (SEE FIGURE 1.3 FOR COMPLEX FLOW CONDITIONS).

CONCLUSIONS:

CONTAMINANT LOADING TO THE ALLUVIAL AQUIFER DUE TO ACID GENERATION IS CURRENTLY SUFFICIENTLY SMALL AND CHEMICAL ATTENUATION SUFFICIENTLY LARGE THAT GROUNDWATER CONTAMINATION AT MONITORING POINTS IS NOT SIGNIFICANT.

RELIABLE ACCURATE BASELINE QUALITY IS NOT AVAILABLE FOR RELIABLE COMPARATIVE PURPOSES



All seepage fronts move downwards with time.

CURRAGH RESOURCES	DATE
FARO ABANDONMENT PLAN EVALUATION	PROJ. NO.
INFILTRATION/SEEPAGE MODEL	APPROVED
	NO. 1.9
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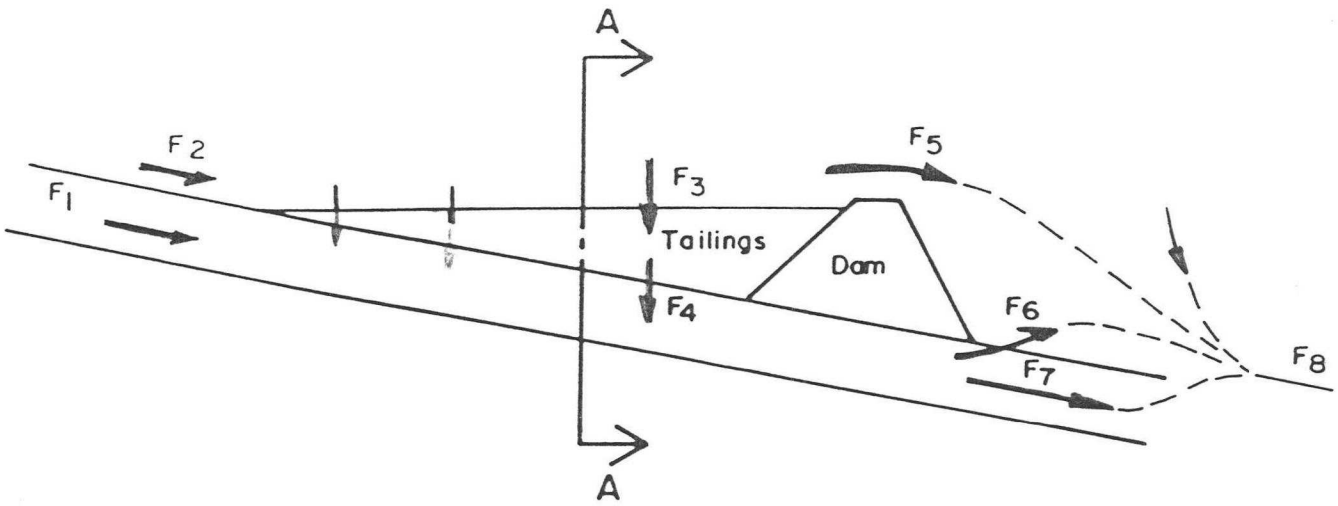
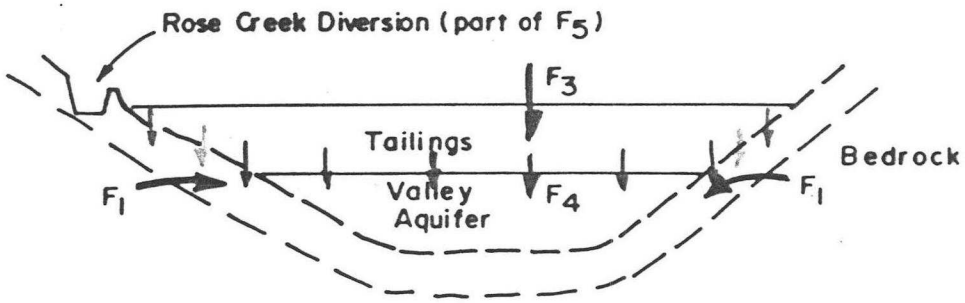


LONG SECTION



CROSS-SECTION A-A

F_1 = Upstream subsurface flow into valley aquifer below tailings

F_2 = Upstream surface flow

F_3 = Infiltration into tailings

F_4 = Seepage from tailings into valley aquifer

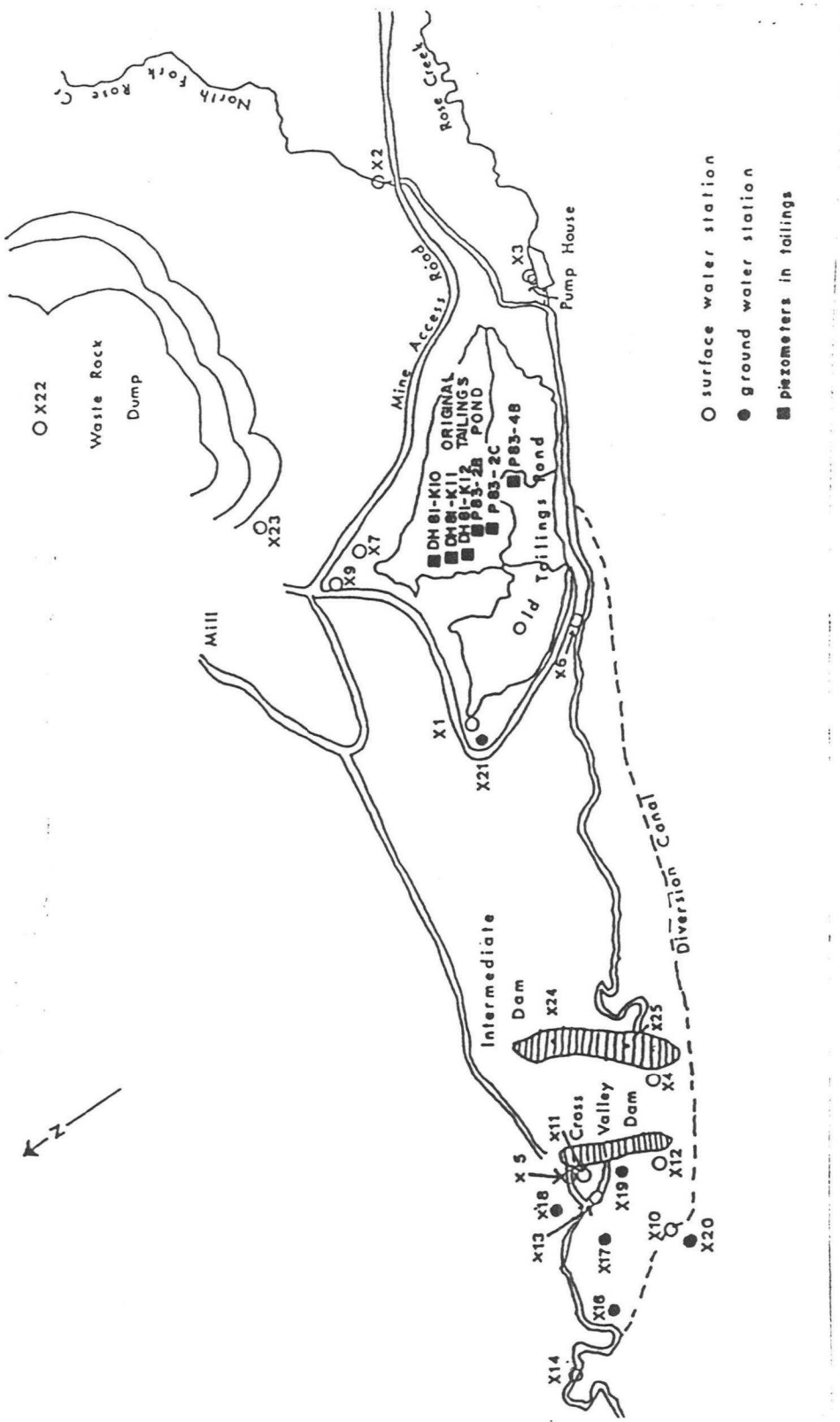
F_5 = Total surface flow passing tailings embankment (Rose Creek and North Channel diversion flows plus discharge from Cross Valley Dam Spillway)

F_6 = Groundwater discharge to surface below embankment

F_7 = Groundwater flow in valley aquifer

F_8 = Combined surface and groundwater flow downstream of tailings impoundment

Figure 1.8 - Definition of Principal Ground and Surface Water Flows



CURRAGH RESOURCES

FARO ABANDONMENT PLAN EVALUATION

WATER QUALITY SAMPLING POINT LOCATIONS FOR WATER LICENSE YIN85-05AL

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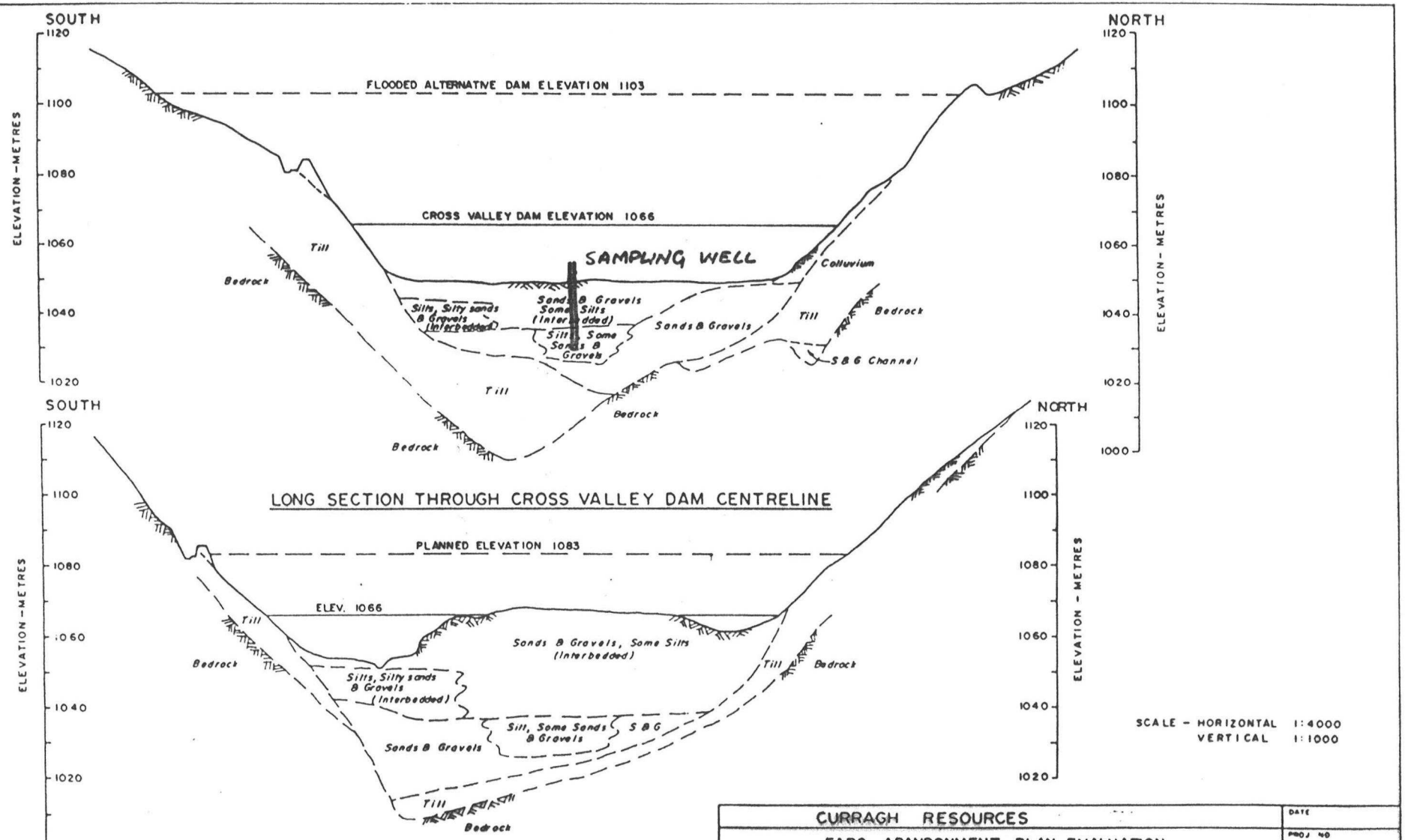
DATE

PROJ. NO.

APPROVED

NO. 7.1



(REFERENCE : KLOHN LEONOFF, 1981, DRWG. D-2758-110
: GOLDER ASSOCIATES DRWG. NO.'S 7922025-8 & 10)

CURRAGH RESOURCES

FARO ABANDONMENT PLAN EVALUATION

CROSS SECTIONS THROUGH ROSE CREEK VALLEY

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DATE
PROJ NO
APPROVED
NO 1.3

MODELLING OF FUTURE IMPACTS

COMPLEX MODELS REQUIRED (SEE FIGURE 1)

SIMPLISTIC "WORST CASE" MODEL USED BY KLOHN-LEONOFF (1981) (SEE FIGURE 2.2)

SIMPLISTIC MODEL USED ALSO BY SRK.
- VARIOUS CONDITIONS OF ACID GENERATION AND INFILTRATION INVESTIGATED

CONCLUSIONS:

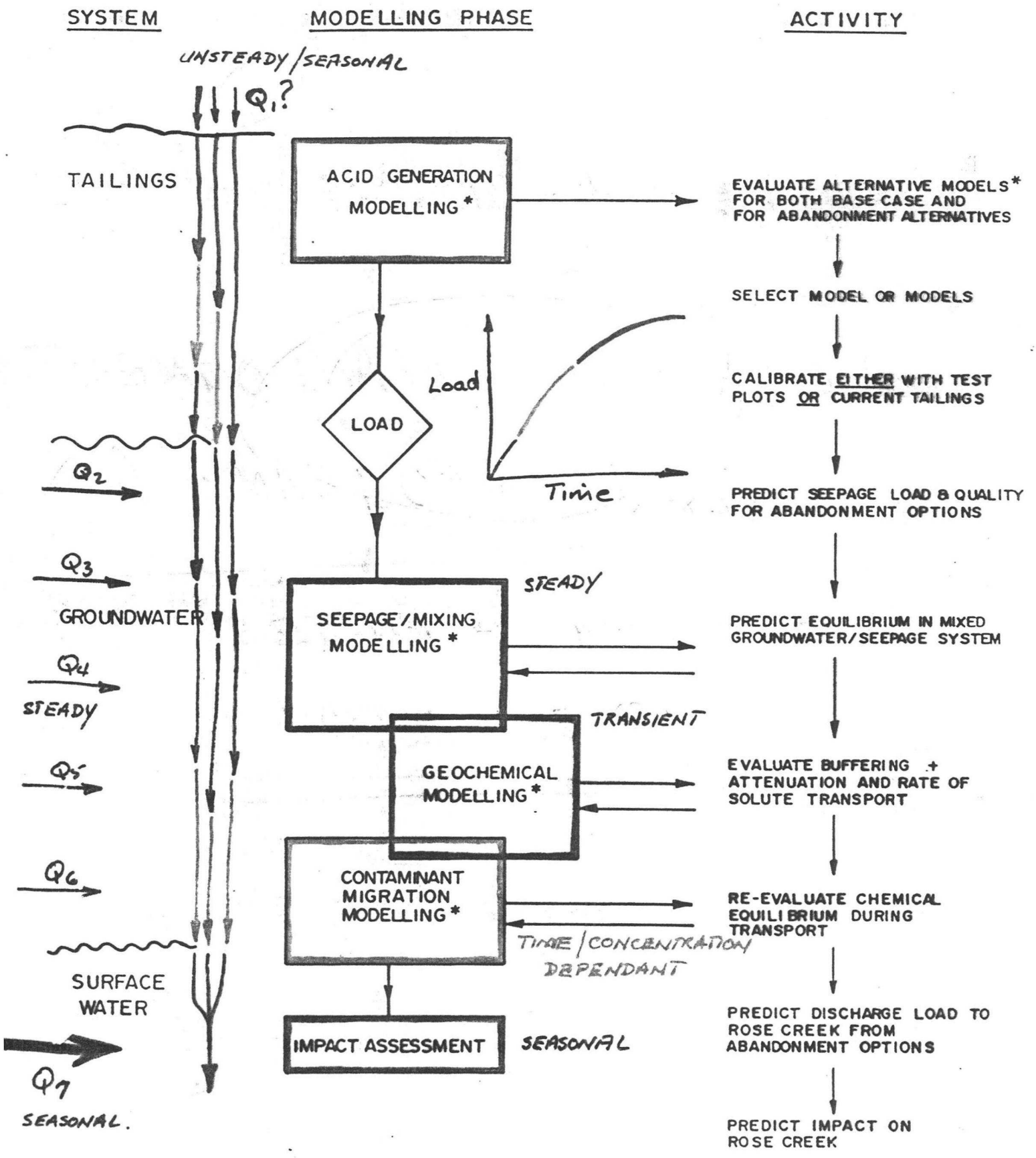
(i) INPUT DATA INADEQUATE
PARTICULARLY - ACID GENERATION RATE
- INFILTRATION
- TAILINGS BUFFERING
- FOUNDATION SOILS BUFFERING
- GROUNDWATER BASELINE QUALITY
- SURFACEWATER BASELINE QUALITY

(ii) MODELS SIMPLISTIC AND INADEQUATE PARTICULARLY FOR ACID GENERATION/CONCENTRATION RATES.

(iii) WORST CASE CONDITIONS GAVE UNACCEPTABLE IMPACTS
BEST CASE CONDITIONS GAVE ACCEPTABLE IMPACTS

(iv) DILUTION RATIOS TO MEET WATER QUALITY STANDARDS WERE CALCULATED.

FIGURE 7.1 : INTERELATIONSHIPS IN MODELLING



(* THIS STAGE — EVALUATE / SELECTION OF MODELS — APPLIES TO ALL MODEL TYPES, NOT JUST ACID GENERATION)

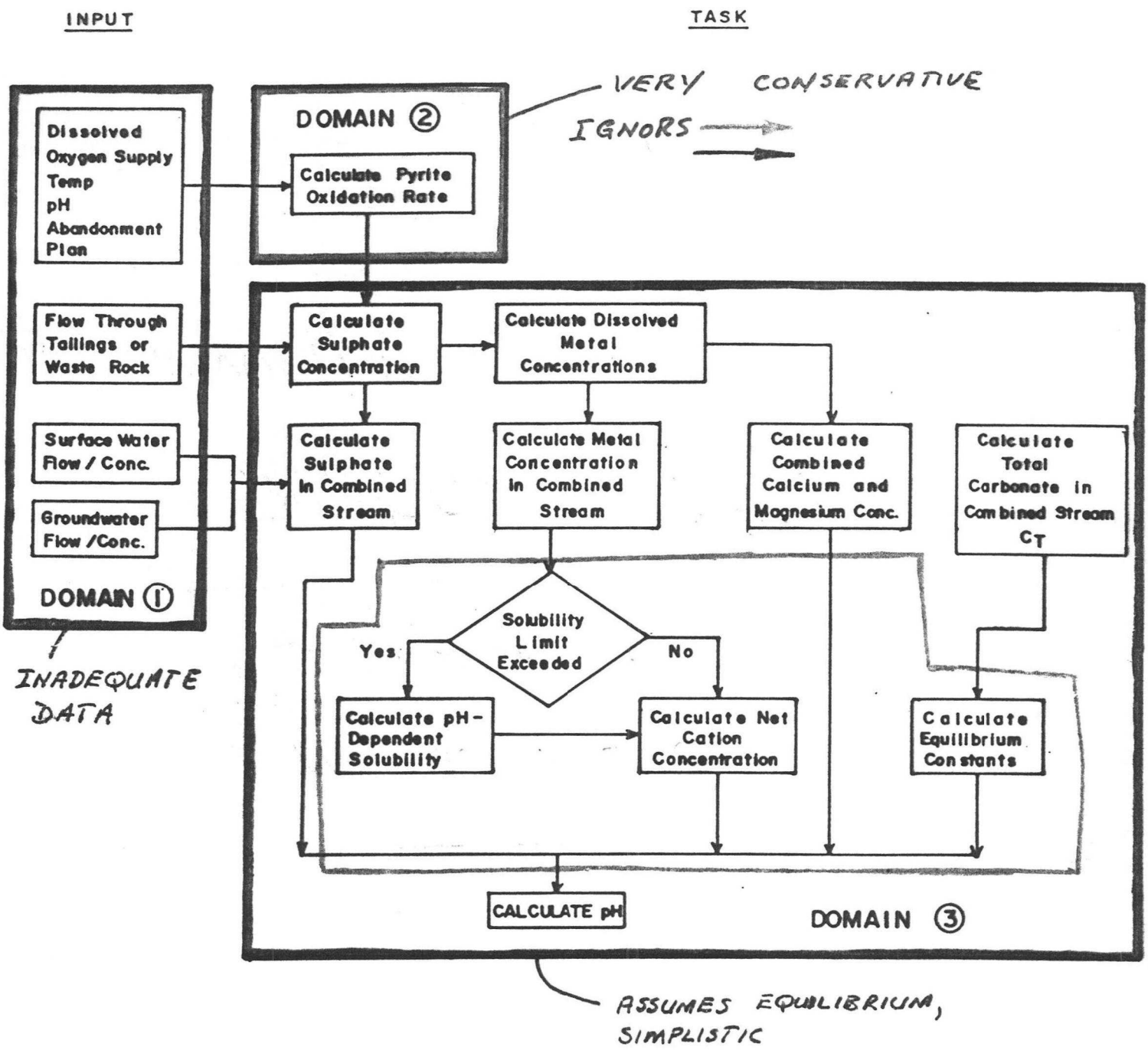
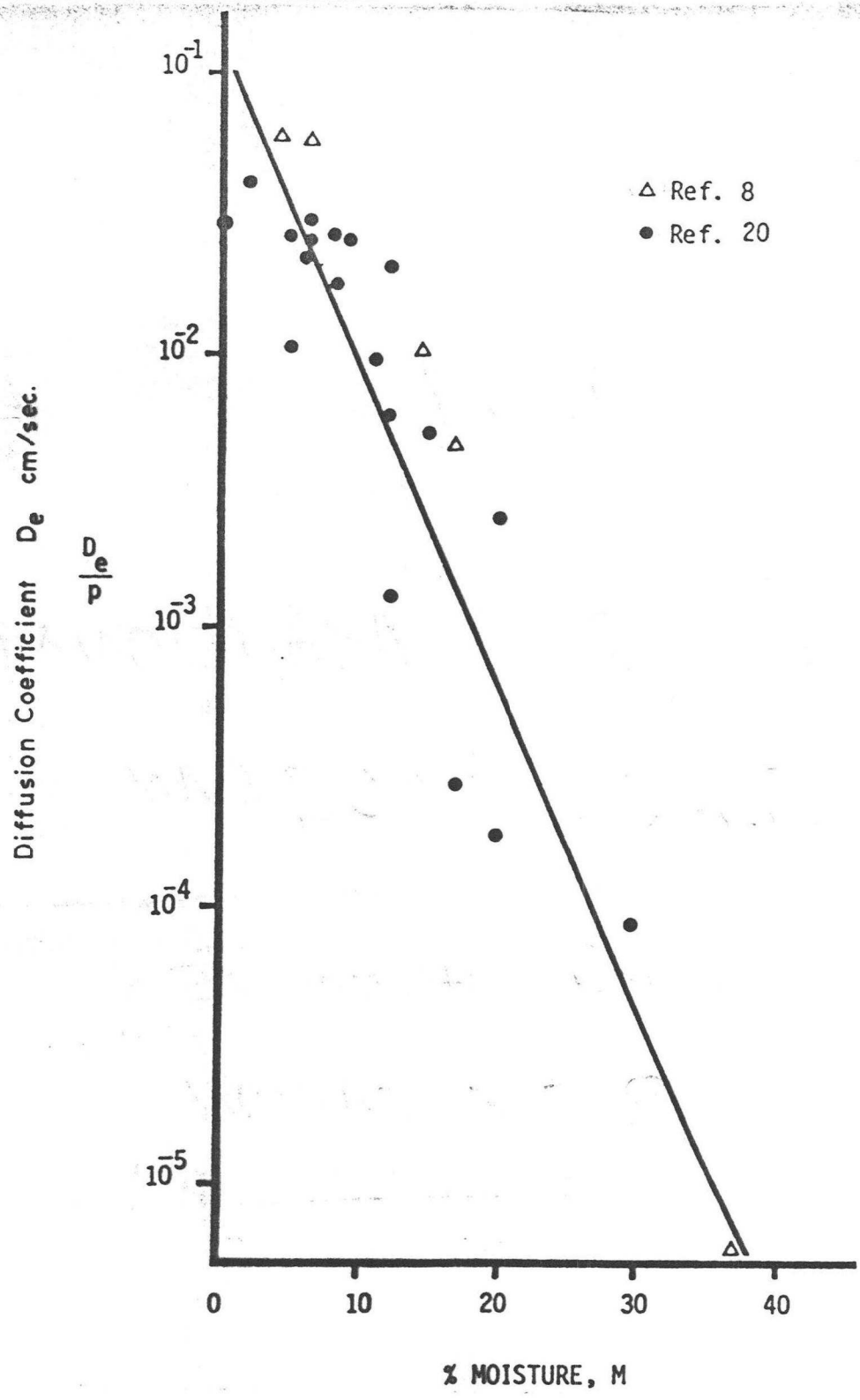


FIGURE 2.2 SCHEMATIC DIAGRAM OF THE KLOHN-LEONOFF WATER QUALITY MODEL (KLOHN-LEONOFF, 1981)

ACID DRAINAGE CONTROL TECHNOLOGY

THREE BASIC CONTROL METHODS

1. CONTROL OF ACID GENERATION.
   - (i) Exclusion of oxygen
     - Water cover
     - Synthetic membrane cover
     - Soil/Clay cover (Gray Eagle mine)
     - Marsh cover (See Figure 8.1)
       (" " 8.2)
   - (ii) Exclusion of water
     - Synthetic membrane cover
     - Soil / Clay cover
   - (iii) Pyrite removal
   - (iv) Temperature control (See figure 8.3)
   - (v) Bacteria control.
2. NEUTRALIZATION OF ACID
   - (i) in-situ
     - lime / lime stone covers.
     - mixing / grouting with base mat.
   - (ii) seepage
     - chemical treatment
     - wetland treatment
     - lime / limestone trenches.
3. PREVENTION OF MIGRATION
   - (i) Barriers
     - liners
     - cut-off's
   - (ii) Collection
     - wells



(ROGERS AND NIELSON, 1981)

CURRAGH RESOURCES	DATE
FARO ABANDONMENT PLAN EVALUATION	PROJ. NO.
MOISTURE DEPENDENCE OF THE DIFFUSION COEFFICIENT	APPROVED
	NO. 8.1
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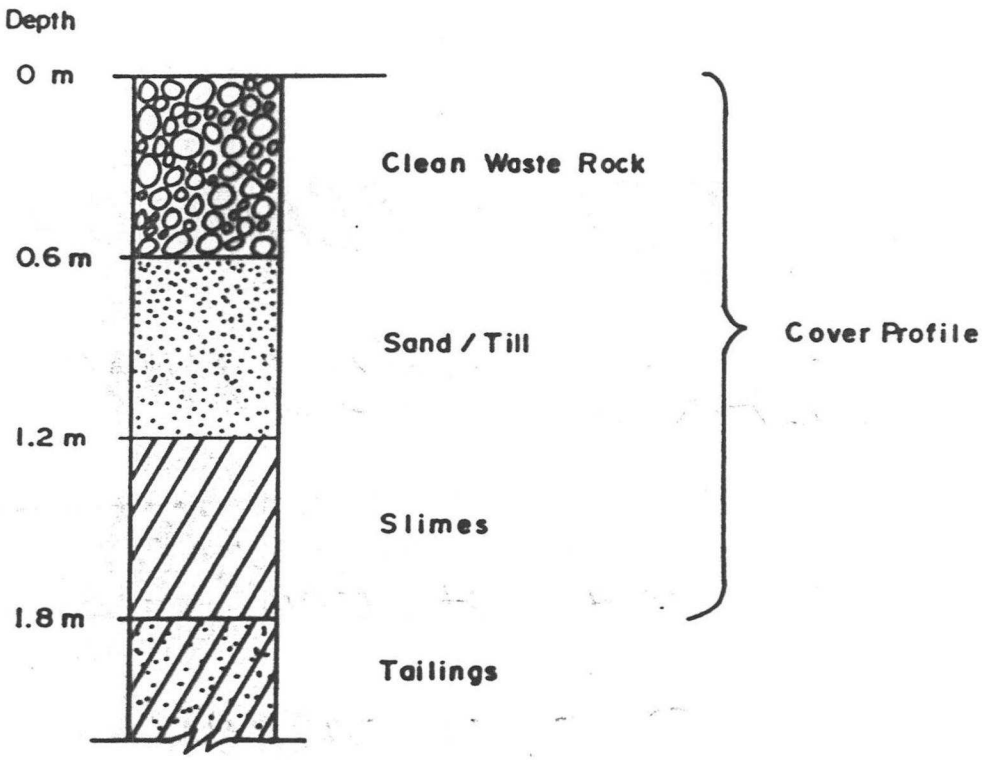


FIGURE 8.2 COVER PROFILE ANALYSED FOR FROST PENETRATION

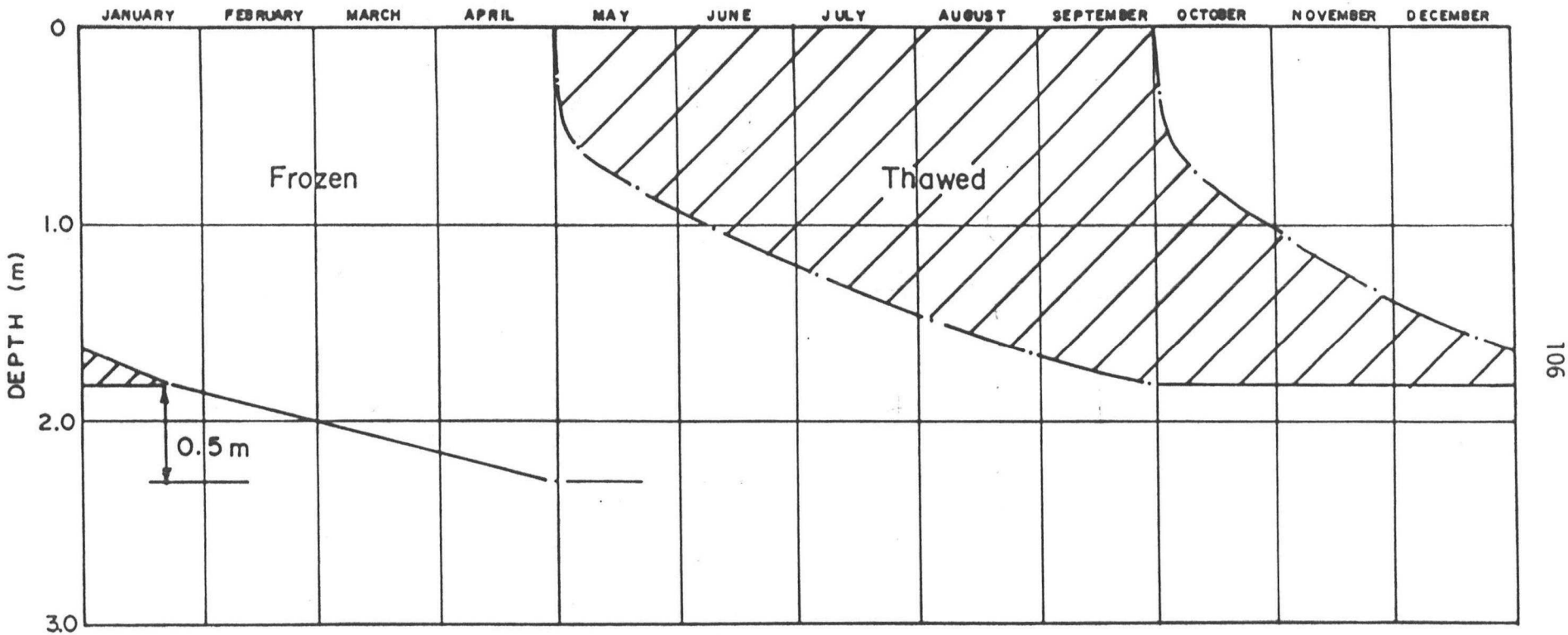


FIGURE 8.3 FROST DIAGRAM - FARO TAILINGS

EVALUATION OF ALTERNATIVE ABANDONMENT PLANS

(i) Do nothing case — See Figure 1.2.

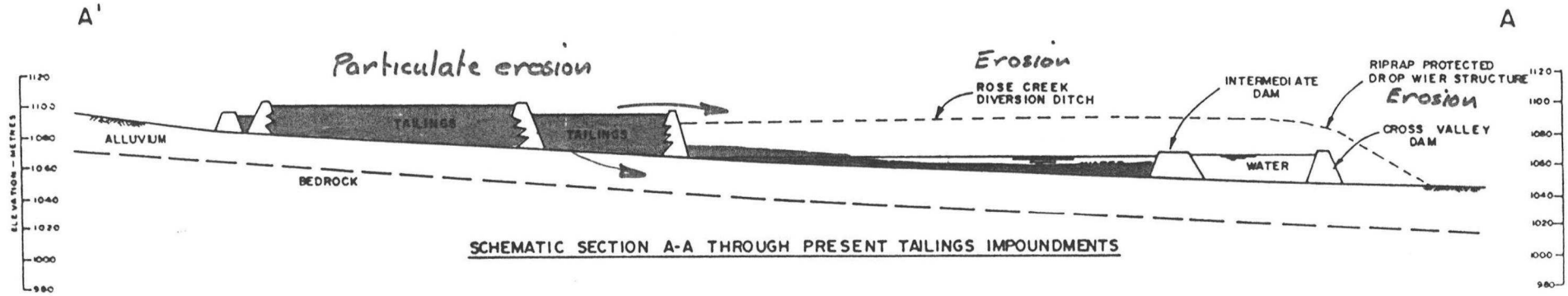
(ii) Base case - 0.6m till cover — See Figure 1.4
See Table 8.5

(iii) Alternative A - Water cover — See Figure 1.5

(iv) Alternative B - Saturated Layer Cover
See Figure 1.6.

(v) Alternative C - Combination A+B — See Figure 1.7

(vi) Alternative D - Combination A and Base Case
See Figure 8.8.



SCHEMATIC SECTION A-A THROUGH PRESENT TAILINGS IMPOUNDMENTS

Do Nothing Option
- Erosion of tailings and chanels
- Rose Creek chanel erosion
- " " spillway erosion
- Unacceptable water quality
-

Cost $8.8 million to raise Cross Valley Dam

CURRAGH RESOURCES	DATE
FARO ABANDONMENT PLAN EVALUATION	PROJ NO
LONG SECTION THROUGH EXISTING IMPOUNDMENTS	APPROVED NO 1.2
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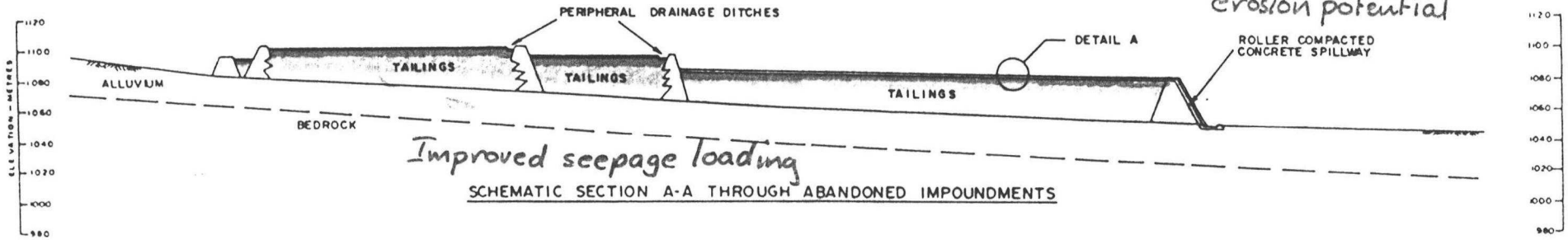
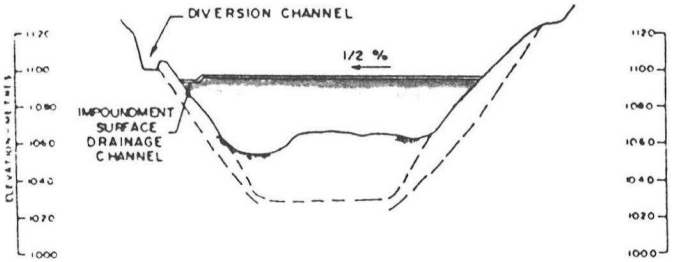
Reduced erosion potential

Considerably reduced erosion potential

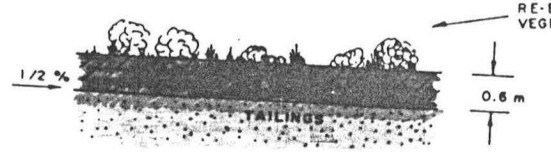


Improved seepage loading

SCHEMATIC SECTION A-A THROUGH ABANDONED IMPOUNDMENTS



CROSS-SECTION @ B-B
(Refer Fig. 1.1)



DETAIL A

Initial cover placed early
Improved erosion protection
Improved seepage water quality

Cost $ 27 million
($ 20)

CURRAGH RESOURCES	DATE
FARO ABANDONMENT PLAN EVALUATION	PROJ. NO
BASE CASE - SHALLOW TILL COVER	APPROVED
	NO. 1.4
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TABLE 8.5

COST ESTIMATE FOR BASE CASE

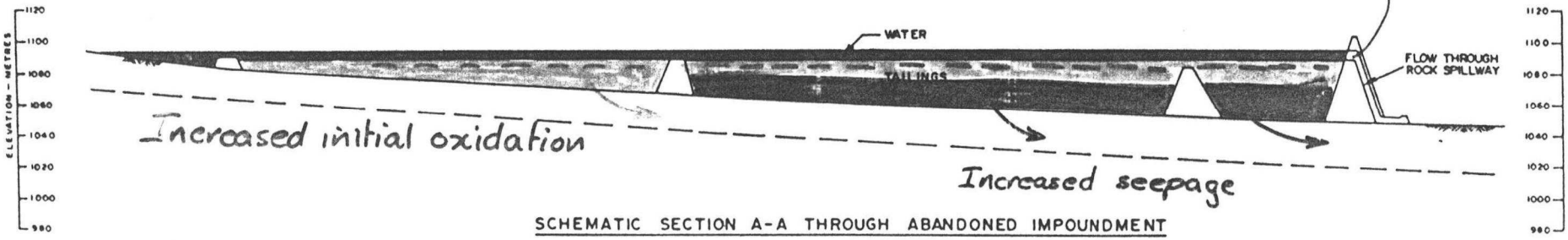
Operation	Description	Cost (millions $)
1. *Costs common to all schemes	Refer Klohn Leonoff, 1981, Table 5.1	0.8
2. *Surface preparation	- spigot discharge to form beach slopes - some dyke building and winter drainage preparation	1.00
3. *Cover placement	- 1.35 x 10^6 m^3 @ $3.00	4.05
4. *Riprap ditches/ embankments	- 75,000 m^3 @ $3.00	0.23
5. *Revegetation	225 ha @ $6,000/ha	1.35
6. *Faro Creek Diversion	- 1,300 m @ $200/m	0.26
7. *Upgrade North Valley Interceptor ditch	- 2500 m @ $400/m	1.00
8. Dredge and riprap	excavate 945,000 m^3 @ $4.00	3.78
9. Rose Creek Channel	Riprap 450,000 m^3 @ $6.00	2.70
10. *Raise Cross Valley Dam to El 1091	1.66 x 10^6 m^3 @ $4.00	6.64
11. *Dam Foundation Prep.	440,000 m^3 @ $5.00	2.2
12. *Construction of Roller Compacted Concrete Spillway	26,000 m^3 @ $90.00	3.10
	TOTAL	$27.11

Notes:

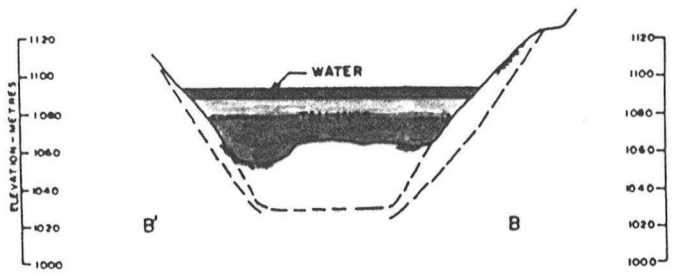
1. Cost estimates in 1986 $
2. *Items that can be entirely or partially constructed during mine operation.
3. Cost of construction that can be commenced only after tailing deposition stops = $ 11.3 million.

Blockage potential

Reduced (elminated) Chanel erosion



SCHEMATIC SECTION A-A THROUGH ABANDONED IMPOUNDMENT



CROSS-SECTION B'-B
(Refer Fig. 1.1)

Chanel erosion eliminiated.
Potential for spillway blockage
Increased initial oxidation
Increased seepage
cover Placed at end of operations
Cost $58 million + $6 million
($48) (+ $6 million)

CURRAGH RESOURCES	DATE
FARO ABANDONMENT PLAN EVALUATION	PROJ NO
ALTERNATIVE A - FLOODED TAILINGS KLOHN LEONOFF (1981)- SCHEME 2	APPROVED NO 1.5
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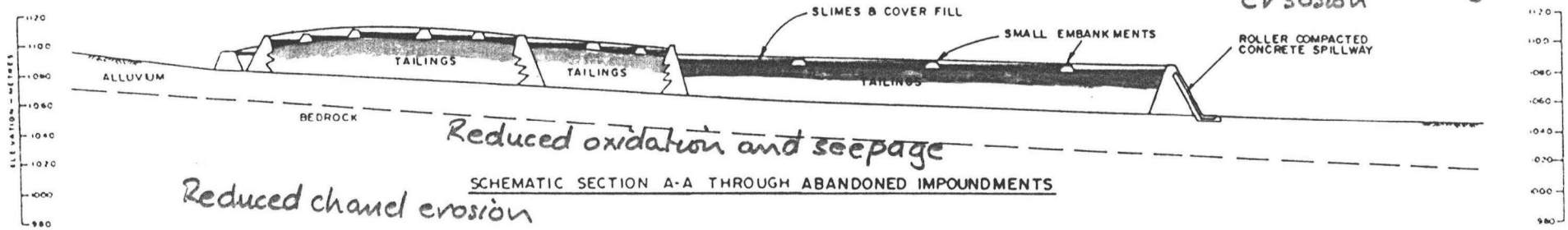
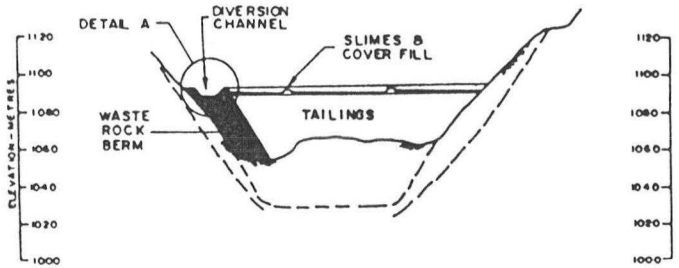
Reduced spillway ersosion



Reduced oxidation and seepage

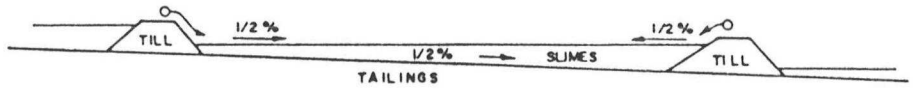
SCHEMATIC SECTION A-A THROUGH ABANDONED IMPOUNDMENTS

Reduced chanel erosion

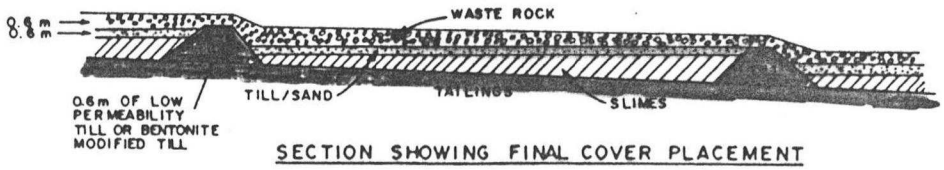


CROSS-SECTION B-B

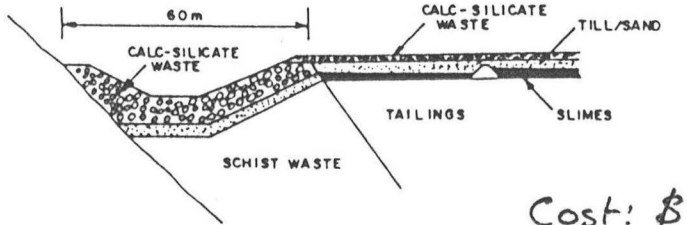
(Refer Fig. 1.1)



SECTION SHOWING SLIMES DEPOSITION



SECTION SHOWING FINAL COVER PLACEMENT



DETAIL A

Initial tailings can be covered early

Cost: $ 37 million ($27)

CURRAGH RESOURCES	DATE
FARO ABANDONMENT PLAN EVALUATION	PROJ. NO.
ALTERNATIVE B - SATURATED COVER	APPROVED
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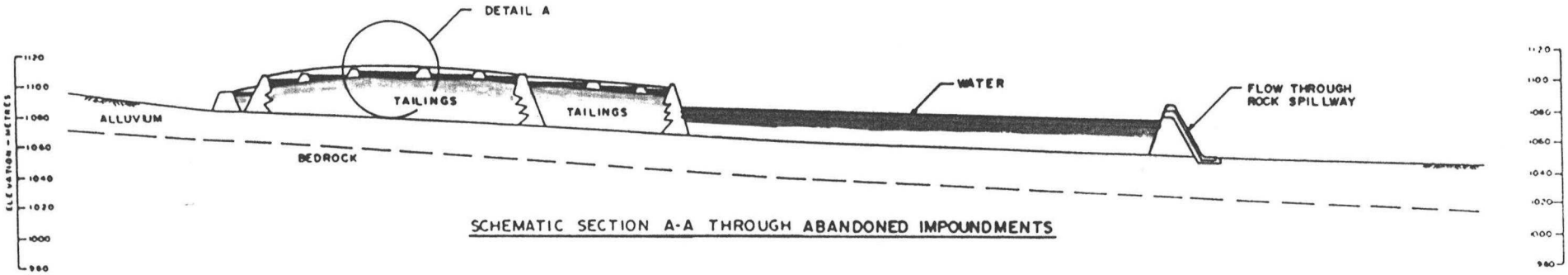
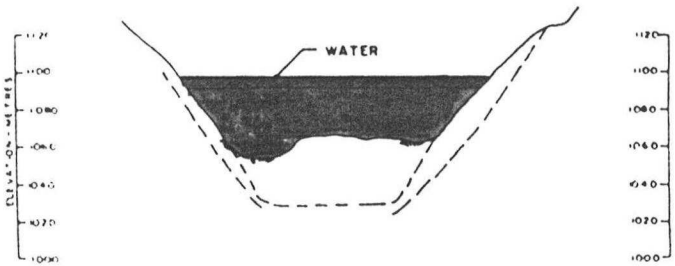
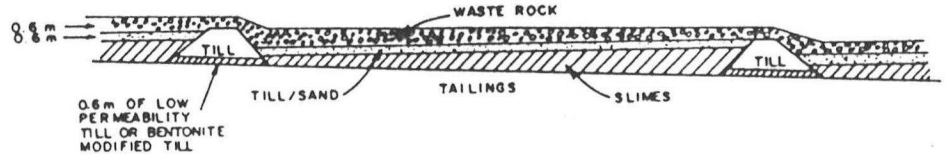


SCHEMATIC SECTION A-A THROUGH ABANDONED IMPOUNDMENTS



CROSS-SECTION @ B-B
(Refer Fig. 1.1)

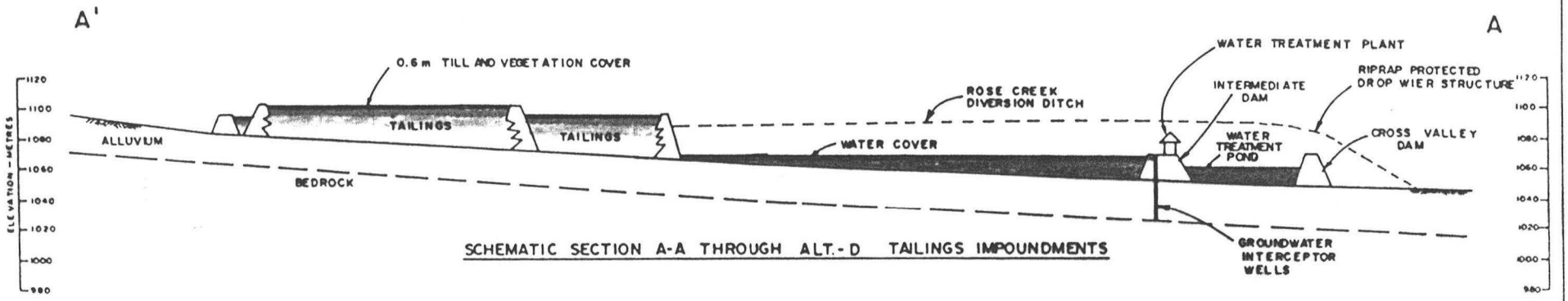


SECTION SHOWING DETAIL A - FINAL COVER PLACEMENT

Most advantages of A and B.
Initial tailings can be covered early

Cost $31 million ($21).

CURRAGH RESOURCES	DATE
FARO ABANDONMENT PLAN EVALUATION	
COMBINATION OF ALTERNATIVE A AND B	
STEFFEN ROBERTSON & KIRSTEN, Consulting Engineers	1.7



SCHEMATIC SECTION A-A THROUGH ALT.-D TAILINGS IMPOUNDMENTS

Maintenance Required.
Groundwater Interception
provided as a contingency.
Early reclamation of initial imp.
Cost $13 million excluding
($3.5) operating costs

CURRAGH RESOURCES	DATE
FARO ABANDONMENT PLAN EVALUATION	PROJ NO
LONG. SECTION THROUGH ALT.-D IMPOUNDMENTS	APPROVED NO 8.8
STEFFEN ROBERTSON & KIRSTEN, Consulting Engineers	

PROPOSED ABANDONMENT PLAN DEVELOPMENT PROGRAM

PHASE I. (4 years)

(i) Obtain site specific data on acid generation rates and contaminant migration to enable more reliable impact prediction (modelling)

(ii) Demonstrate effectiveness of alternative cover types.

(iii) Determine the most cost effective method of acid generation control at Faro

(iv) Develop Abandonment Plan.

PHASE II (Year 5 to close-out)

Impliment and monitor pre-close-out measures and re-evaluate the Abandonment Plan

PHASE III (After mine closure)

Implimient Final Abandonment Plan

PHASE IV (Long-term)

Long term monitoring and maintenance

PHASE I PROGRAM.

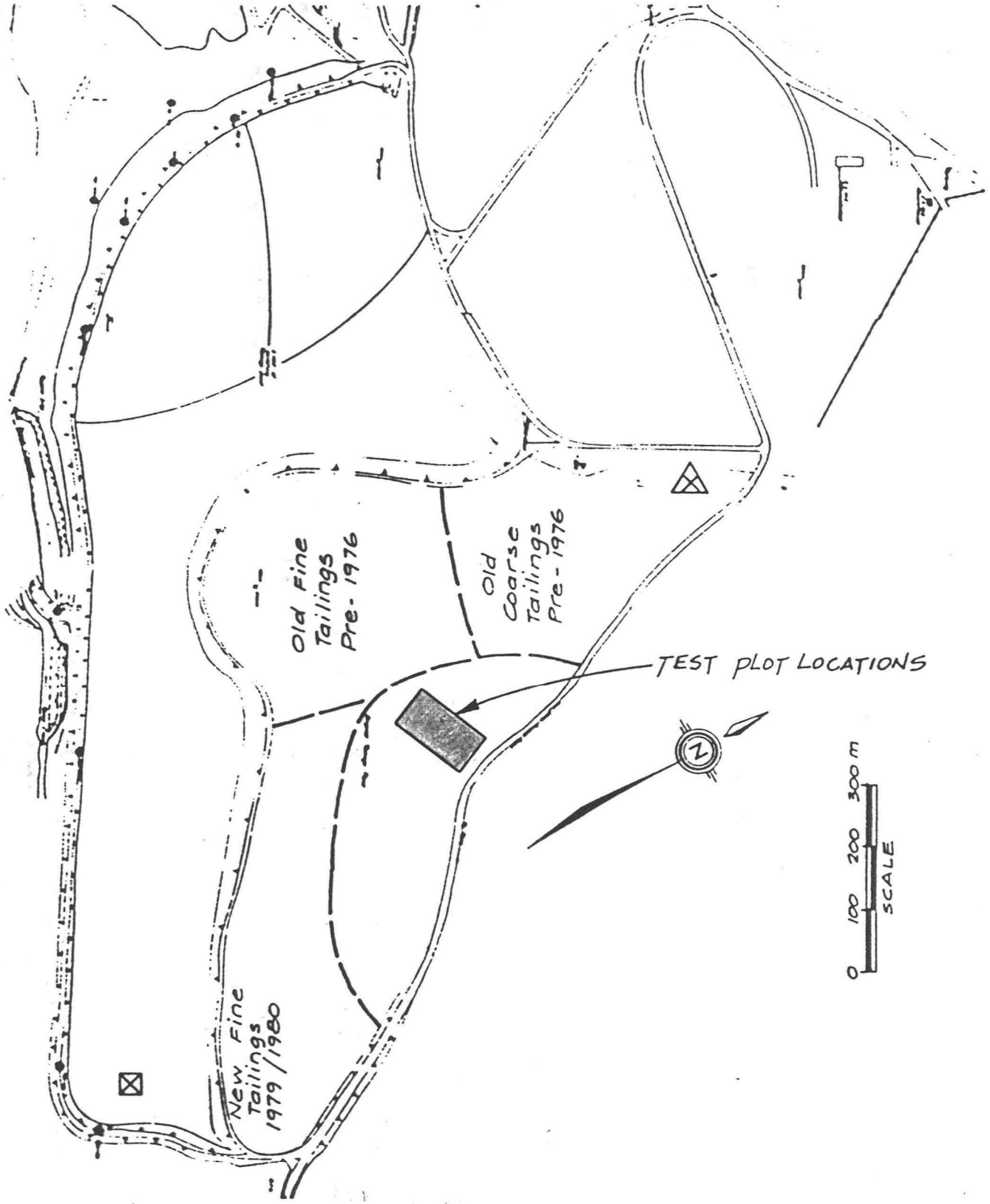
- TEST PLOT PROGRAM
- TAILINGS CHARACTERIZATION PROGRAM
- GROUNDWATER BASELINE PROGRAM
- SURFACE WATER BASELINE PROGRAM
- MODELLING PROGRAM
- PREPARATION OF ABANDONMENT PLAN

TEST PLOT PROGRAM

COVER TYPES TO BE TESTED

1. NO COVER - OLD TAILINGS
2. NO COVER - NEW TAILINGS
3. SHALLOW TILL COVER
4. DEEP COMPOSITE COVER
5. " " " WITH SATURATION
6. WATER COVER
7. SYNTHETIC MEMBRANE PLUS SHALLOW TILL

See Figures 2.1
2.2.



CURRAGH RESOURCES

DATE

PROJ. NO

APPROVED

SITE PLAN AND TEST PLOTS LOCATION

NO 2.1

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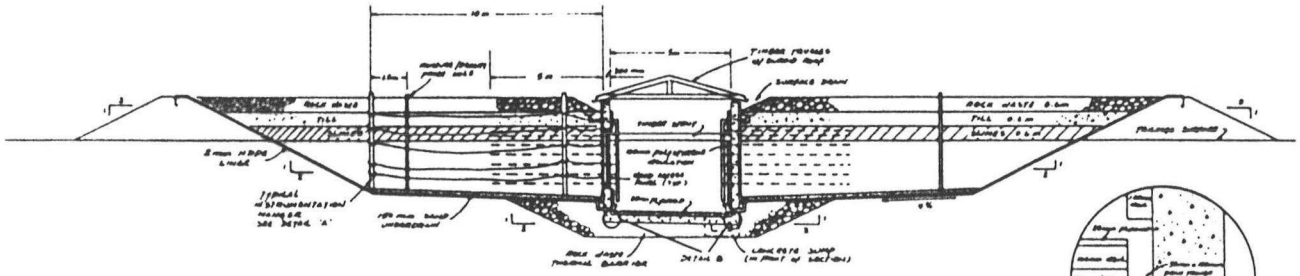
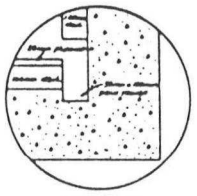


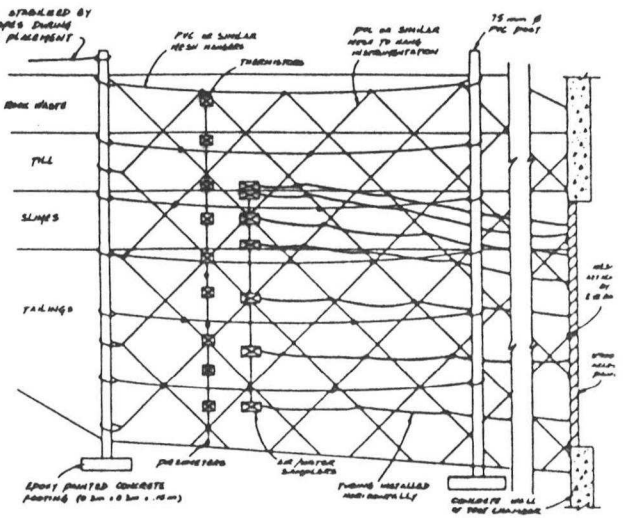
SECTION A-A'

SCALE - 1:100



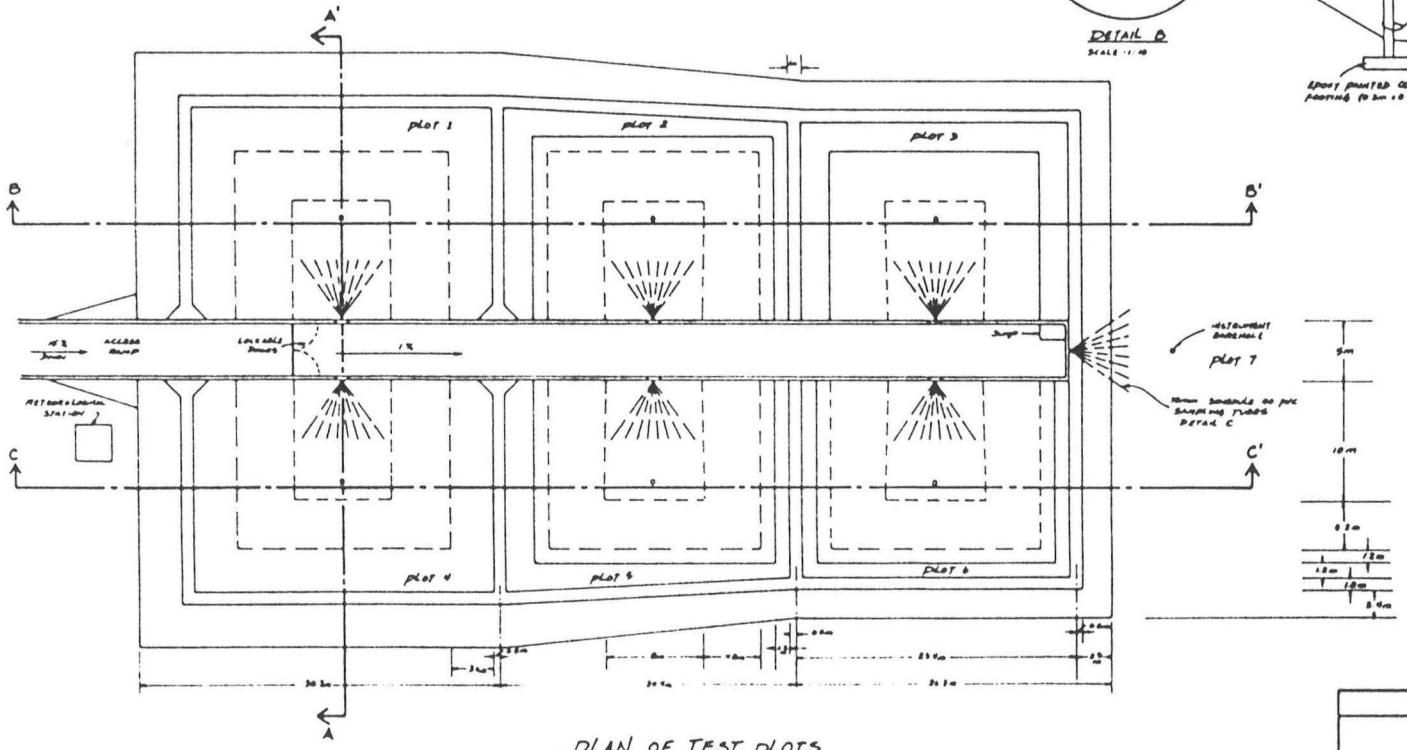
DETAIL B

SCALE 1:10



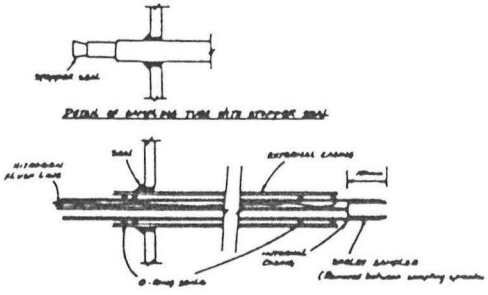
DETAIL A

DIAGRAMMATIC SKETCH SHOWING TYPICAL DETAILS OF INSTRUMENTATION HANGERS - NOT TO SCALE



PLAN OF TEST PLOTS

SCALE - 1:200



SECTION DETAIL OF HORIZONTAL SAMPLING TUBES WITH SHELBY SAMPLER IN SERTED

NOT TO SCALE

CURRAGH RESOURCES	
ACID GENERATION ABATEMENT PROGRAM	
TEST PLOT LAYOUT	2.2
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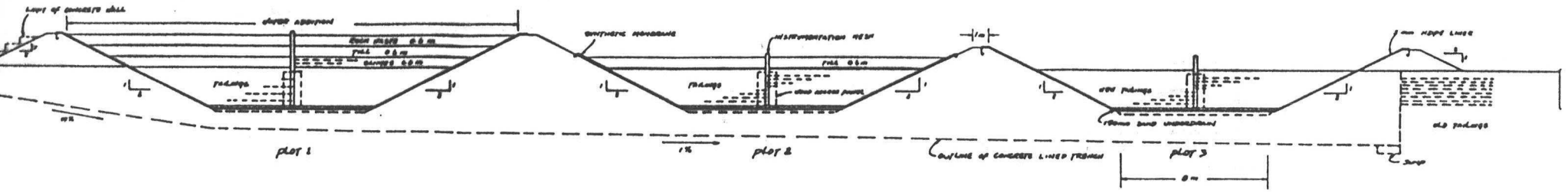
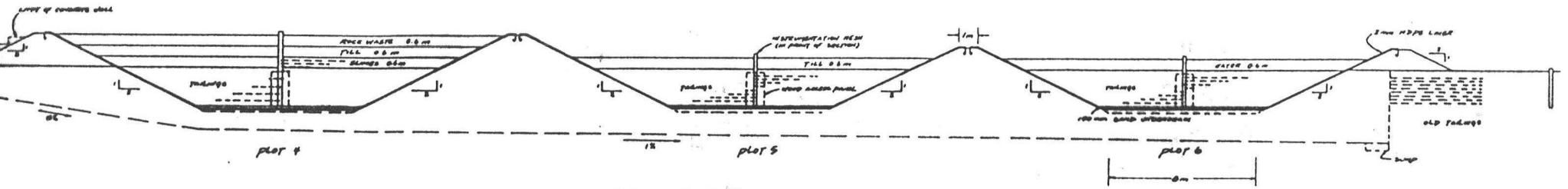


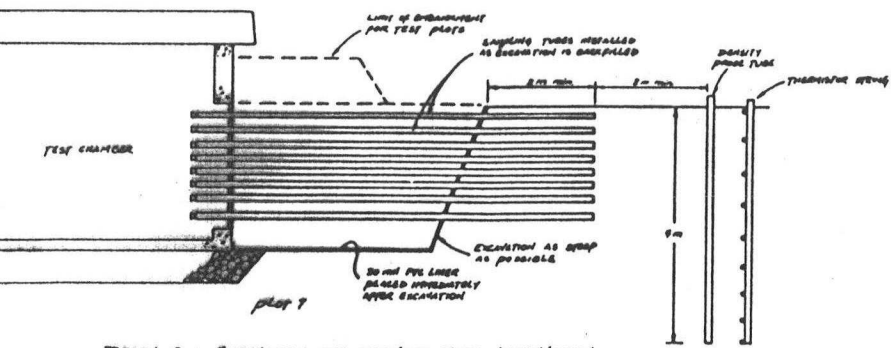
SECTION B-B'

SCALE - 1:100



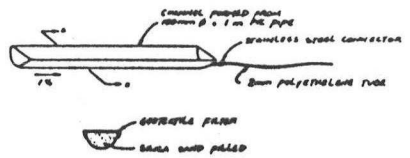
SECTION C-C'

SCALE - 1:100



DETAIL C : EXCAVATION AND SAMPLING TUBE INSTALLATION AT END OF TEST CHAMBER

not to scale



DETAIL OF WATER/AIR SAMPLER

not to scale

CURRAGH RESOURCES

ACID GENERATION ABATEMENT PROGRAM

SECTIONS THROUGH TEST PLOTS

STEFFEN ROBERTSON & KIRSTEN, Consulting Engineers

TEST PLOT INSTRUMENTATION AND MONITORING

(i) QUALITY AND QUANTITY OF SEEPAGE
(ii) PROFILE OF INTERSTITIAL WATER QUAL.
(iii) TEMPERATURE PROFILE
(iv) OXYGEN CONCENTRATION PROFILE
(v) MOISTURE PROFILE
(vi) INFILTRATION RATE

See Figure 2.2.
2.3.

PROGRAM MANAGEMENT AND QUALITY CONTROL

(ADVISORY COMMITTEE)

(i) PRE-PLANNING
(ii) PROGRAM MANAGEMENT
(iii) QUALITY CONTROL / QUALITY ASSURANCE

PHASE I COST ESTIMATE

The approximate expenditure for Phase I would be:

Year 1	$ 425,000
Year 2	$ 164,000
Year 3	$ 164,000
Year 4	$ 319,000
TOTAL	$1,072,000

CO-OPERATIVE RESEARCH AND FUNDING

COMMON INTEREST PROBLEM

- SHARED SAMPLES AND/OR TESTING
- SHARED DATA AND DATA PROCESSING
- CO-OPERATIVE MODELLING
- CO-SPONSORSHIP OF FIELD PROGRAMS AND MODELLING.