CONTROL OF SURFACE WATER AND GROUNDWATER FOR TERRAIN STABILIZATION - LAKE LOUISE SKI AREA

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ABSTRACT

Skiing conditions at the Lake Louise Ski Area may be improved by the application of artificial snow. Concern has been expressed that artificial snow may contribute to the development of slope failures. Geotechnical and hydrological investigations indicate that the proposed surface water and groundwater control systems will reduce groundwater recharge. This will result in lowering the groundwater surface, contributing to an overall improvement in slope stability.

INTRODUCTION

In 1981, the Lake Louise Ski Area produced a Development Plan. This plan contained various components which were designed to improve the overall quality of skiing at Lake Louise. The principal component of the plan is artificial snowmaking. Parks Canada expressed concern that snowmaking would aggrevate existing terrain stability problems on the ski hill. A study to ameliorate these problems produced a surface and groundwater control system. This will stabilize slopes in areas where soil slumping has occurred, or is probable.

The area of emphasis for the study was the lower elevations - below the treeline - of Whitehore Mountain (Drawing 1) where snowmaking is proposed. Some slope instability, both natural and man-induced, exists throughout this area. Visible evidence of instability takes the form of surficial slumps. These are typically 30 to 50 m long, 20 m wide and 2 m deep. The instability of the glacial drift soil, which underlies the area, is related to the soil moisture condition, with failures almost always occurring within a saturated soil. The control of soil moisture content was achieved by lowering the groundwater surface in localized areas and by restricting groundwater recharge from water courses and springs.

TOPOGRAPHY AND SURFACE DRAINAGE

The gradient of the central ski runs varies from relatively gentle at the Whitehorn Mountain base to comparatively steep near the top of the ski runs. The terrain rises from an elevation of 1660 m at Whiskeyjack Lodge, at an average gradient of 5° to the base of the ski runs. From elevation 1700 m to 1860 m, slopes are approximately 14°, leveling to 10° towards the 1900 m elevation. The final rise to the top of the ski runs averages a slope of 20°. Some sections as steep as 30° are also encountered, particularly midway along the Juniper and Men's Downhill runs.

The primary contributors to surface flows on the Whitehorn face are two springs. One is located under, and the other just above the upper terminus of the Glacier chair. The precise location of these water sources, Triple Creek and Glacier Seep, are shown on Drawing 1. The streams originate at the 2100 m level and flow generally in the area of the ski runs. The two streams join in a swampy area located at the 1900 m level. The stream then flows to the 1700 m level where a portion enters a cistern or sump which eventually supplies water to Whiskeyjack Lodge. The remaining flow joins Fish Creek.

GENERAL GEOLOGICAL CONDITIONS

Bedrock Geology

Bedrock in the Whitehorn face consists of a number of sedimentary rock types belonging to the Corral Creek Formation. The major rock types are slate, sandstone, siltstone and conglomerate. In the upper slopes, where rock exposures have been mapped, bedding dips at between 30° and 70° toward the southwest. (Geological Survey of Canada, 1975).

Overburden Geology

Soil overburden consists of glacial till deposited during the Pleistocene Period. Although there is little subsurface information available to permit an interpretation of overburden thicknesses along the Whitehorn face, in general, the till deposit is thin (less than 5 m) near the 2135 m elevation and is relatively thick towards the bottom of the slope and the location of the Whiskeyjack Lodge.

GROUNDWATER CONDITIONS

The hydrogeological exploration indicates that the till varies significantly in the relative proportions of fine and coarse grained material. Therefore, the distribution of these variable permeability surficial deposits will have an important bearing on groundwater movement within the slopes (Drawing 2). Another important factor is the ability of the weathered bedrock surface to transmit water. Jointed indurated shale bedrock with iron staining on the joint surfaces indicates an appreciable groundwater flow at the bedrock surface. During drilling, a discharge of about 0.4 L/s (5 gpm) was air-lifted from the overburden-bedrock interface. Water moving downslope in the weathered bedrock is confined by the less permeable till deposits (high clay or silt content). However, where comparatively permeable tills are present (low clay or silt content), groundwater can selectively move under pressure up into the surficial deposits. This water can reach the ground surface, forming local swampy seepage zones (Drawing 2).

Groundwater is therefore moving downslope through two media. Firstly, through the more permeable of the till units. Secondly, through the bedrock, especially the weathered upper zone. Meltwater can recharge the weathered bedrock surface via sandy to gravelly tills in the upper slopes.

WHITEHORN SLOPE STABILITY

Parameters Used in Analysis

The primary soil properties required in the analysis of stability are the material density and drained strength parameters. The following parameters were used for the till:

a) Saturated density of 220 kg/m^3. This corresponds to a moisture content of 12%.

b) Effective stress strength parameters:

cohesion (c) = 19 kPa

friction angle (Ø) = 27°

Groundwater Assumptions

The level of the groundwater surface is expected to fluctuate within the upper 7.5 m of the soil overburden during the course of the year. Water levels are generally near their lowest point in the cycle during the month of March. Hence, higher levels are anticipated in late spring and early summer. To assist in understanding the importance of groundwater levels on the stability of critical slopes, a sensitivity analysis was conducted of stability as described in the following paragraphs.

Results

A series of calculations were made for the staility of a range of failure surfaces. The results are shown on Drawing 3. The analysis is generated for the steepest ski slope on Whitehorn (30°). For example, considering a depth of 6 m and the water surface at a depth of 4 m below the surface of the slope, a safety factor of 1.0 would result. If the water surface was any higher than this position, a failure would ensue at a depth of approximately 6 m, or less.

The stability analyses assumed a quasi-circular shaped failure surface. A generalized method of slices was used. This is applicable to both circular and non-circular slip surfaces. Utilizing an in-house computer program, GEOSLP, the failure geometry was analysed on a slice-by-slice basis, calculating driving and resisting forces for each slice. The factor of safety is proportional to the ratio of resisting to driving forces.

EFFECT OF DRAINAGE AND SNOWMAKING SYSTEMS ON STABILITY

Moisture Balance

Under current conditions, groundwater is recharged from higher elevations in the Whitehorn slope, as well as from direct precipitation. With the installation of the snowmaking system, additional moisture will be placed on the slope. This will contribute to the amount of incoming moisture during the spring melt period. On the other hand, it is possible to divert water which is re-entering the slope from springs emerging on the hillside at approximately elevation 2100 m and below. From a gauging measurement of the spring emerging near the level of the Whitehorn lodge, it is estimated that approximately 4.5 L/s (60 igpm) is flowing. By visual comparison, the other stream has a flow of approximately 3 L/s (40 igpm). These streams can be diverted away from the slope.

The balance between moisture which will be added from the snowmaking system, and which can be diverted, is shown conceptually on Drawing 4. The surface area considered is approximately 2 km x 0.5 km (10^6 m^2). The ski runs where additional snow will be placed are, in reality, only a small fraction of this surface area. The hydrological system is shown for two conditions. Firstly, under existing natural conditions. Secondly, with additional precipitation (artificial snow) over the whole area and with the new drainage system installed. The percentage figures for infiltration, evapotranspiration and runoff, and the amount of added snow cover, are selected to be highly conservative. A worst case scenario is therefore represented. As the potential groundwater drainage and surface water diversion (containment) exceed increased infiltration, the moisture condition of the slope will be improved.

Under natural conditions, the moisture input to the area per annum is 32 L/s (422 igpm, Drawing 4). This comprises 8 L/s (105 igpm) stream inflow and 24 L/s (317 igpm) precipitation. A conservative infiltration figure of 20% is assumed. This gives an infiltration rate of 6.4 L/s (84 igpm) on a yearly basis. An infiltration factor of 20% is highly conservative considering the local topography, geology, and potential evapotranspiration. The relatively steep slopes will enhance runoff. The presence of clay till as indicated by drilling, will also inhibit infiltration. Potential evaporation figures for the area actually exceed the precipitation figures (Hydrological Atlas of Canada, 1978). This gives an infiltration rate of 6.4 L/s (84 igpm) on a yearly basis.

With an added artificial snow cover, the moisture input is increased to 37.6 L/s (496 igpm, Drawing 4). The infiltration effectiveness of the stream inflow is conservatively reduced by 50% in response to diversion and containment. The moisture input is therefore made up of 3.7 L/s (49 igpm) stream inflows and 33.9 L/s (447 igpm) combined natural and artificial precipitation. At 20% infiltration, this gives the amount of water recharging the slope as 7.5 L/s (100 igpm). This represents an increase of 1.1 L/s (15 igpm) over natural conditions. However, improved drainage is calculated to reduce overall infiltration by 3.0 L/s (40 igpm). The result is a net improvement in the moisture balance of 1.9 L/s (25 igpm) on a yearly basis.

With the addition of an effective system of surface and subsurface drainage, it is anticipated that the water table can be depressed under most circumstances envisaged.

The proposed drainage system is relatively shallow compared with the depression in the water level required to assure slope stability in the critical areas. Lowering of the groundwater surface within the slope area will be a result of a reduction of groundwater recharge by interception of groundwater flow by the drains. Further reduction of groundwater recharge will be achieved by the diversion and containment of surface water.

Effect on Stability

If water levels are maintained at no higher than 6 m from the ground surface in the steepest portion of the Whitehorn slopes, the slopes will retain a minimum safety factor of 1.1, thereby ensuring stability.

PROPOSED DRAINAGE SYSTEM

Interception of Surface Drainage

The interception of surface water before it can recharge the groundwater is essential to stabilization of the steeper pitches on the Whitehorn face. There are three possible methods of preventing the surface water from contributing to the groundwater flow:

1. Intercept and divert the two streams at their highest elevation to a channel completely outside the ski runs;

2. Collect and contain the water from the two streams in a pipeline and convey it to cistern storage below the control/compressor building near Whitehorn Lodge;

3. Channelize the two streams in their existing courses and improve the culverts and streambeds to reduce infiltration into the subsurface soil.

All of the above measures will reduce icing areas on the slopes and will improve the quality of skiing on the Whitehorn face.

Subsurface Drainage System

French drains should be installed in steep, critical slopes where instability has occurred in the past, or there is evidence of incipient slumping (Drawing 1).

The design of a typical French drain is shown on Drawing 5. The design consists of filter gravel placed into a trench with dimensions 0.75 m wide by approximately 2-3 m deep. Filter cloth should be installed in the trench walls to prevent migration of silt fines from the native till into the filter gravel.

Supplementary Drainage Measures

The subsurface drainage system discussed above is anticipated to produce a significant impact on existing groundwater conditions. However, the system may require extension as indicated by the relative success achieved during its first year of operation.

Also, due to the presence of low permeability fine-grained tills locally, it may be unavoidable that some sections of the system may be less effective than elsewhere. In these circumstances, it may be necessary to drill sub-horizontal drainage holes to increase the effectiveness of the system in critical areas.

SUMMARY OF FINDINGS

The geological conditions underlying the Whitehorn slope and preventative measures being proposed for ensuring that slope stability is maintained after the introduction of snowmaking are summarized in the following:

1. The Whitehorn slopes are underlain by a relatively thin deposit of glacial till. This rests directly on shale bedrock. In the past, slumps have occurred within the till in steeper portions of Juniper run.

2. The till is markedly heterogeneous with the proportions of clay, silt, sand, gravel and boulders varying appreciably. The deposits are moderately dense, with relatively low natural moisture contents. This material has a relatively high undrained shear strength. However, the till is susceptible to failures in the steeper slopes if the groundwater surface should rise to certain levels. Susceptibility to failure in these critical slopes is examined in detail in the report.

3. Because of previous slumping in the Whitehorn face, a program of drainage interception is recommended. The small creek which is fed by a spring emerging from bedrock west of the Whitehorn Lodge should be diverted or contained. This creek is considered to be responsible to a large degree for the high water levels experienced in the slope locally. In addition to intercepting surface flows, subsurface drains should be installed in critical sections of the slopes to ensure that the water surface is depressed. Water levels should then be monitored

in the piezometers installed in the slope. If levels are not depressed sufficiently after the subdrains have been installed, it may be necessary to drill sub horizontal drainage holes in critical sections of the slope.

The necessity of providing supplementary drainage holes should be established after the performance of the recommended drainage system has been monitored during the first year of operation.

4. The additional amount of water infiltrating the slopes due to the proposed artificial snow-making is estimated at 1.1 L/s (15 igpm). However, the recommended surface and groundwater drainage system is estimated to reduce overall infiltration by 3.0 L/s (40 igpm). Hence, the drainage system will more than compensate for the effect that the snow-making system may have in raising water levels in the slope.

5. The surface and subsurface drainage systems should be installed in advance of constructing the water pipeline system. Trench excavation should proceed upwards from the toe of the slopes to assist in drainage. Trenching equipment should not be brought onto the slopes until satisfactory drainage has been achieved.

6. Flexibility should be exercised in determining the depth of the pipeline trench to be excavated. In dry ground, no difficulty is anticipated for conventional backhoes reaching the design depth. However, in wet ground, it may be difficult to excavate a stable trench. A shallow trench design is required in wet areas, whereby the trench depth would

be limited to approximately 1 m. Continuous water circulation and/or insulation would be necessary to prevent freezing. A further alternative would be to have the pipe heat traced through these areas.

7. Following construction, the work area should be levelled and re-vegetated, using established reclamation practices for the ski area.

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REFERENCES

Geological Survey of Canada, F.C. Taylor, 1975; Map 1428A.

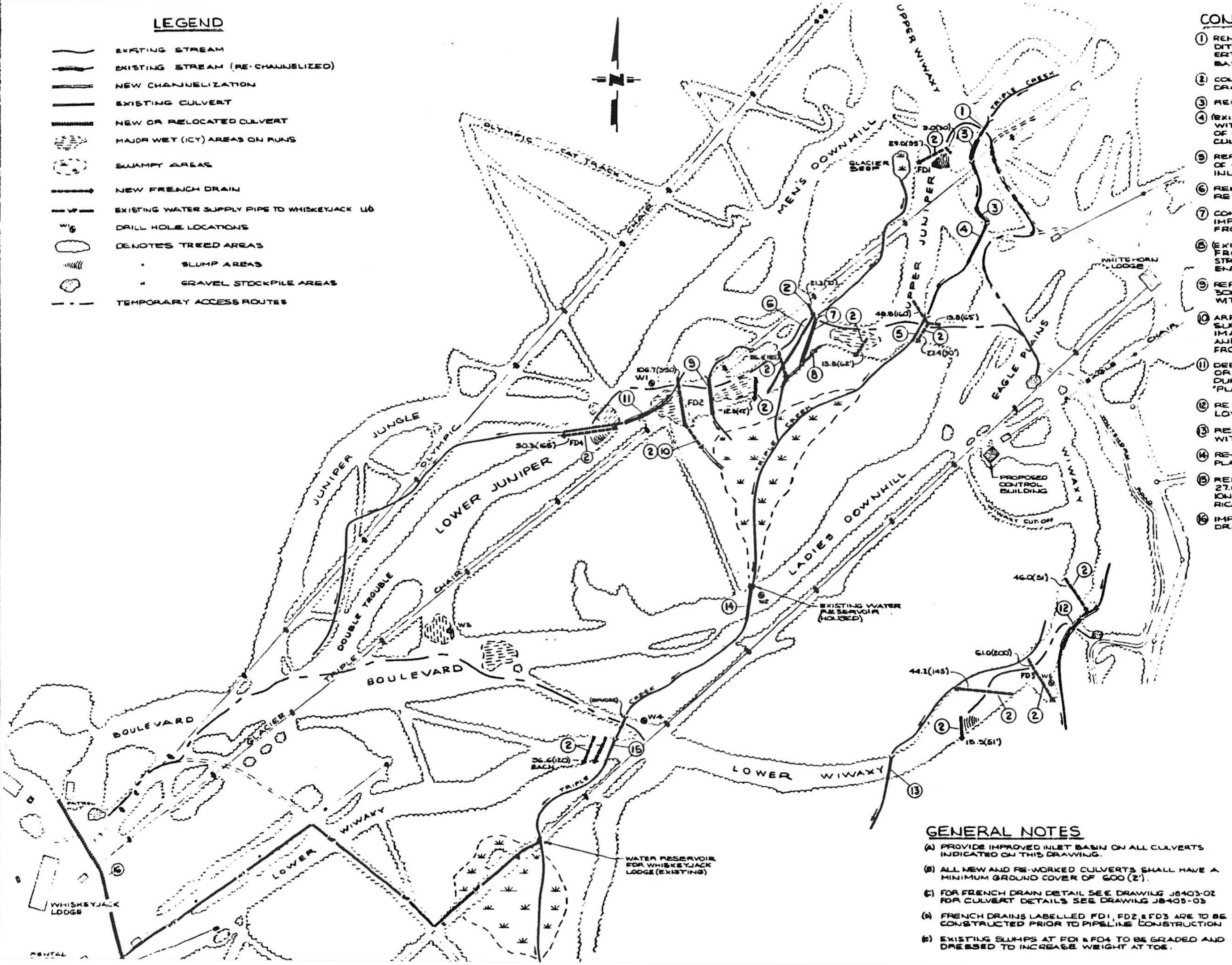
Hydrological Atlas of Canada, 1978.

Nanuk Engineering & Development Ltd., 1984; Preliminary Study for Skiing Louise Snowmaking System - Terrain Stability and Water Supply.

Nanuk Engineering & Development Ltd. and Komex Consultants Ltd., 1984; Report to Skiing Louise Ltd., Snowmaking System - Geotechnical Studies.

LEGEND

- EXISTING STREAM
- EXISTING STREAM (RE-CHANNELIZED)
- NEW CHANNELIZATION
- EXISTING CULVERT
- NEW OR RELOCATED CULVERT
- MAJOR WET (ICY) AREAS ON RUNS
- SWAMPY AREAS
- NEW FRENCH DRAIN
- EXISTING WATER SUPPLY PIPE TO WHISKEYJACK U/G
- DRILL HOLE LOCATIONS
- DENOTES TREED AREAS
- " SLUMP AREAS
- " GRAVEL STOCKPILE AREAS
- TEMPORARY ACCESS ROUTES



CONSTRUCTION METHODS

1. REMOVE EXISTING PLYWOOD COVER OVER OPEN DITCH AND INSTALL 25.0m(82') OF 460ᶲ CULVERT FROM (6), BACKFILL AND IMPROVE INLET BASIN AS PER DRAWING J8403-03
2. CONSTRUCT FRENCH DRAIN AS INDICATED ON THIS DRAWING AND AS PER DRAWING J8403-02
3. RECHANNELIZE PORTION OF STREAM.
4. (EXISTING 400ᶲ × 21.0(69') CULVERT, COVERED WITH LOGS.) REMOVE DEBRIS, ADD 7.0m(23') OF CULVERT TO UPPER END, BACKFILL ENTIRE CULVERT AND PROVIDE INLET BASIN
5. REPLACE EXISTING 300ᶲ CULVERT WITH 30.0m(98') OF 460ᶲ CULVERT FROM (6) AND CONSTRUCT NEW INLET BASIN.
6. REMOVE 460ᶲ × 170.0m(558') CULVERT AND RE-USE AS INDICATED
7. CONSTRUCT 460ᶲ × 105.0m(345') CULVERT WITH IMPROVED INLET BASIN, USING 460ᶲ CULVERT FROM (6)
8. (EXISTING SNOWMAKING POND) REMOVE BERM FROM AROUND POND AND RE-CHANNELIZE STREAM FROM ABOVE POND TO WHERE STREAM ENTERS TREES BELOW.
9. REPLACE PLYWOOD COVERED TRENCH WITH 300ᶲ × 45.0(148') CULVERT (FROM LOCATION (5)). WITH IMPROVED INLET BASIN.
10. ARRANGE SLOPE OF BOTTOM OF FRENCH DRAIN SUCH THAT DOWNSTREAM END IS APPROXIMATELY 600(2') BELOW EXISTING GROUND AND PROVIDE 30.0m(100') OF NEW CHANNEL FROM THIS POINT TOWARD TRIPLE CREEK.
11. DEEPEN CHANNEL OF EXISTING STREAM TEMPORARILY TO REDUCE SURFACE WATER IN AREA DURING CONSTRUCTION. INSTALL IMPERVIOUS "PLUG" IN THIS TRENCH AFTER CONSTRUCTION.
12. RE-CHANNELIZE STREAM AS INDICATED AND LOWER CULVERT.
13. REPLACE EXISTING WOOD CRIB CULVERT WITH 460ᶲ × 40.0m(130') NEW STEEL CULVERT.
14. RE-BUILD WOOD BOX CULVERT WITH REMOVEABLE PLANK COVER, SAME SIZE AS EXISTING.
15. REMOVE AND REPLACE EXISTING 600ᶲ × 27.0(89') CULVERT USING SALVAGEABLE SECTIONS WHERE POSSIBLE AND INSTALL PREFABRICATED END SECTION ON INLET.
16. IMPROVE FISH CREEK CONVEYANCE AND DRAINAGE AT OLYMPIC BASE

GENERAL NOTES

(A) PROVIDE IMPROVED INLET BASIN ON ALL CULVERTS INDICATED ON THIS DRAWING.

(B) ALL NEW AND RE-WORKED CULVERTS SHALL HAVE A MINIMUM GROUND COVER OF 600 (2').

(C) FOR FRENCH DRAIN DETAIL SEE DRAWING J8403-02 FOR CULVERT DETAILS SEE DRAWING J8403-03

(D) FRENCH DRAINS LABELLED FD1, FD2 & FD3 ARE TO BE CONSTRUCTED PRIOR TO PIPELINE CONSTRUCTION

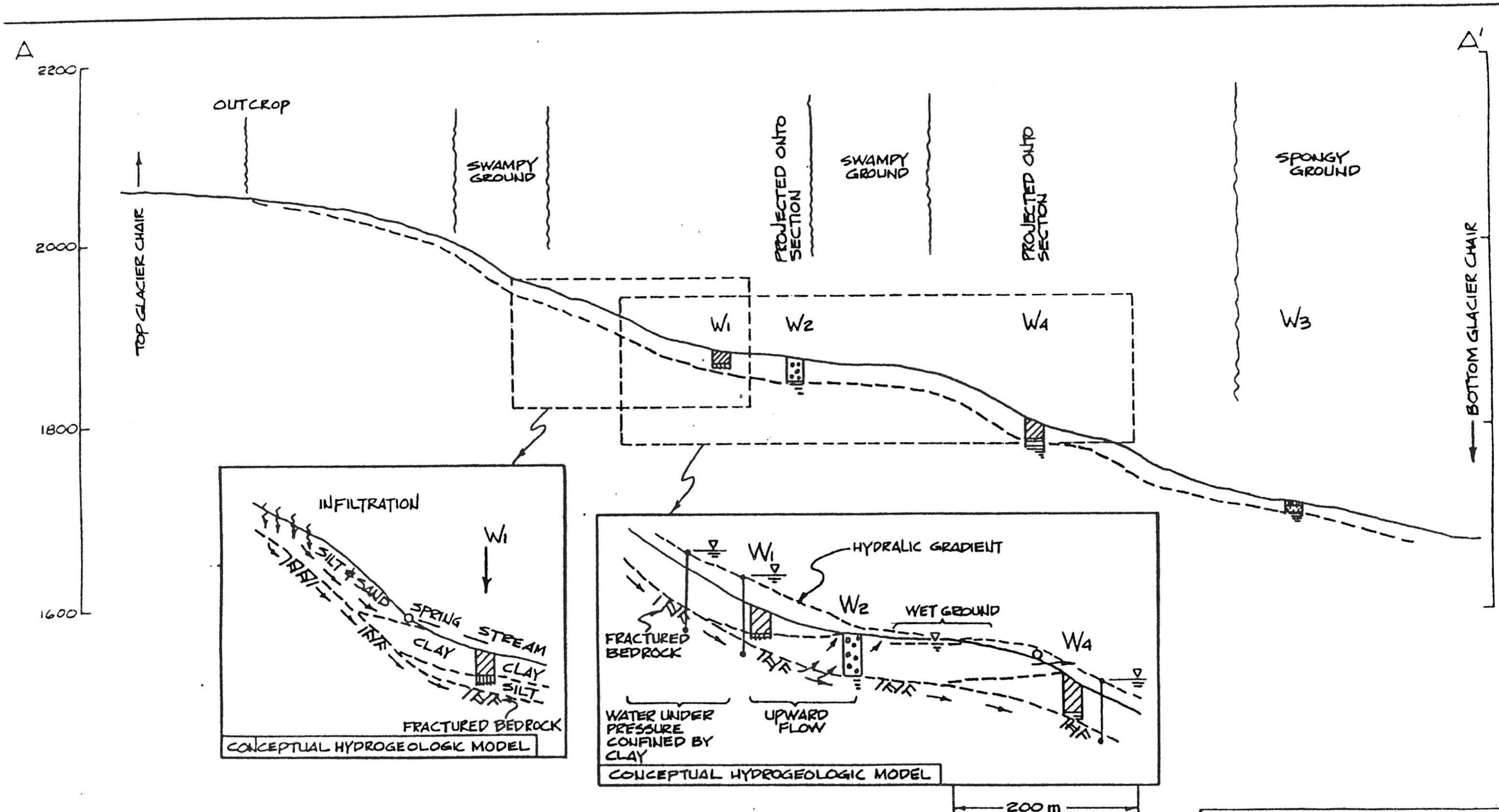
(E) EXISTING SLUMPS AT FD1 & FD4 TO BE GRADED AND DRESSED TO INCREASE WEIGHT AT TOE.

REV	DATE	DESCRIPTION
1	6 JUL 84	POST-RECONNAISSANCE REVISIONS

NANUK ENGINEERING & DEVELOPMENT
BOX 817 COCHRANE ALBERTA

SKIING LOUISE
WHITEHORN

SURFACE & GROUNDWATER CONTROL SYSTEM

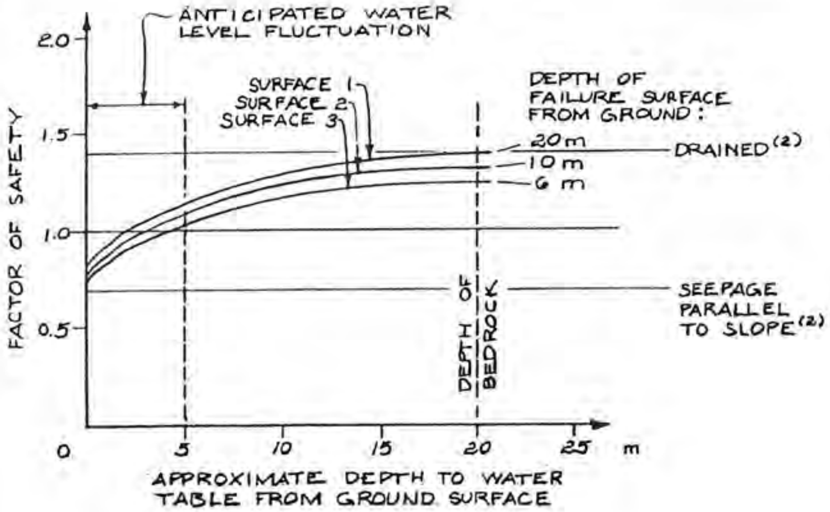


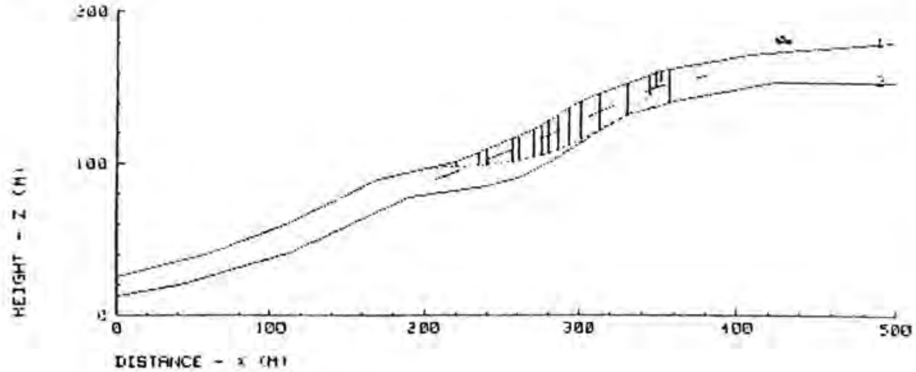
NOTE:

SUBSURFACE PROFILE BETWEEN CONTROL POINTS (DRILLHOLES) ARE INFERRED ONLY. ACTUAL GEOLOGIC CONDITIONS MAY THEREFORE VARY CONSIDERABLY FROM THE ABOVE INTERPRETATION.

1:4000

SKIING LOUISE			
GEOTECHNICAL STUDIES			
WHITEHORN - SLOPE PROFILE AND CONCEPTUAL HYDROGEOLOGICAL MODELS BENEATH GLACIER CHAIR			
KOMEX		APR	2





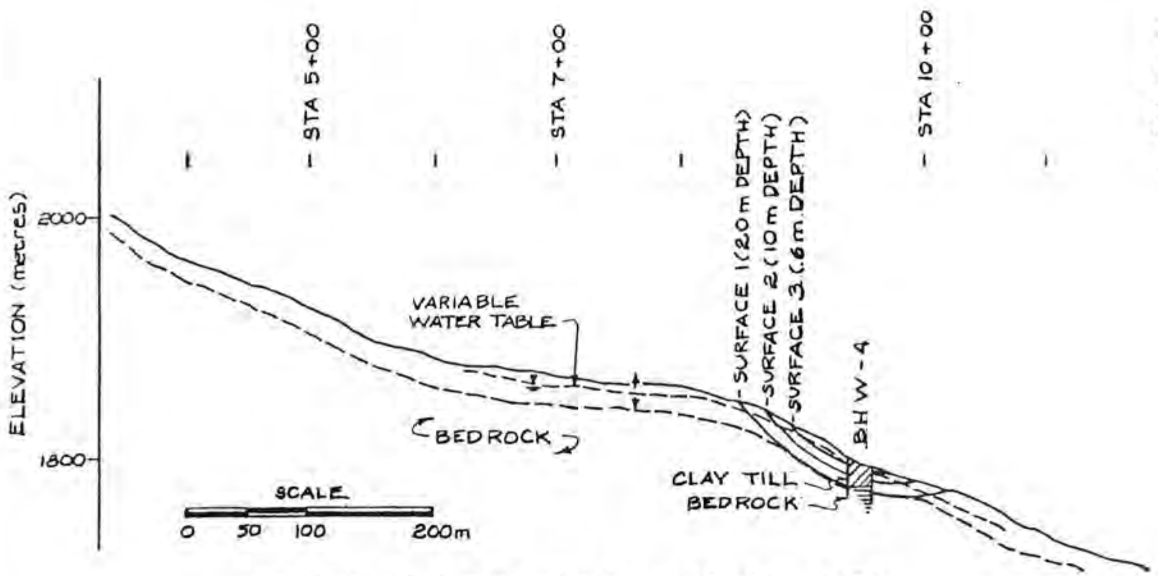
CORRECTION FACTOR: 1.056

FOS CONVERGENCE:

1.093
1.111
1.114

FINAL FOS = 1.114 RESISTING FORCE= 23001 DRIVING FORCE= 21801

EXAMPLE OF COMPUTER GENERATED DATA:
SURFACE 1, DEPTH OF WATER TABLE = 5m



SECTION OF GLACIER CHAIR FACING SE SLOPE
GEOMETRY AND SLOPE FAILURE VARIABLES

STRENGTH AND DENSITY PARAMETERS USED

	UNIT WEIGHT (Kg/m³)	COHESION (KPa)	FRICTION ANGLE (DEGREES)
CLAY TILL	2200	15	27°

NOTES:

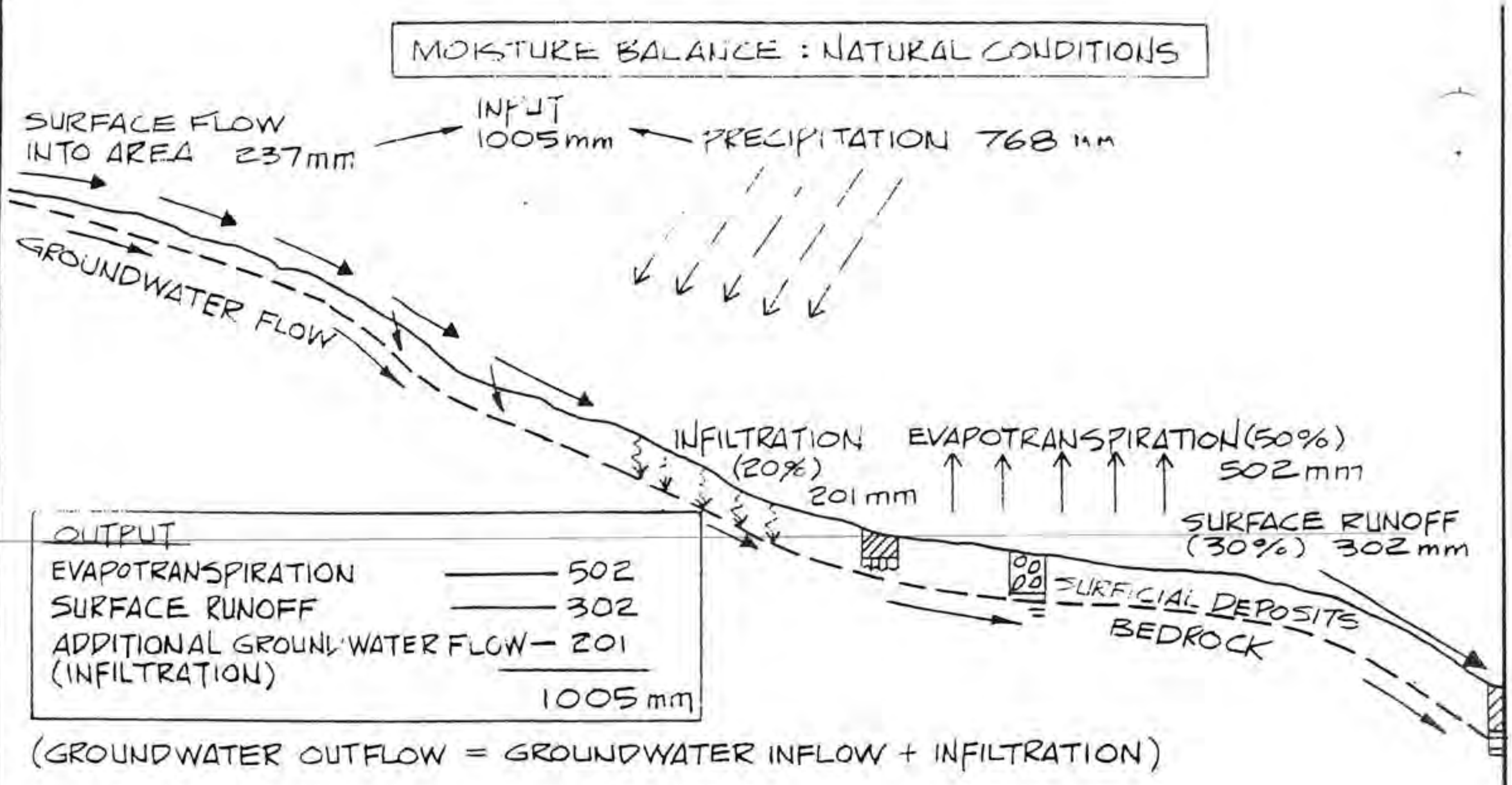
1) CONFIGURATIONS SHOWN ARE APPROXIMATE. ACTUAL SLOPE ANGLES AND DIMENSIONS MAY VARY.
2) THEORETICAL BOUNDARIES AS DEFINED BY INFINITE SLOPE ANALYSIS.

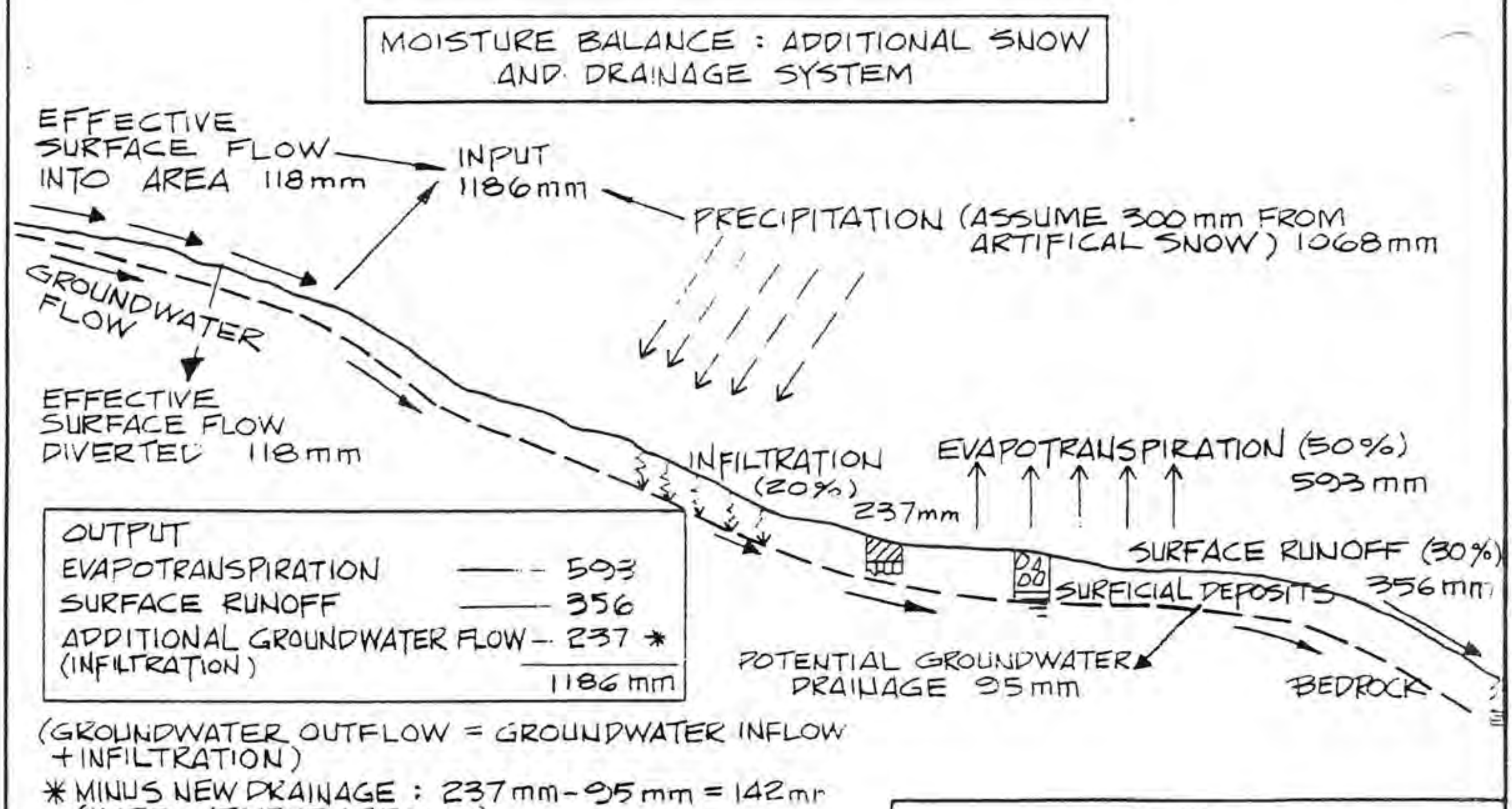
SKIING LOUISE

GEOTECHNICAL STUDIES

STABILITY ANALYSIS

KOMEX | APRIL '94 | 3





SKIING LOUISE

GEOTECHNICAL STUDIES

WHITEHORN - SCHEMATIC MOISTURE BALANCE FOR SLOPE UNDER NATURAL AND MODIFIED CONDITIONS

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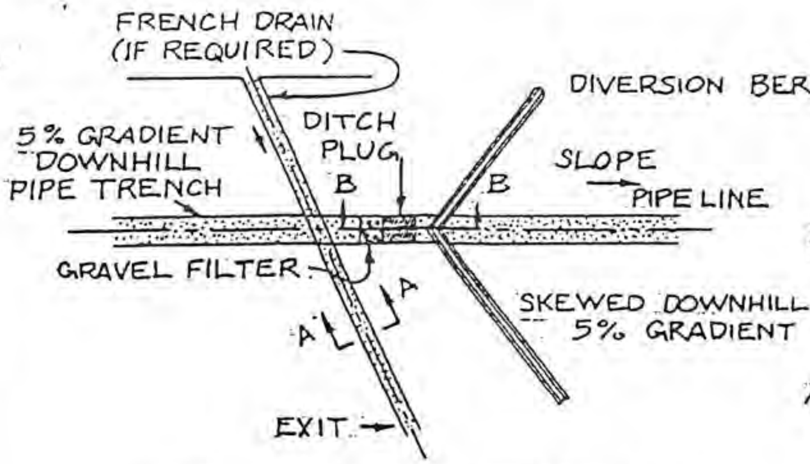
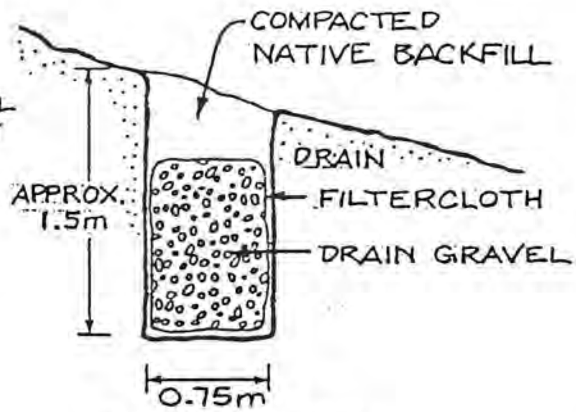
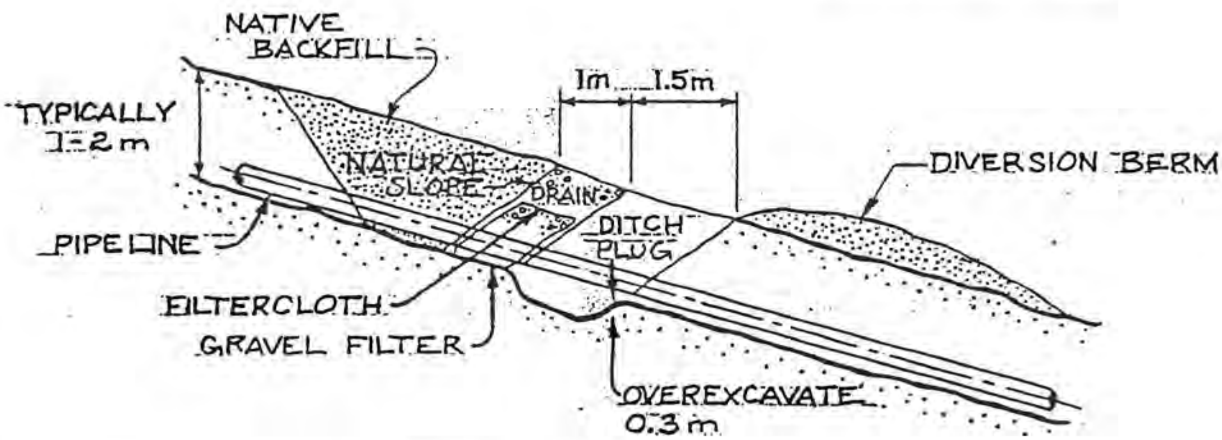


TYPICAL LAYOUT OF FRENCH DRAINS AND DIVERSION BERMS



SECTION A-A
FRENCH DRAIN



SECTION B-B

NOTES:

1. DITCH PLUG TO CONSIST OF MIXTURE OF 15% BENTONITE AND SAND (BY WEIGHT).
2. FILTER FABRIC TO CONSIST OF POLYESTER, HAVING A MINIMUM WEIGHT OF 200 gm/m² AND A MINIMUM HYDRAULIC CONDUCTIVITY OF 1 mm/S.
3. DRAIN GRAVEL TO CONSIST OF FOLLOWING GRADATION: D100 = 40 mm LESS THAN 10% PASSING #200 SIEVE.

SKIING LOUISE			
GEOTECHNICAL STUDIES			
WHITEHORN DETAIL OF DIVERSION BERMS & FRENCH DRAINS			
KOMEX	MWT	APR. 84	5

CLRA

NINTH ANNUAL MEETING
CANADIAN LAND
RECLAMATION ASSOCIATION

RECLAMATION IN MOUNTAINS, FOOTHILLS AND PLAINS: **DOING IT RIGHT!**

AUGUST 21-24, 1984
Calgary, Alberta, Canada

CANADIAN LAND RECLAMATION ASSOCIATION

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A C K N O W L E D G E M E N T S

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Westmin Resources Limited

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Alberta Sand & Gravel Producers Association
Coal Association of Canada
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