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REPORT ON

FEASIBILITY DESIGN OF RECLAMATION DRAINAGE SYSTEMS FOR THE MUSKEG RIVER MINE PROJECT

Submitted to:

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December 1997 **972-2237**

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Proj. No. 972-2237

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RE: Final report - Reclamation Drainage System

Dear Doug

Attached is the final report for the for the Muskeg River Mine Project. This report complements the work completed on the Closure Plan for the Muskeg River Mine Project. This report focuses on consideration of: hydrologic and wind design parameters; and drainage design for in-pit CT and overburden storage, the tailings setting pond, wetlands and lakes and the end pit lake.

Should you have any questions about this report, please contact me at 299-5640.

Yours very truly,

GOLDER ASSOCIATES LTD.

John R. Gulley, M.Sc., P. Biol.
Oil Sands Project Director

attachment

cc. Judy Smith (Shell)
Ian Mackenzie (EIA Project Manager)

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1. INTRODUCTION

1.1 BACKGROUND

purpose of the feasibility design of the closure reclamation drainage systems

Shell Canada Limited (Shell) commissioned Golder Associates Ltd. (Golder) to conduct a feasibility design of the closure reclamation drainage systems for the Muskeg River Mine Project (the Project). This feasibility-level design was conducted as a part of Shell's Environmental Impact Assessment (EIA) to demonstrate the feasibility of the proposed mine closure drainage plan and to support Shell's application for the proposed Project.

The local study area for the Shell Project

The Local Study Area (LSA) for the EIA is shown in Figure 1. The Muskeg River Mine Project area lies on the east side of the Athabasca River, and most of the Project activities will occur between the Athabasca River and the Muskeg River.

contents of this report

A conceptual layout of the proposed closure reclamation drainage systems is presented in the report entitled "Water Management Plan for the Muskeg River Mine Project" (Golder 1997a). Since issue of that report, a feasibility-level design of the closure reclamation drainage systems was undertaken, including design approach, criteria, assumptions, and typical plans and cross sections of the proposed drainage systems. The results of this work are presented herein.

1.2 SCOPE OF WORK

main tasks for the feasibility-level design of the closure reclamation drainage systems

The scope of work for this feasibility level design of the closure reclamation drainage systems included the following tasks:

- Identify design criteria for the closure drainage systems.
- Analyze flood hydrology and derive flood peak discharges and design parameters of extreme winds.
- Identify and evaluate alternative closure reclamation drainage schemes.
- Provide a feasibility-level design for the proposed closure reclamation drainage systems including shoreline protection for the end pit lake.

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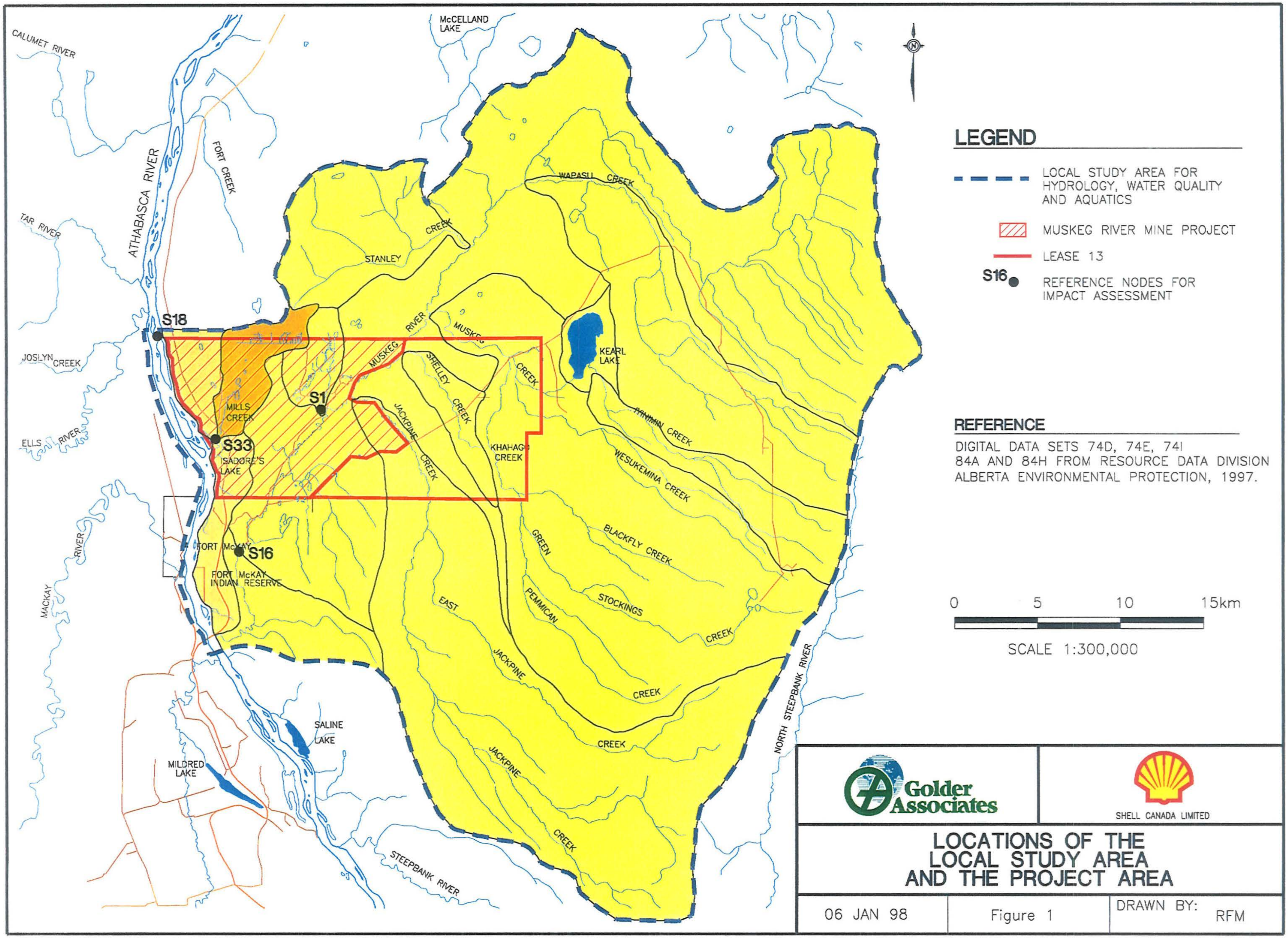


output of this feasibility-level design work

The scope of work was limited to the feasibility-level design sufficient to provide a sound basis for assessing the environmental impacts and long-term sustainability of the proposed closure reclamation drainage systems. The results of this work include recommended design criteria, proposed drainage scheme and drainage system layout, and feasibility-level design of the main drainage facilities including typical plans, profiles and cross sections. It is recognized that the design specifications contained herein will be revised over the life of the Project, although the preformance objectives will not.

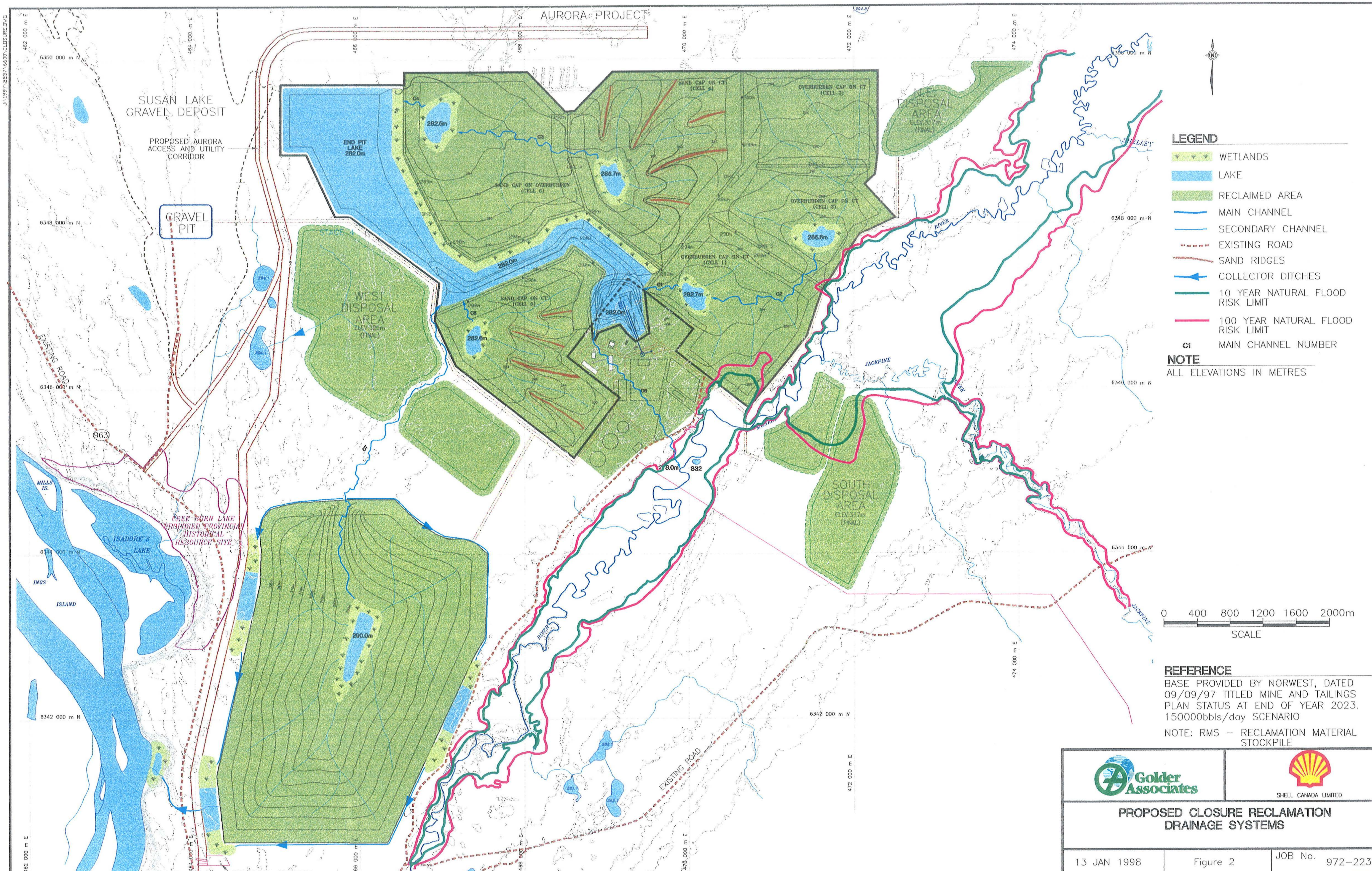
1.3 GENERAL LAYOUT OF CLOSURE RECLAMATION DRAINAGE SYSTEMS

layout and main facilities of the proposed closure reclamation drainage systems

The layout of the proposed closure reclamation drainage systems, including main channels, secondary channels, shallow wetlands and lakes, and an end pit lake, is shown in Figure 2. The proposed drainage systems consist of the following main drainage facilities:

- the east drainage system collects surface runoff and upward CT porewater release from Cells 1, 2 and 3 and discharges near the outlet of the end pit lake;
- the north drainage system collects surface runoff and upward CT porewater release from Pits 4 and 6 and discharges to the north end of the end pit lake;
- the south drainage system collects surface runoff and upward CT porewater release from Pit 5 and discharges near the south central part of the end pit lake;
- the drainage system for the reclaimed tailings settling pond collects the surface runoff, drains northward, and discharges to the end pit lake; and
- the collector system around the perimeter of the reclaimed tailings settling pond receives the surface runoff and sand seepage and routes through a series of shallow wetlands and lakes before direct discharge to the Athabasca River.

Each of these drainage systems includes shallow wetlands and lakes. A littoral zone with shallow wetlands is provided along the west shoreline of the end pit lake. The total surface area of the littoral zone is about 1.0 km^2, which represents about 20% of the total surface area of the end pit lake.


AURORA PROJECT
SUSAN LAKE GRAVEL DEPOSIT
PROPOSED AURORA ACCESS AND UTILITY CORRIDOR
GRAVEL PIT
END PIT LAKE 282.0m
282.6m
285.7m
285.8m
282.7m
282.0m
282.8m
290.0m
SAND CAP ON OVERBURDEN (CELL 6)
SAND CAP ON CT (CELL 4)
OVERBURDEN CAP ON CT (CELL 3)
OVERBURDEN CAP ON CT (CELL 2)
OVERBURDEN CAP ON CT (CELL 1)
SAND CAP ON CT (CELL 5)
WEST DISPOSAL AREA
N.E. DISPOSAL AREA
SOUTH DISPOSAL AREA
EXISTING ROAD
963
MILLS IS.
ISADORE'S LAKE
INGS
ISLAND
CREE BURN LAKE PROPOSED PROVINCIAL HISTORICAL RESOURCE SITE
INDUSTRIAL CAMPSITE
SHELLEY
RIVER
JACKPINE
8.0m
S32
6350 000 m N
6348 000 m N
6346 000 m N
6344 000 m N
6342 000 m N
462 000 m E
464 000 m E
466 000 m E
468 000 m E
470 000 m E
472 000 m E
474 000 m E
LEGEND
WETLANDS
LAKE
RECLAIMED AREA
MAIN CHANNEL
SECONDARY CHANNEL
EXISTING ROAD
SAND RIDGES
COLLECTOR DITCHES
10 YEAR NATURAL FLOOD RISK LIMIT
100 YEAR NATURAL FLOOD RISK LIMIT
C1 MAIN CHANNEL NUMBER
NOTE
ALL ELEVATIONS IN METRES
0 400 800 1200 1600 2000m
SCALE
REFERENCE
BASE PROVIDED BY NORWEST, DATED 09/09/97 TITLED MINE AND TAILINGS PLAN STATUS AT END OF YEAR 2023. 150000bbls/day SCENARIO
NOTE: RMS – RECLAMATION MATERIAL STOCKPILE
Golder Associates
SHELL CANADA LIMITED
PROPOSED CLOSURE RECLAMATION DRAINAGE SYSTEMS
13 JAN 1998
Figure 2
JOB No. 972-2237

2. DESIGN APPROACH, CRITERIA AND ASSUMPTIONS

2.1 PERFORMANCE OBJECTIVES

closure reclamation drainage systems should be stable, robust and sustainable

Sustainable reclamation drainage systems should have the same characteristics as the pre-development natural drainage systems in terms of dynamic stability, robustness, and longevity with self-healing mechanisms. This can be accomplished by designing drainage systems that are patterned after natural analogues subject to similar climatic, topographic and soil conditions. Although it is impossible to replicate the original natural drainage systems at the Project area, it is possible to replicate the stability and robustness of the original natural systems.

provision of drainage features such as shallow wetlands and lakes, floodplains and an end pit lake

The closure reclamation drainage systems should also provide a biologically productive landscape and have the capability to handle extreme hydrologic events. This can be accomplished by incorporating drainage features such as shallow wetlands/lakes, floodplains and an end pit lake for bioremediation of the surface runoff from the reclaimed surfaces as well as attenuation of flood peak discharges.

2.2 DESIGN APPROACH

shortcomings of conventional approaches

Conventional approaches for the design of reclamation drainage systems often provide rigid, non-erodible drainage facilities, which are designed to handle specific extreme flood events. This results in uniformity of design and construction but does not necessarily accomplish the closure drainage system performance objective of minimizing erosion and achieving long-term sustainability.

major deficiency of conventional approaches

A major deficiency of the conventional approaches is the absence of a self-healing mechanism. Man-made channels fail because of overtopping, washout of erosion protection, or channel degradation. This failure often leads to accelerated erosion and/or channel relocation. This is unacceptable because the failure may cause high sediment yields and loss of aquatic habitats.

dynamic systems as alternatives to rigid systems

The alternative to such rigid systems designed for specific extreme events is a dynamic system capable of accommodating evolutionary changes without accelerated erosion or unacceptable environmental impacts. Such dynamic systems must have robust drainage facilities with several lines of defense and self-healing capability. These can be built into the reclamation drainage systems by design. This fundamental approach was used for the design of closure reclamation drainage systems for the Muskeg River Mine Project.

anticipation of changes enables design of robust drainage systems

This geomorphic approach is based on a natural process, where drainage systems will change over time. Similar changes are anticipated in the closure reclamation drainage systems. Anticipation of such changes enables the design of robust drainage systems with second and third lines of defense. The types of changes that may occur to the closure reclamation drainage systems include the following:

- deposition of sediment, which could raise the channel bed and reduce the channel conveyance capacity;
- erosion of the channel bed that could lower the channel bed and result in channel degradation;
- bank erosion;
- vegetation growth on the channel bed and banks that could increase the channel roughness and the water levels;
- reduction of the width of channel because of sedimentation on one side of a wide channel that is built wider than the regime width;
- overtopping and consequent relocation of the drainage channels because of excessive sedimentation, beaver dams or icing; and
- bank erosion and subsequent failure because of slope instability or slumping.

reclamation drainage channels are designed to be in regime

Natural channels are in regime and exhibit sediment equilibrium. The existing literature has extensive data collected by fluvial geomorphologists to correlate channel regimes with hydrologic, topographic and soil conditions. These data provide a sound basis for designing channels in regime to replicate the dynamic character of natural channels and to avoid progressive and rapid channel degradation or aggradation. Regime channels are capable of handling extreme flood events. Rigid erosion control measures are unnecessary because regime channels are designed to accommodate erosion. Reduction of flow velocities during extreme flood events is achieved by building drainage channels in well-defined swales or valleys, just like natural drainage systems. Floodplains and wetlands provide extra storage to attenuate flood peak discharges.

2.3 DESIGN CRITERIA

design criteria are presented in Table 1

Table 1 presents the design criteria developed to achieve the performance objectives of the closure reclamation drainage systems by following the fluvial geomorphic approach. These design criteria were adopted for evaluation of various surface drainage alternatives, selection of the proposed scheme, and feasibility design of the drainage systems.

Table 1 Design Criteria for Developing Closure Reclamation Drainage Systems

Design Criteria	Design Considerations or Features Provided for Drainage Systems
Sustainability in Geological Time Frame	• Structures such as dams and reservoirs, which could cause rapid deterioration of the landscape in the event of an extreme flood event, should be excluded from the closure landscape. • Channels should be subject to gradual change over geologic time frame and basin sediment yields should be similar to natural conditions.
Drainage Effectiveness	• Drainage effectiveness and landscape stability should be similar to pre-development conditions.
Channel in Regime	• Regime channels should be designed by selecting appropriate channel parameters based on hydrologic and soil conditions and replication of natural analogues.
Channel Dimensions	• Channel dimensions and width-depth ratios should be selected based on regime relationships. • Maximum channel side slope should be 3H:1V in sandy soils, 2.5H:1V for overburden (OB) materials, and 1.5H:1V in select clay soils where the channel depth is less than 1 m. • Minimum channel bed width should be 3 m for major channels and 1 m for minor channels.
Channel Slope	• Main and secondary drainage channel slopes should be designed based on regime relationships. • Minimum slope of main drainage channels on sandy soils should be 0.001 to allow adequate drainage but to minimize channel erosion.
Channel Sinuosity	• Channels should have a sinuous pattern to replicate natural systems and reduce channel bed slopes.

Design Criteria	Design Considerations or Features Provided for Drainage Systems
Floodplains	• Main drainage channels should be sized to convey low flows and frequent small flood events. • Floodplains should be provided to convey high flows and large flood events with low recurrence intervals.
Drainage Density of Secondary Drainage Channels	• Secondary drainage channels should be built on the reclaimed landscape to suit the characteristic drainage density of the terrain. Design drainage densities are estimated to be as follows: - Sand at 0.5% slope = 1.0 km/km^2 - OB material at 0.5% slope = 2.5 km/km^2
Grassed waterways on OB material	• Grassed waterways on OB material should be designed as follows: - width (m) = $10\,A^{1/2}$, where A = drainage area (km^2) - organic soil depth = 0.8 m - slopes (%) $\leq 0.5 \times \frac{1}{A}$, where A = drainage area (km^2)
Channels on Bouldery Ground	• Where channels cannot meet the erosion control specification indicated below, supply bouldery ground beneath the channel and along the channel with an initial armour layer on the channel bed.
Channel Erosion Protection	• Regime channels should be characterized by sediment equilibrium, subject to gradual evolution over geologic time frame. • Allowable erosion levels for unlined regime channels are as follows: - no erosion during the 10 year flood event - little erosion during the 100 year flood event - moderate erosion during the probable maximum flood (PMF) event • Maximum allowable flow velocities for channels in sandy soils are as follows: - 2-year flood event: 0.5 m/s - 10-year flood event: 1.0 m/s - 100-year flood event: 1.5 m/s - PMF: 2.0 m/s • Maximum allowable flow velocities for channels in overburden or natural ground (clay/silt/gravel soils) are as follows: - 2-year flood event: 1.0 m/s - 10-year flood event: 1.5 m/s - 100-year flood event: 2.0 m/s - PMF: 3.0 m/s

Design Criteria	Design Considerations or Features Provided for Drainage Systems
Shallow Wetlands and Lakes	• Shallow wetlands and lakes with an average depth of one metre should be built into the drainage systems to provide for bioremediation and flood attenuation. • Shallow wetlands and lakes should be sized with a total combined surface area of about 5% of the catchment area. • A shallow lake of about 1.5 m deep should be built with each shallow wetlands, with an average depth of about 0.5 m. The surface area of the shallow lake should be approximately equal to the surface area of the shallow wetlands.
End Pit Lake	• End pit lake should have a zone of littoral vegetation, occupying about 20% of the lake surface area to ensure biological productivity. • Average water depth of the littoral zone should be about 0.5 m. • The littoral zone should be protected by a rock breakwater designed to protect against 100 year wind events. The breakwater will enable the initial development of the littoral zone. • The breakwater should be designed to prevent damage during the 100-year wind and to allow about 5% damage by the 1000-year wind. This modest criteria is acceptable because shoreline protection of the end pit lake is not a major concern and because shoreline erosion would not threaten the containment or spillage of the lake and would not cause catastrophic sedimentation to occur.
Sand Ridges in CT Storage Areas with Sand Caps	• Ridges of sand (underflow sand) should be provided on consolidated tailings(CT) storage areas with sand caps. • Sand ridges are necessary to provide drained soil conditions to ensure access, leach CT porewater residue, and support small patches of vegetative cover during initial period of reclamation, when consolidation of CT results in upward flux of CT porewater. • A 0.5 m thick layer organic soil mixed with overburden material should be placed on the surface of sand to provide the appropriate moisture balance to support deciduous trees or a mixedwood forest cover with dense understorey vegetation.
Sand Trenches in CT Storage Areas with Overburden Caps	• Sand trenches should be provided in CT storage areas with overburden caps to allow release of CT porewater. • Collector ditches will form naturally on the sand trenches to become the secondary drainage channels.

There are various types of channel regime relationships governing channel width, depth, width-depth ratio, sinuosity and meander wave length. These parameters are normally a function of mean annual flow, bankfull flow, soil type and slope. However, the regime formulations are not exact. There is a range of acceptable channel parameters as illustrated by the scatter in the baseline data from which the relationships were used to guide the channel design.

The following regime relationships provided by Schumm (1977) were used to guide the channel design:

$$W = 37\frac{Q^{0.38}}{M^{0.39}} \qquad \{ft\}$$

$$D = 0.6M^{0.342} \cdot Q^{0.29} \qquad \{ft\}$$

$$S = \frac{60}{M^{0.38} \cdot Q^{0.32}} \qquad \{ft/mile\}$$

$$\lambda = 1890\frac{Q^{0.34}}{M^{0.74}} \qquad \{ft\}$$

$$P = 0.94M^{0.25}$$

where, Q = mean annual discharge (ft^3/s)
M = silt/clay content of the bed material (%)
W = channel bankfull width (ft)
D = channel bankfull depth (ft)
S = channel bed slope
λ = channel wave length
P = channel sinuosity

2.4 DESIGN ASSUMPTIONS

assumptions incorporated in the design of the closure reclamation drainage systems

This feasibility-level design of closure reclamation drainage systems was conducted based on the following assumptions:

Provision of Drainage Outlets

It is assumed that all closure landscapes will be equipped with surface drainage outlets. Closed systems resulting in saline lake areas are not acceptable in the mine closure landscape.

No Dams

It is assumed that dams containing deep ponded areas cannot form part of the closure landscape. Any potential ponded areas must be limited to shallow ponded wetlands/lakes with depths less than 2 m.

Permanent Walk-Away Closure

The drainage systems and landscape will enable permanent walk-away closure after a period of monitoring and management of the reclamation systems.

Top Soil Cover

It is assumed that a reclamation soil cover with sufficient depth of topsoil will be supplied. This will provide the necessary soil moisture storage to support a mixedwood tree cover with dense understory vegetation and grasses to provide effective erosion resistance.

Consolidation of CT Materials

It is assumed that consolidation of CT materials will be accommodated by providing managed drainage outlet channels. The invert of a managed drainage channel is lowered during a management period to suit the rate of CT consolidation.

Topographic Slope

It is assumed that a minimum slope of 0.5% is required for the overall reclaimed surfaces to provide positive drainage.

3. HYDROLOGIC AND WIND DESIGN PARAMETERS

3.1 HYDROLOGIC ANALYSES

detailed hydrologic analyses are presented in the Shell Project EIA document

Detailed hydrologic analyses were conducted as part of the Muskeg River Mine Project EIA. The analyses included a derivation of climatic and hydrologic parameters to characterize the baseline conditions in the LSA and at the Project area. Hydrologic modelling was conducted to derive simulated flow series for various types of reclaimed surfaces, which were analyzed to derive the hydrologic parameters for quantifying runoff characteristics of the reclaimed surfaces.

relevant climatic and hydrologic design parameters are presented in this report.

This report summarizes the methodology and results of the analyses related to flood hydrology and extreme wind estimates required for the design of the closure reclamation drainage systems. A detailed discussion of the methodology and results of the detailed hydrologic analyses were presented in the Muskeg River Mine Project EIA report (Shell 1997).

3.2 RECLAIMED LANDFORMS FOR CLOSURE

3.2.1 Landform Types

there are four principal types of reclaimed landforms

There are four principal types of reclaimed landforms planned for the Muskeg River Mine Project, as listed below:

- reclaimed CT and overburden storage areas capped with sand or overburden materials, located within the mine pits;
- reclaimed tailings settling pond, constructed above the original ground;
- reclaimed overburden storage facilities constructed above original ground; and
- End pit lake.

3.2.2 In-Pit CT and Overburden Storage Cells

relevant climatic and hydrologic design parameters are presented in this report.

CT material will be stored in Cells 1 to 5. The CT will be capped with sand or overburden materials to raise the elevations of the final topography to enable positive drainage of the surface runoff toward the end pit lake.

Cell 6 will store overburden materials. It will also need to be capped with sand to raise the topography to enable positive drainage of surface water. Table 2 lists the average elevations of the final topography at each pit.

Table 2 In-Pit CT and Overburden Storage Cells

Cell No.	Average Cell Bottom Elevation (m)	Bottom Layer		Top Layer		Hydrologic Characteristic
		Material Type	Average Level (m)	Material Type	Average Level	
1	215	CT	275	OB	285	Initial - wet Final - dry
2/3	210	CT	283	OB	290	Initial - wet Final - dry
4	225	CT	285	Sand	290	Wet lowland Dry ridges
5	220	CT	283	Sand	287	Wet lowland Dry ridges
6	225	OB	273	Sand	285	Well drained upland conditions

During mine operation, the material for raising the cell areas will be obtained from mining operations such as tailings sand and overburden stripping. As part of reclamation activities, the sand material needed to raise the elevation of the cell surfaces will be supplied by hydraulic transport from the sand tailings area.

3.2.3 Reclaimed Tailings Settling Pond

surface topography and drainage systems

The reclaimed tailings settling pond will be above the original ground level. The structure will have an average outside side slope of 5H:1V and a relatively mild inside side slope of 25H:1V. The majority of the surface runoff from this concave structure will drain to a shallow wetlands and lake before conveyance to the end pit lake. The structure will be built mainly of sand, with some remnant layers of fine tailings settling. A collector system with shallow wetlands and lakes will be built around the perimeter of the structure to collect perimeter surface runoff and sub-surface seepage from the structure.

drainage characteristics and vegetation cover

The top surface and side slopes of this sand structure will be covered by a layer of topsoil composed of a mixture of organic soil and mineral soil over sand. The underlying sand is expected to be fairly pervious like the sand of

Suncor's Tar Island Dyke, because the oil sands of the Muskeg River Mine Project resemble Suncor's sand gradation as opposed to the less pervious sand of Syncrude's sand storage areas. The surface of most of the sand structure will therefore be characterized by rapid infiltration and relatively low potential for gullying after the establishment of mature vegetation. However, the perimeter and the lowland interior area of the tailings sand structure are expected to be composed of saturated soils because these are groundwater discharge areas. Except for the perimeter and interior lowland area, the remaining area is expected to be characterized by relatively dry soil conditions capable of supporting upland vegetation. The seepage discharge areas at the perimeter and internal lowland areas will be covered with wetlands vegetation.

3.2.4 Out-of-Pit Overburden Disposal Areas

drainage characteristics of out-of-pit overburden disposal areas

Overburden disposal areas will be built above original ground level at out-of-pit locations during the initial years of mine development. Sides slopes are expected to be about 3H:1V. These structures will be reclaimed with a layer of topsoil. The reclaimed overburden disposal areas will be subject to relatively low surface water yield in summer due to the high porosity of the reclamation topsoil and well-drained conditions of the relatively steep topography. The relatively impervious sub-soils and high soil storage capacity of surficial soils are expected to result in conditions favourable for upland forest production.

The top surfaces at the Northeast and South Disposal Areas will be crowned to encourage drainage to the edges. No ditches or grassed waterways are required for these facilities because the path length for overland flow is less than 400 m. A collector drainage system is needed on the surface of the West Disposal Area because it is a larger facility and would otherwise result in overland path lengths of up to 800 m.

3.2.5 End Pit Lake

An end pit lake is a necessary feature of the mine closure landscape because end of mine operations involve mining in the final pit. The final pit would fill naturally with surface area drainage and groundwater. The resulting lake would become an unproductive, highly saline waterbody without sufficient surface inflow to compensate for evaporation losses and provide for flushing. Therefore, surface runoff will be routed through the end pit lake to provide for a productive lake in the mine closure landscape.

3.3 HYDROLOGY OF RECLAIMED SURFACES

3.3.1 Hydrologic Modelling Analysis

HSPF model was used to simulate surface runoff from reclaimed surfaces

The Hydrologic Simulation Program Fortran (HSPF) model was used to simulate surface runoff from reclaimed surfaces and to route surface flows through channels and lakes. The HSPF model is a continuous simulation hydrologic model from the U.S. Environmental Protection Agency (USEPA). It uses a combination of empirical and physically-based relationships to predict runoff, evaporation and changes in soil moisture storage. This model can be used to simulate both rainfall and snowmelt runoff processes.

estimating model parameters for reclaimed surfaces

The HSPF model was calibrated for the natural upland and lowland areas based on the recorded streamflow data in the LSA. The calibrated model parameters for the natural basins provide a basis for estimating the model parameters for the reclaimed surfaces as shown in Table 3. The estimation of these parameters is also based on a good understanding of the runoff processes of the reclaimed surfaces as described below.

water yield and seepage characteristics of the reclaimed sand storage area

External Sand Storage Area: This area will be composed largely of free draining subsoil. The underlying sand material will limit the moisture storage in the surficial soils because any increase in soil moisture above field capacity will be lost to percolation through the free draining subsoil. Without a relatively impervious subsoil, the tailings sand storage area will have less moisture available for evapotranspiration (ET) and surface runoff. The reduced ET will report to increased deep percolation losses. Deep percolation losses will report mainly to seepage discharge in perimeter ditches of the tailings sand storage area but some will bypass the seepage interceptor system and seep into waterbodies such as Muskeg and Athabasca rivers.

flood runoff characteristics of the reclaimed sand storage area

Flood runoff from the reclaimed sand storage area will be much smaller than natural lowland surface in summer because of the relatively dry conditions and pervious soils. However, flood runoff during snowmelt will be higher because the relatively steep slopes will convey flow more quickly down reclaimed surfaces, which will be nearly impervious when frozen.

Table 3 Summary of Calibrated and Estimated Parameters for the HSPF Model

					Calibrated Values for Natural Basins		Estimated Values for Reclaimed Surfaces						
Parameter Description	**Parameter Name**	**Unit**	**Min Value**	**Max Value**	**Lowland Areas**	**Upland Areas**	**Reclaimed Sand Cap on CT**	**Reclaimed Overburden Cap on CT**	**Reclaimed Sand Cap on Overburden**	**Reclaimed Overburden Storage**	**Reclaimed Tailing Settling Pond Area**	**Wetlands**	**End Pit Lake**
1)Elevation Adjustments													
Precipitation, Coefficient =1 at Ft. McMurray	PREC	mm			1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017
Air temperature	ATMP	°C			varies	varies	varies	varies	varies	varies	varies	varies	varies
2) Snow Simulation													
Latitude of Pervious Land Segment (PLS)	LAT	degrees	-90	90	56.8	56.8							
Mean Elevation of PLS	MELEV	m	0	10000	varies	varies	289	290	286	290	290	282	282
Shade Fraction of PLS	SHADE	none	0	1	0.9	0.9	0.3	0.6	0.5	0.6	0.5		
Snow Catch Factor	SNOWCF	none	1	100	1.1	1.1	1.1	1.1	1.1	1.1	1.1		
Maximum Pack (Water Equivalent)	COVIND	mm	0.25	none	100	100	100	100	100	100	100		
Density of Cold, New Snow relative to Water	RDCSN	none	0.01	1	0.19	0.19	0.19	0.19	0.19	0.19	0.19		
Air Temperature below which Precip will be Snow, under Saturated Conditions	TSNOW	deg C	-1	5	5	5	5	5	5	5	5		
Parameter which Adapts the Snow Evaporation Equation to Field Conditions	SNOEVP	none	0	1	0.02	0.02	0.02	0.02	0.02	0.02	0.02		
Parameter which Adapts the Snow Condensation Melt Equation to Field Conditions	CCFACT	none	0	2	1	1	1	1	1	1	1		
Maximum Water Content of the Snow Pack	MWATER	none	0	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		
Maximum rate of snow melt by ground heat	MGMELT	mm/day	0	25	0	0	0	0	0	0	0		
3) Rainfall Runoff Simulation													
Fraction of the PLS Which Is Covered by Forest	FOREST	none	0	1	0.9	0.9	0.3	0.6	0.5	0.6	0.5		
Lower Zone Nominal Storage in Winter	LZSN	mm	0.25	2500	225	200	125	60	11	60	11		
Lower Zone Nominal Storage in Summer	LZSN	mm	0.25	2500	100	100	125	60	11	60	11		
Index to the Infiltration Capacity of the Soil in Winter	INFILT	mm/hour	0.0025	2500	70	70	0.6	18	25	18	25		
Index to the Infiltration Capacity of the Soil in Summer	INFILT	mm/hour	0.0025	2500	2	2	0.6	18	25	18	25		
Length of the Assumed Overland Flow Plane	LSUR	m	0.3	none	830	830	830	830	830	830	830		
Slope of the Assumed Overland Flow Plane	SLSUR	none	0.000001	10	0.0015	0.00777	0.0015	0.0015	0.0015	0.0015	0.0015		
Parameter Which Affects the Behavior of Groundwater Recession Flow	KVARY	1/mm	0	none	0.05	0.05	0.05	0.05	0.05	0.05	0.05		
Basic Groundwater Recession Rate	AGWRC	1/day	0.001	1	0.096	0.096	0.94	0.94	0.99	0.94	0.99		
Ratio between the Max. and Mean Infiltration Capacity over PLS	INFILD	none	1	2	2	2	2	2	2	2	2		
Fraction of Groundwater Inflow Which Will Enter Deep Groundwater	DEEPFR	none	0	1	0	0	0.1	0	0	0	0		
Fraction of Remaining Potential E-T Which Can Be Satisfied from Baseflow	BASETP	none	0	1	0.03	0.03	0.03	0.03	0.03	0.03	0.03		
Fraction of Remaining Potential E-T Which Can Be Satisfied from Groundwater Storage	AGWETP	none	0	1	0.05	0.05	0.05	0.05	0.05	0.05	0.05		
Interception Storage Capacity (varies by month, max value is stated)	CEPSC	mm	0	250	4	8	2	2	0.3	2	0.3		
Upper Zone Nominal Storage (varies by month, max value is stated)	UZSN	mm	0.25	250	100	195	20	20	14	20	14		
Manning's n for the Assumed Overland Flow Plane	NSUR	none	0.001	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25		
Interflow Inflow Parameter	INTFW	none	1E-30	none	3	3	3	3	3	3	3		
Interflow Recession Parameter	IRC	1/day	1E-30	1	0.9	0.9	0.9	0.9	0.9	0.9	0.9		
Lower Zone E-T Parameter (varies by month, max value is stated)	LZETP	none	0	1	0.55	0.85	0.55	0.55	0.55	0.55	0.55		
4) Channel Routing Simulation													
Length of the Channel	LEN	km	0.016	none	varies	varies	varies	varies	varies	varies	varies	varies	varies
Drop in Water Elevation from Upstream to Downstream	DELTH	m	0	none	varies	varies	varies	varies	varies	varies	varies	varies	varies
Correction to the Channel depth to Calculate Stage	STCOR	m	none	none	0	0	0	0	0	0	0	0	0
Weighting Factor for Hydraulic Routing	KS	none	0	0.99	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

basin and runoff characteristics of the reclaimed overburden storage areas

Overburden Storage Areas: These areas are expected to have hydrologic characteristics similar to the natural upland conditions. However, water yield and flood peak discharges of the overburden storage areas are expected to be greater than the natural upland areas because of steeper slopes and smaller surface soil storage capacity.

CT water will not seep to the receiving water bodies

In-Pit CT Storage Areas (Cells 1 to 5): The final elevations of the CT surfaces in Cells 1 to 5 will be below original ground. Consequently, there will be no seepage of the CT porewater to the receiving waterbodies. Instead, there will be a net inflow of seepage into the CT area from the perimeter area.

basin characteristics of reclaimed sand cap on CT

The reclaimed sand cap on CT (Cells 4 and 5) will be characterized by wet conditions in lowland areas between the sand ridges. The hydrologic conditions are expected to be similar to the existing muskeg terrain. The periphery areas, which are situated below the existing ground level, will be subject to particularly wet conditions as a result of groundwater seepage into the cell from the terrain around the cells. Any areas located above original ground level at the periphery of the mine pit (i.e., east sides of Cells 1, 2 and 3) will be relatively dry and are expected to support dry upland vegetation.

sand ridges on reclaimed sand cap on CT

Sand ridges are necessary to provide drained soil conditions to support small areas of vegetative cover during initial reclamation when consolidation of CT results in upward flux of CT porewater. The ridges will also enable early planting of upland vegetation so that the vegetation progression can begin, during a time when upward flux of CT porewater is causing most of the area to perform as a wetlands. The ridges, composed of sand, will be built by controlled spigotting and incremental lengthening of the spigot pipeline along the location of the spigot. The development of the ridges will cause channelization to occur in the area between the wetlands. This dendritic secondary drainage system will drain to the wetlands.

runoff characteristics of reclaimed sand cap on CT

The wet areas of the sand cap on CT in cells 4 and 5 will be subject to relatively high evapotranspiration losses because of the greater available soil moisture. Consequently, the annual water yield and flood discharge characteristics of these areas are expected to be similar to the existing muskeg terrain. Annual water yield may be slightly greater at CT areas than at natural muskeg areas because of the smaller soil moisture storage capacity of reclamation topsoil and the presence of sand ridges which will result in lower evaporation than natural lowland areas. Surface runoff from drier portions of the sand-capped CT areas will be relatively small except during snowmelt when melting governs water yield.

basin and runoff characteristics of reclaimed overburden cap on CT

Portions of the overburden-capped CT areas (Cells 1 to 3) will have similar basin and runoff characteristics as the reclaimed overburden storage areas. However, the channel areas will be capped by sand to enable release of upward flux of CT porewater. These areas will be very wet with similar runoff characteristics as the natural lowland muskeg terrain. The periphery areas will be subject to wet conditions, like the original muskeg terrain, because of groundwater seepage into the CT areas from the higher ground surface of perimeter areas.

basin and runoff characteristics of reclaimed sand cap on overburden

In-Pit Sand Cap on Overburden Area (Cell 6): Cell 6 will contain overburden material below original ground and tailings sand infill on top of overburden material to raise the ground level to near the original ground level. The sand infill material will be overlain by reclamation topsoil. The final topography will have an overland slope of 0.5%, similar to the natural muskeg terrain.

runoff characteristics of reclaimed sand cap on CT

The in-pit sand cap on overburden in Cell 6 is expected to have similar runoff characteristics as the reclaimed tailing settling pond area. Most of the area is expected to be characterized by well-drained conditions similar to upland areas. However, the lowland areas alongside the channels are expected to be wet due to seepage and runoff collection. The perimeter areas situated below original ground levels will be particularly wet as a result of seepage from the adjacent natural terrain situated at higher elevations. These areas are expected to result in higher water yield because of the high water table and relatively small soil moisture storage.

shallow lakes/wetlands will be beneficial for flood attenuation and biological treatment of runoff from reclaimed surfaces

Shallow Lakes and Wetlands: Shallow lakes and wetlands will be built into the reclaimed landscape at in-pit CT storage areas and the external sand storage area. The lakes/wetlands will attenuate flood peak discharges and provide for residence time which will improve drainage water quality through biological treatment. The lake/wetlands areas are sized to represent about 5% of the contributing catchment area.

physical characteristics of the end-pit lake

EndPit Lake: An endpit lake is an unavoidable feature of the closure landscape. However, it is highly beneficial because it provides containment for the residual MFT material which cannot be converted to CT prior to the end of mining and because it provides for remediation of CT porewater seepage, sand porewater seepage and MFT pore water release during consolidation of MFT. It will also contribute to the balance of dry and wet landscape in the reclaimed project area. A large littoral zone occupying 20% of the endpit lake area will be developed along the east shore to provide for biological productivity of the lake.

end-pit lake will cause a net loss of water yield

The presence of an endpit lake in the reclaimed landscape will reduce flood flows by providing lake storage for flow attenuation. However, the lake will reduce the net annual water yield because annual lake evaporation exceeds annual precipitation.

3.3.2 Annual Runoff from Reclaimed Surfaces

estimates of annual runoff from reclaimed surfaces

The estimated annual water yields from various types of reclaimed and natural surfaces are presented in Table 4 based on the analysis described in Section 3.3.1.

Table 4 Estimated Annual Runoff from Natural and Reclaimed Surfaces

Area Type	Parameter	Annual Water Yield (mm)				
		100 Year Dry	10 Year Dry	Mean	10 Year Wet	100 Year Wet
All	Precipitation	269	319	423	545	712
Natural Lowland	Evapotranspiration	269	302	357	427	522
	Percolation	0	0	5	5	5
	Runoff	0	17	61	113	185
Natural Upland	Evapotranspiration	235	264	319	389	484
	Percolation	0	0	5	5	5
	Runoff	34	55	99	151	223
Reclaimed Sand Cap on CT	Evapotranspiration	237	267	322	383	464
	Percolation	0	0	8	20	39
	Runoff	32	52	93	142	209
Reclaimed Overburden Cap on CT	Evapotranspiration	256	266	304	339	383
	Percolation	0	0	4	6	12
	Runoff	8	43	115	200	317
Reclaimed Sand Cap on Overburden	Evapotranspiration	185	208	231	254	277
	Percolation	79	102	174	202	393
	Runoff	7	12	21	33	48
Reclaimed Overburden Storage	Evapotranspiration	256	266	293	322	350
	Percolation	5	10	15	23	45
	Runoff	8	43	115	200	317
Reclaimed Tailing Sand	Evapotranspiration	185	208	231	254	277
	Percolation	79	102	174	202	393
	Runoff	7	12	21	33	48
Wetlands	Evaporation	677	640	588	534	495
	Percolation	32	32	32	32	32
	Runoff	-440	-353	-197	-21	185
EndPit Lake	Evaporation	677	640	588	534	495
	Percolation	11	11	11	11	11
	Runoff	-419	-332	-176	0	206

The water yields from natural upland and lowland areas are included in the table for comparative purposes. These water yield estimates were made based on the available records of measured flow data at the regional WSC gauging stations and an understanding of the differences in runoff characteristics between natural and reclaimed surfaces.

3.3.3 Flood Peak Discharges From Reclaimed Surfaces

derivation of flood peak discharges from reclaimed surfaces

The simulated flows derived by the HSPF model were analyzed to determine flood peak discharges from reclaimed surfaces. The resulting flood flow parameters provide a basis for designing the closure reclamation drainage systems. Table 5 presents the derived flood peak discharges for each main channel shown on Figure 2. Detailed flood frequency estimates for other channel reaches are shown on the design drawings as discussed in Section 4. The Probable Maximum Flood (PMF) peak discharges were also derived by simulating the rainfall-runoff process resulting from the Probable Maximum Precipitation (PMP) event.

Table 5 A Summary of Flood Peak Discharges for Main Drainage Channels

Channel Number	Drainage Area (km^2)	Flood Peak Discharges at Specified Recurrence Interval			
		2 Year (m^3/s)	10 Year (m^3/s)	100 Year (m^3/s)	PMF (m^3/s)
C1	6.7	0.27	0.59	1.07	3.45
C2	5.2	0.27	0.59	1.07	6.16
C3	6.2	0.21	0.44	0.79	6.40
C4	7.5	0.21	0.44	0.79	3.10
C5	3.0	0.09	0.22	0.46	1.67
C6	29.3	0.33	0.70	1.21	2.48
C7	7.6	0.19	0.36	0.59	4.91

3.4 DESIGN WIND PARAMETERS

data used for derivation of the design wind parameters

Design wind parameters in the project area were required to provide a basis for designing shoreline protection for the end pit lake. The available wind data from the Aurora Station and other nearby climate stations have short periods of record. Therefore, these data cannot be directly used to derive reliable wind parameters, which require a long period of record. Therefore, the long-term (1959 to 1996) hourly wind data recorded at the Fort McMurray Airport station were used to derive the design wind parameters for the project site. However, the long-term wind characteristics recorded at the Fort McMurray station vary from the project area due to the differences in topographic features including elevation and surrounding landscape. This may introduce some errors into the derived design wind parameters at the project site.

design wind parameters derived for the project site

Table 6 presents the derived design wind parameters for various return periods and for various directions. It shows that the extreme winds from the west and southwest directions are stronger than the extremes from any other directions. The extreme hourly 100 year wind speed from the west and southwest directions are about 70 and 61 km/hr, respectively.

Table 6 Design Wind Parameters Based on the Climate Data at the Fort McMurray Airport

Wind Direction	Design Wind Speed for the Specified Return Period (km/hr)		
	2 Year	10 Year	100 Year
N	30	37	47
NE	26	33	42
E	33	40	47
SE	32	39	47
S	39	36	44
SW	37	48	61
W	43	55	70
NW	36	44	56

4. DESIGN OF RECLAMATION DRAINAGE SYSTEMS

4.1 GENERAL DRAINAGE SCHEME

main water handling facilities of the closure reclamation drainage systems

Figure 2 presents the layout of the proposed mine closure drainage systems, including main and secondary drainage systems and the reclamation topography at the Project area. A cross sectional representation of the reclamation drainage scheme and reclaimed mine facilities are shown in Figure 3. The proposed drainage scheme includes the following main drainage facilities:

- main channel C1 and C2 collect surface runoff from Cells 1 to 3 and route surface runoff to the end pit lake;
- main channel C3 and C4 collect surface runoff from Cells 4 and 6 and routes flows to the end pit lake;
- main channel C5 collects surface runoff from Cell 5 and routes the surface flows to the end pit lake;
- main channel C7 collects surface runoff from the reclaimed tailings settling pond and routes the flows to the end pit lake; and
- Main outlet channel C6 discharges the outflow from the end pit lake to the Muskeg River.

alternative channel routes

Figure 4 presents alternative routes of the main drainage channels labelled B1 to B11 that were evaluated during this feasibility design.

4.2 DRAINAGE SYSTEMS FOR IN-PIT CT AND OVERBURDEN STORAGE AREAS

4.2.1 Final Landscape

primary materials stored in Pits 1 to 6

As shown in Figure 2, the CT storage areas will be located in Cells 1 to 5. These mine pits will be filled with CT materials, but consolidation of those materials is expected to cause the surfaces to settle to the post settlement elevations shown in Table 2. Mine Cell 6 will be filled with overburden disposal materials to an elevation of 273 m.

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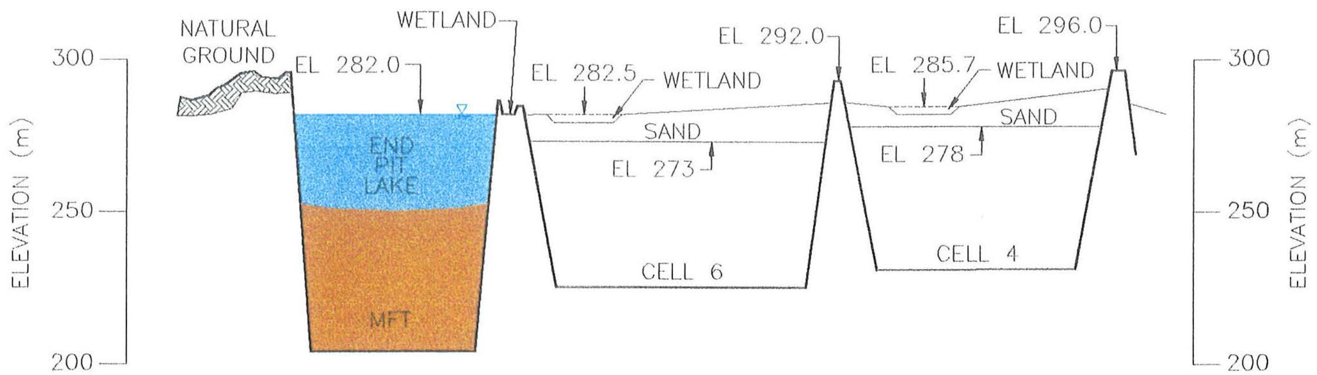
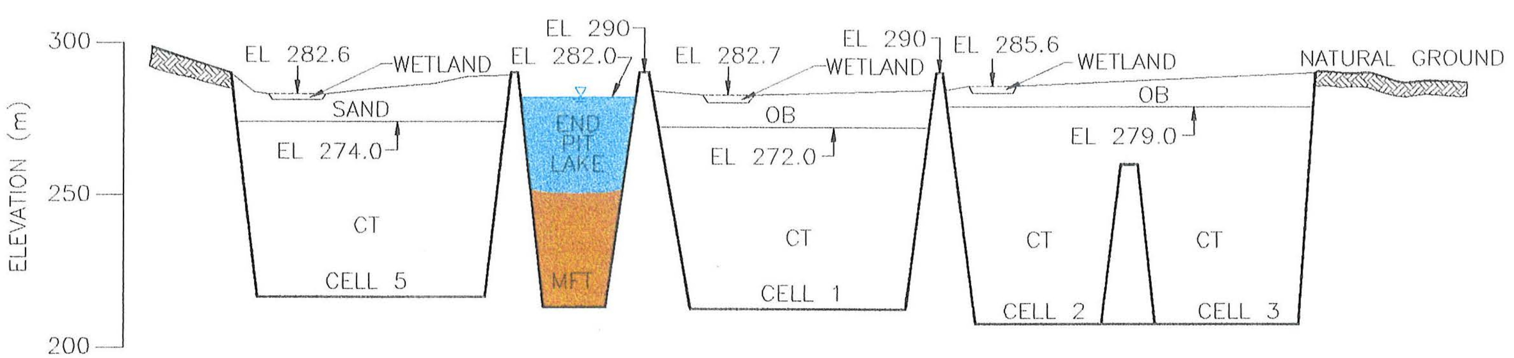


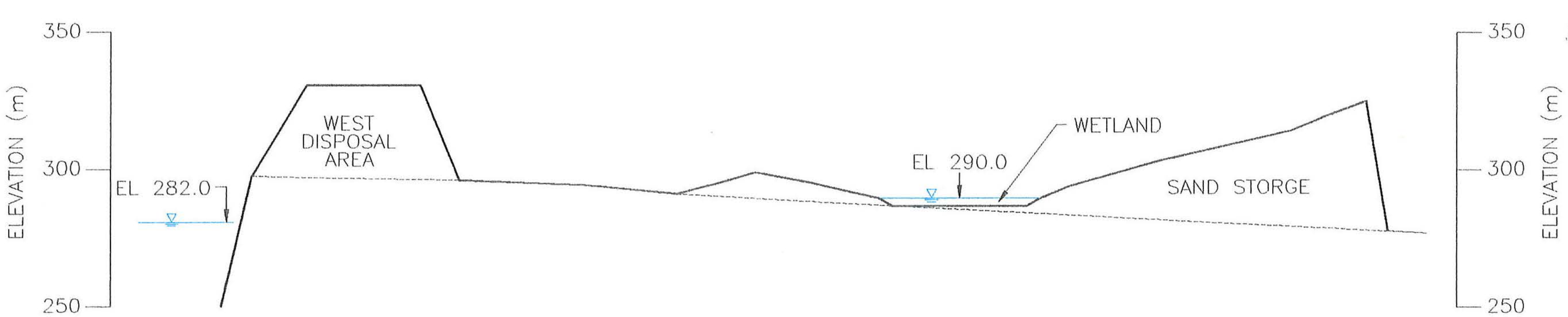
CROSS SECTION A-A' THROUGH CELL 4, CELL 6 AND END PIT LAKE

0 500 1000 1500 2000m
HORIZONTAL SCALE



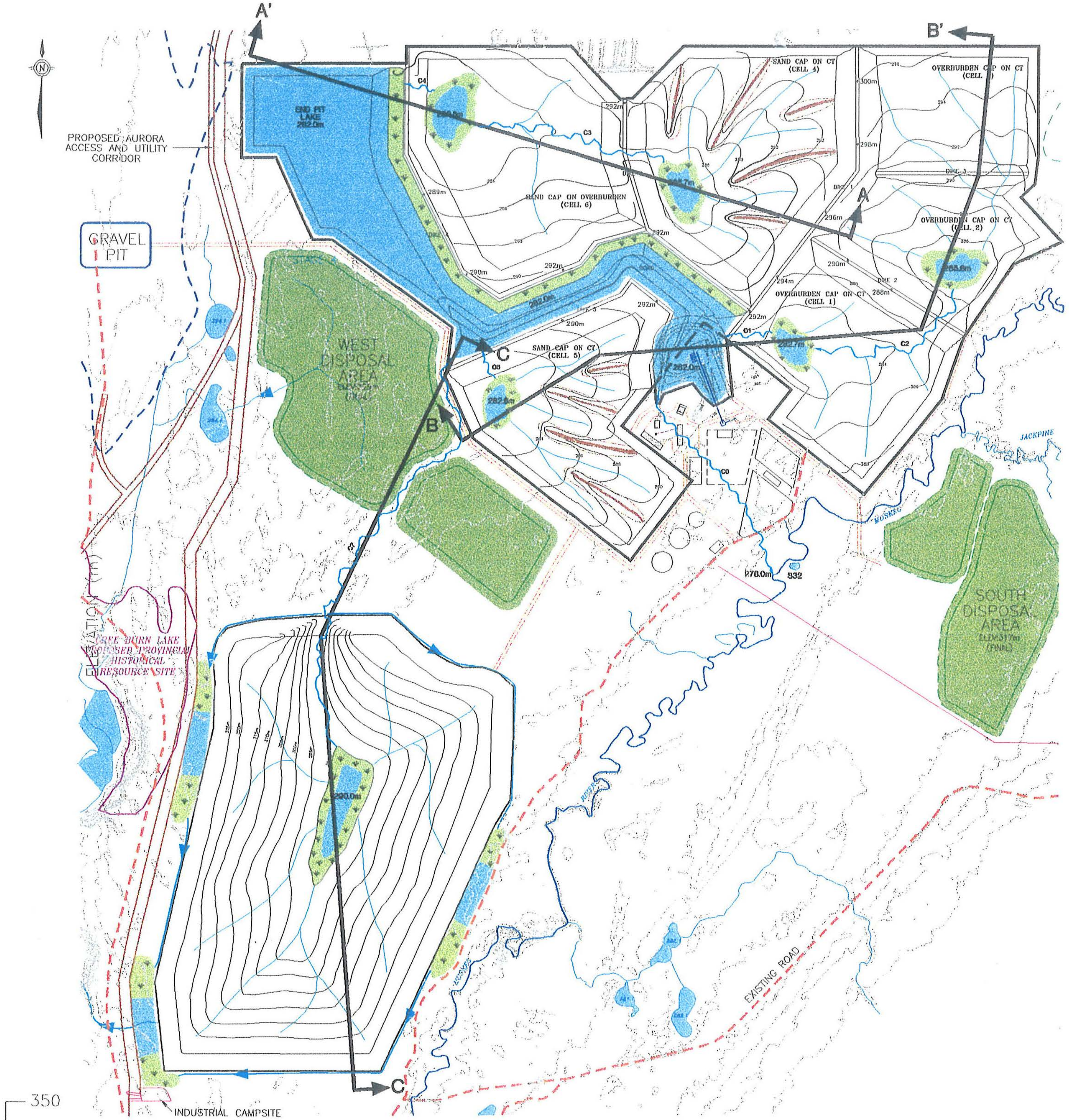
CROSS SECTION B-B' THROUGH CELL 1, CELL 2/3, CELL 5 AND END PIT LAKE

0 500 1000 1500 2000m
HORIZONTAL SCALE



CROSS SECTION C-C' THROUGH RECLAIMED TAILINGS SETTLING POND AND END PIT LAKE

0 500 1000 1500 2000m
HORIZONTAL SCALE



RECLAMATION DRAINAGE PLAN

SCALE 1:50,000

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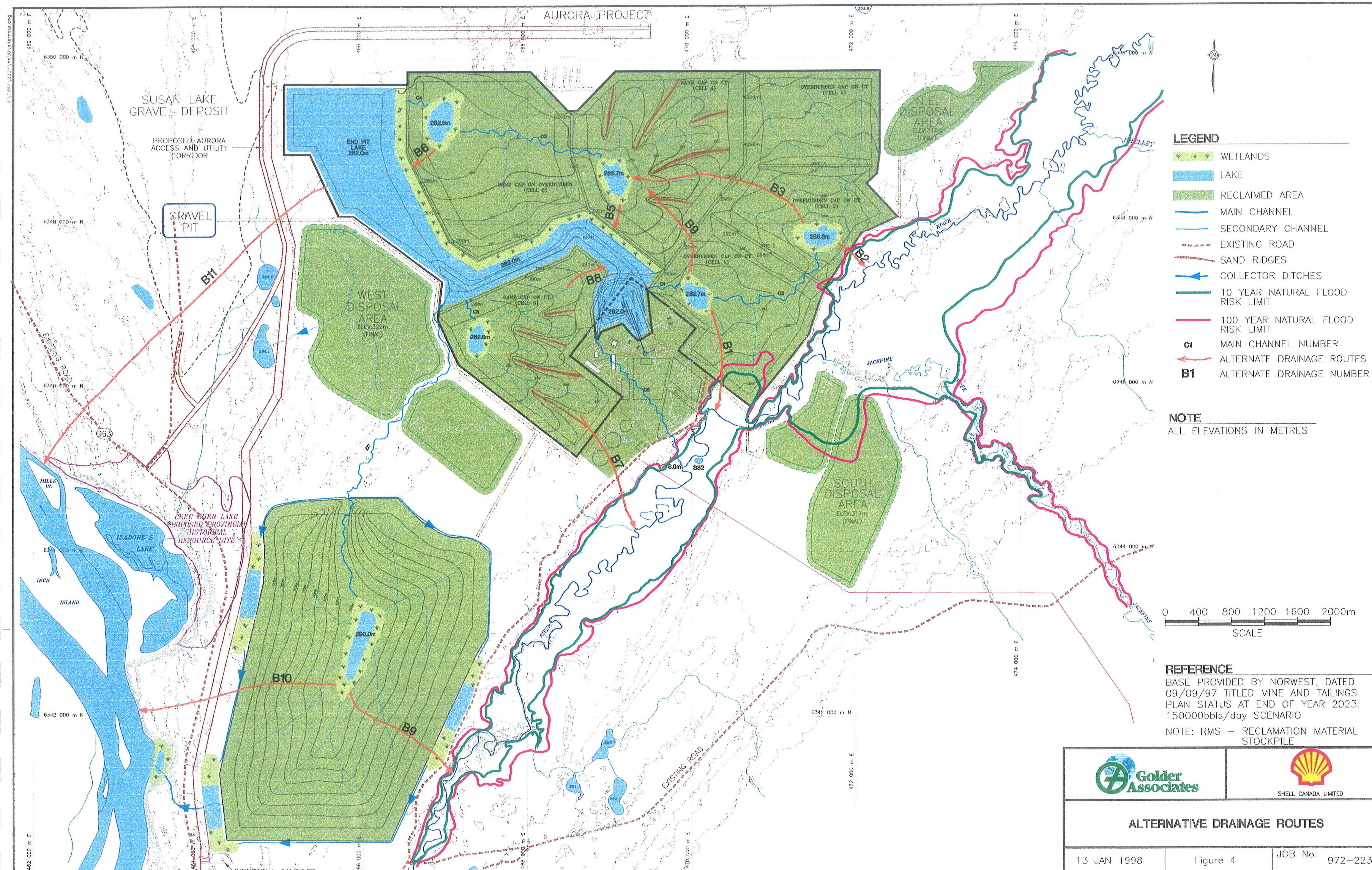
CROSS SECTION DETAILS FOR RECLAIMED MINE FACILITIES

13 JAN 1998	Figure 3	DRAWN BY: TM



AURORA PROJECT
SUSAN LAKE GRAVEL DEPOSIT
PROPOSED AURORA ACCESS AND UTILITY CORRIDOR
GRAVEL PIT
END PIT LAKE 282.0m
WEST DISPOSAL AREA ELEV.329m (FINAL)
N.E. DISPOSAL AREA ELEV.317m (FINAL)
SOUTH DISPOSAL AREA ELEV.317m (FINAL)
SAND CAP ON CT (CELL 4)
OVERBURDEN CAP ON CT (CELL 3)
SAND CAP ON OVERBURDEN (CELL 6)
OVERBURDEN CAP ON CT (CELL 2)
OVERBURDEN CAP ON CT (CELL 1)
SAND CAP ON CT (CELL 5)
282.5m
288.7m
288.8m
282.7m
282.0m
282.6m
290.0m
8.0m
B1
B2
B3
B5
B6
B7
B8
B9
B10
B11
EXISTING ROAD
963
MILLS IS.
ISADORE'S LAKE
INGS ISLAND
CREE BURN LAKE PROPOSED PROVINCIAL HISTORICAL RESOURCE SITE
INDUSTRIAL CAMPSITE
JACKPINE
SHELLEY
LEGEND
WETLANDS
LAKE
RECLAIMED AREA
MAIN CHANNEL
SECONDARY CHANNEL
EXISTING ROAD
SAND RIDGES
COLLECTOR DITCHES
10 YEAR NATURAL FLOOD RISK LIMIT
100 YEAR NATURAL FLOOD RISK LIMIT
C1 MAIN CHANNEL NUMBER
ALTERNATE DRAINAGE ROUTES
B1 ALTERNATE DRAINAGE NUMBER
NOTE
ALL ELEVATIONS IN METRES
0 400 800 1200 1600 2000m
SCALE
REFERENCE
BASE PROVIDED BY NORWEST, DATED 09/09/97 TITLED MINE AND TAILINGS PLAN STATUS AT END OF YEAR 2023. 150000bbls/day SCENARIO
NOTE: RMS – RECLAMATION MATERIAL STOCKPILE
Golder Associates
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ALTERNATIVE DRAINAGE ROUTES
13 JAN 1998
Figure 4
JOB No. 972-2237

capping performed to raised the final elevations of the reclaimed surfaces

The final reclamation surface elevations of Cells 1 and 2/3 will be raised by 10 m and 7 m to about 285 m and 290 m, respectively, by capping the CT surfaces with overburden materials. The final reclamation surface elevations at Cells 4 and 5 will be raised by 5 m and 4 m to about 290 m and 287 m, respectively, by capping them with sand. The final surface elevation of Cell 6 will be raised by 12 m to about 285 m by capping the overburden materials with sand. Capping material during mining operations will be available from tailings sand, which would otherwise be conveyed to the sand tailings structure. After the end of mining, sand for capping will be obtained from the sand tailings facility by hydraulic transport.

topographic slopes of reclaimed surfaces

The average slope of the reclaimed surfaces at Cells 1 to 6 is expected to be about 0.5%. This is similar to the pre-development surface slopes at the Project area. Milder slopes would cause excessive ponding and reduce surface runoff to the end pit lake and the Muskeg River. Steeper slopes would result in better drainage conditions, but would require more earthworks and would unnecessarily increase the cost of reclamation.

4.2.2 Main Drainage Systems for Cells 1 to 3

Proposed Systems

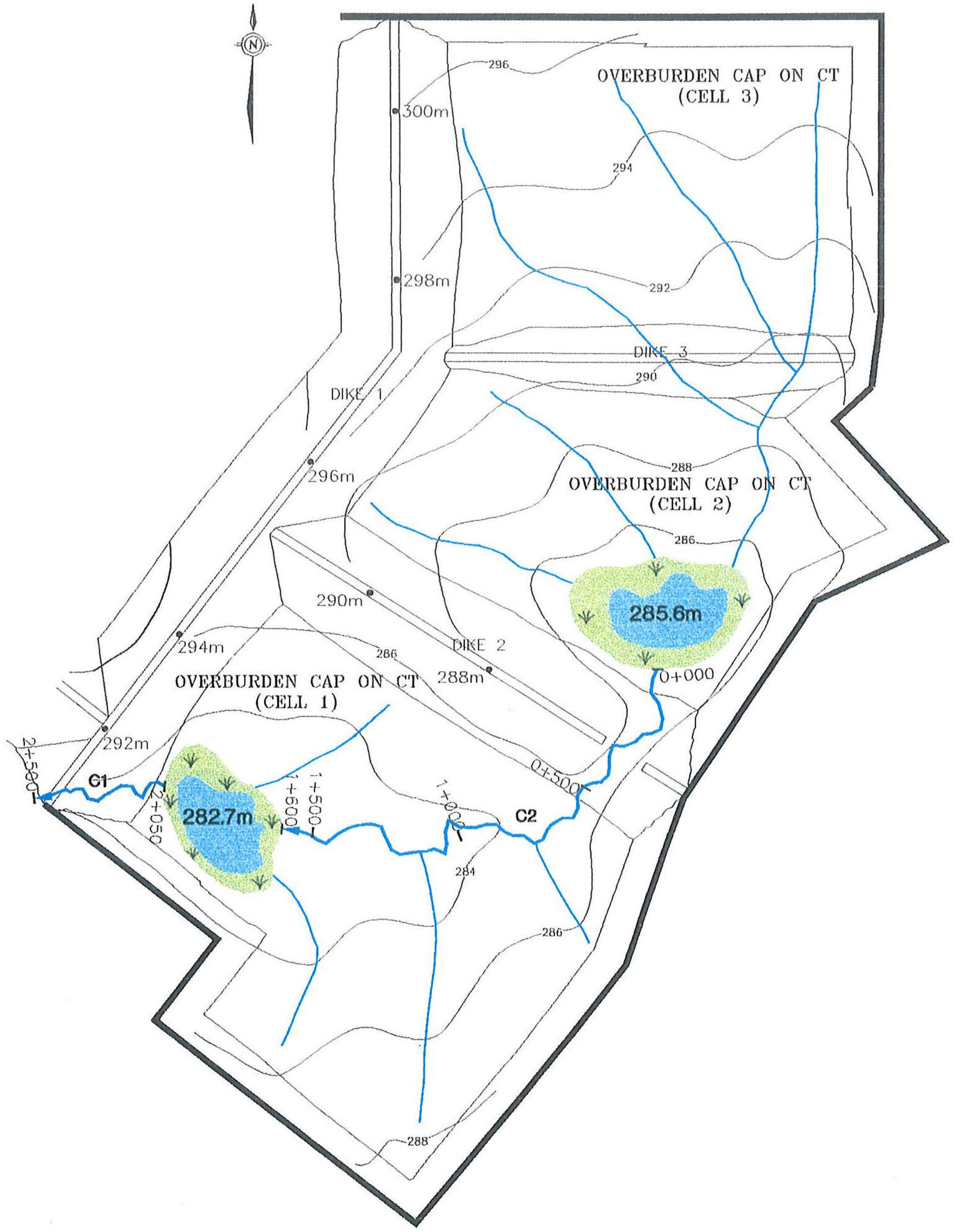
proposed drainage systems for Cells 1 to 3 and design drawings

The proposed drainage systems for Cells 1 to 3 include two main channels (C1 and C2) and two shallow wetlands/lakes. The drainage systems collect surface runoff and discharge of CT porewater caused by consolidation of the CT materials. The collected flows will be conveyed to the end pit lake. The total drainage area at the outlet of main channel C1 is about 6.7 km^2. Figure 5 presents the designs of the main drainage channels C1 and C2, and shows the plans of the channel alignment, profiles, typical cross sections, and summaries of channel design parameters. As illustrated in Figure 5, the channel width, depth, width-depth ratio, meander wavelength and sinuosity were selected based on the regime equations discussed in Section 2.

channel and valley design slopes

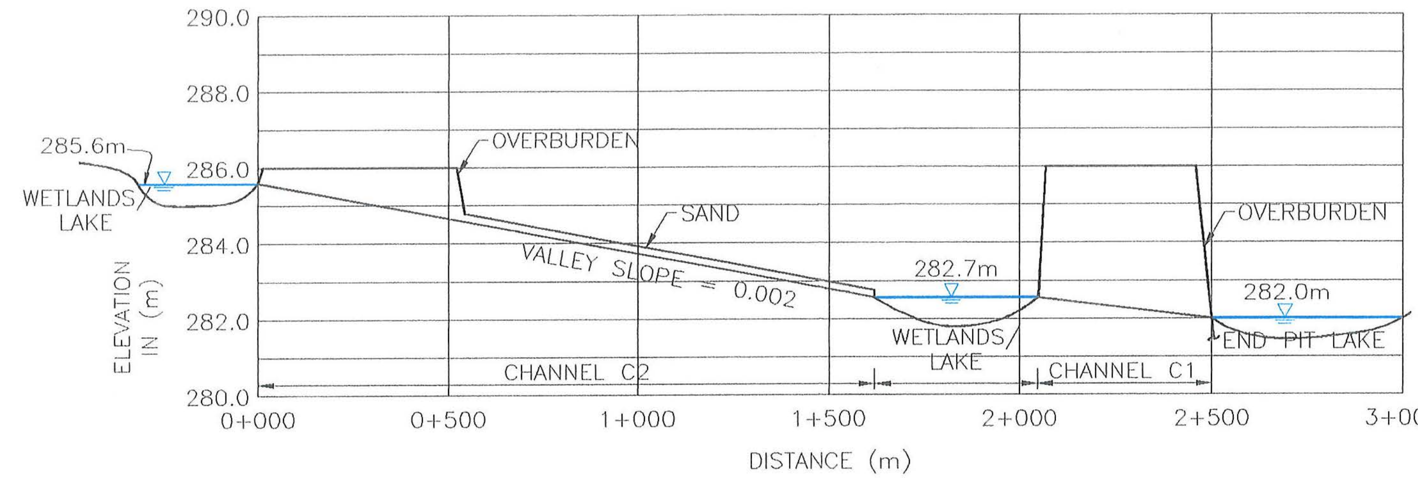
The valley slope for the C1 and C2 channels length is 0.2% and the channel slope is 0.13%, allowing for a channel sinuosity (channel length to valley length ratio) of 1.5 for both channels. The proposed channels have shallow depths to suit the small annual water yield, and large floodplains to accommodate larger flood flows. The estimated channel flow velocities are less than 0.43 m/s, even during the extreme PMF event. This design will minimize the channel erosion potential.

J:\1997\2237\6600\CHANC1-2.dwg



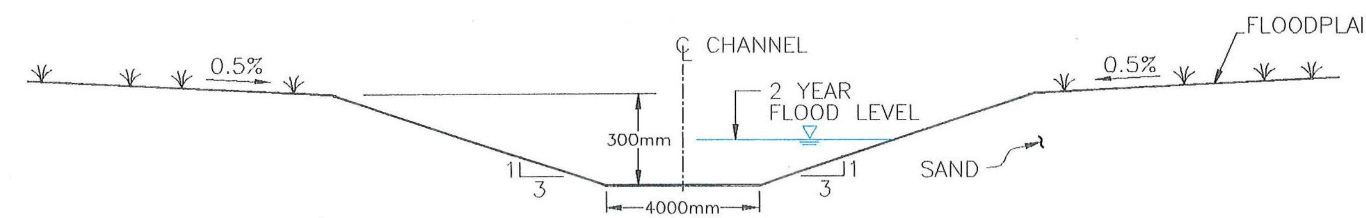
PLAN OF MAIN DRAINAGE CHANNELS FOR CELLS 1, 2 AND 3

SCALE 1:25,000



PROFILE OF MAIN DRAINAGE CHANNELS C1 AND C2

SCALE H=1:20,000 V=1:200



TYPICAL CROSS SECTION FOR MAIN CHANNELS C1 AND C2

NTS

SUMMARY OF CHANNEL DESIGN PARAMETERS

CHANNEL No.	DRAINAGE AREA (km²)	ASSUMED SILT/CLAY CONTENT OF CHANNEL BED (%)	AVERAGE ANNUAL FLOW (m³/s)	RETURN PERIOD (YEAR)	PEAK DISCHARGE (m³/s)	CHANNEL BED SLOPE	VALLEY SLOPE	CHANNEL BOTTOM WIDTH (m)	CHANNEL SIDE SLOPE (H:V)	CHANNEL LENGTH/ VALLEY LENGTH (SINUOSITY)	CHANNEL FLOW DEPTH (m)	CHANNEL FLOW VELOCITY (m/s)
C1	6.7	5	0.0234	2	0.27	0.0013	0.002	4.0	3:1	1.5	0.17	0.34
				10	0.59						0.36	0.43*
				100	1.07						0.41	0.43*
				PMF	3.45						0.51	0.43*
C2	5.2	5	0.0189	2	0.27	0.0013	0.002	4.0	3:1	1.5	0.17	0.34
				10	0.59						0.36	0.43*
				100	1.07						0.41	0.43*
				PMF	6.16						0.51	0.43*

NOTE: *BANKFULL FLOW VELOCITY

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DESIGN OF MAIN CHANNELS C1 AND C2

21 JAN 98 | Figure 5 | DRAWN BY: TM

Alternative Drainage Routes

routes B1 and B2 are not recommended because routing through the end pit lake provides bioremediation of the water from reclaimed surfaces

As shown in Figure 4, the flows from Cells 1 to 3 could alternatively be routed directly to Muskeg River through routes B1 and B2. This direct release of the surface water from the reclaimed CT areas would result in a discharge of water with less desirable water quality to Muskeg River. Routing the flows to the end pit lake would allow bioremediation of the CT release and the runoff from the reclaimed surfaces. Therefore, routes C1 and C2 are preferred to the alternative routes B1 and B2.

route B3 was not selected because it would require a large increase in reclamation cost

Runoff from Cells 1 to 3 could also be routed in a northeasterly direction (Route B3) to connect with the drainage systems for Cells 4 and 6. This would allow a longer residence time in the end pit lake for improved bioremediation of the inflows to the end pit lake, because the discharge point would be located at a point furthest from the lake outlet. However, this would require a large increase of the final elevations of the reclaimed surfaces at Cells 1 to 3 and would result in an unnecessary, large increase in cost. Therefore, this alternative route B3 was not selected.

4.2.3 Main Drainage Systems for Cells 4 and 6

Proposed Systems

proposed drainage systems for Cells 4 and 6 and design drawings

The reclamation drainage systems proposed for Cells 4 and 6 include two main channels (C3 and C4) and two shallow wetlands/lakes. The drainage systems collect runoff from Cells 4 and 6 and discharge to the end pit lake. The total drainage area at the outlet of main channel C4 is about 7.5 km^2. Figure 6, which presents the designs of the main drainage channels C3 and C4, shows the plans of the channel alignment, profiles, typical cross sections, and summaries of channel design parameters. As illustrated in Figure 6, the channel width, depth, width-depth ratio, meander wave length and sinuosity were selected based on the regime equations discussed in Section 2.

hydraulic parameters of drainage channels

The valley slope for the C3 and C4 channels is 0.2% and the channel slope is 0.13% allowing for a channel sinuosity (channel length to valley length ratio) of 1.5 for both channels. The proposed channels have shallow depths to suit the small annual water yield and large floodplains to accommodate larger flood flows. The estimated channel flow velocities is less than 0.5 m/s even for the extreme PMF event.

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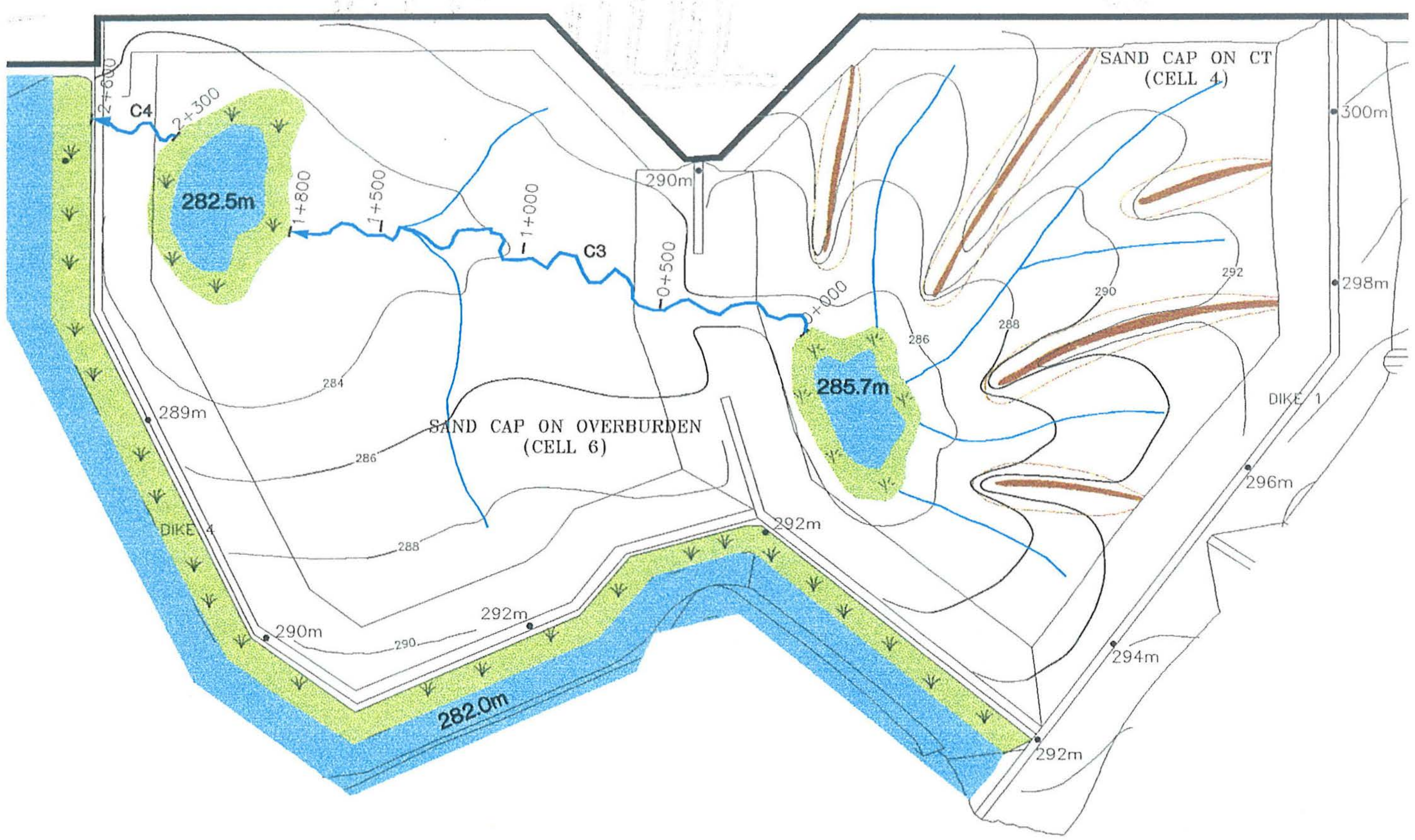
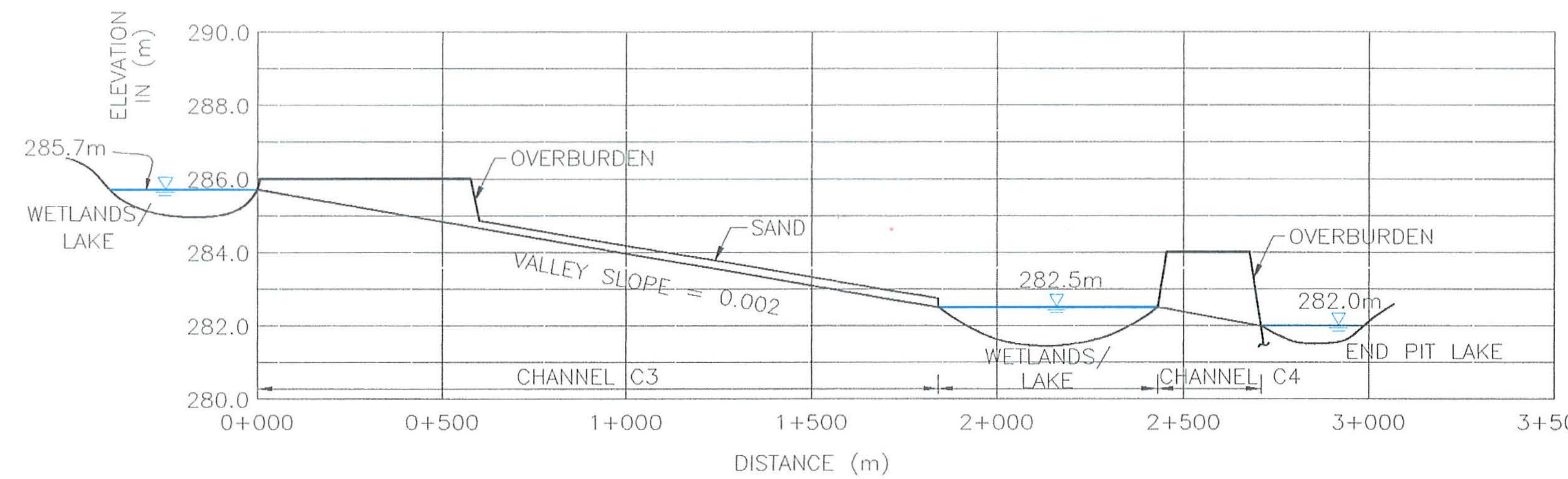


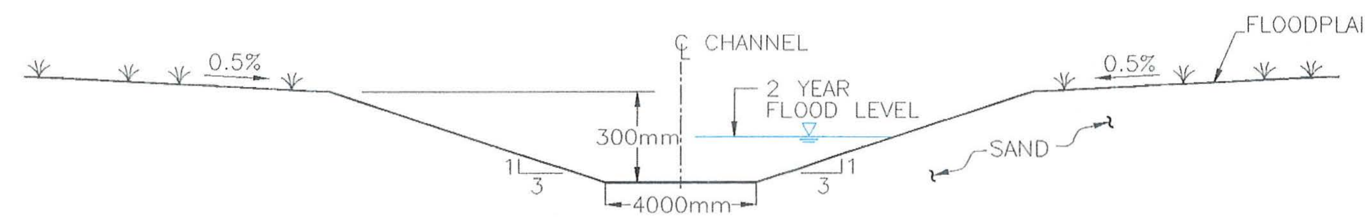
PLAN OF MAIN DRAINAGE CHANNELS FOR CELLS 4 AND 6

SCALE 1:25,000



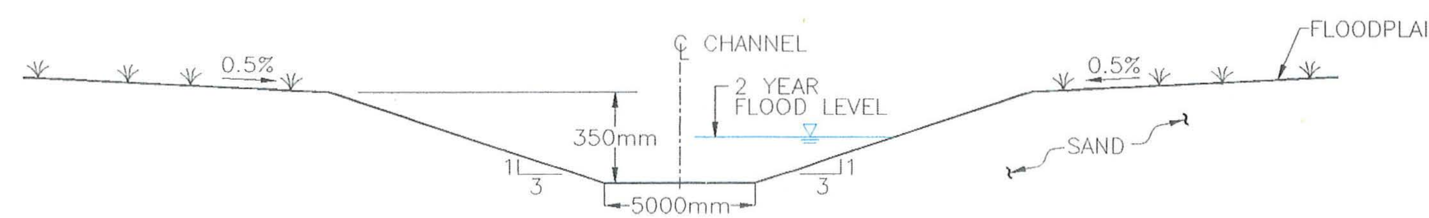
PROFILE OF MAIN DRAINAGE CHANNELS C3 AND C4

SCALE H=1:20,000 V=1:200



TYPICAL CROSS SECTION FOR MAIN CHANNEL C3

NTS



TYPICAL CROSS SECTION FOR MAIN CHANNEL C4

NTS

SUMMARY OF CHANNEL DESIGN PARAMETERS

CHANNEL No.	DRAINAGE AREA (km 2)	ASSUMED SILT/CLAY CONTENT OF CHANNEL BED (%)	AVERAGE ANNUAL FLOW (m 3/s)	RETURN PERIOD (YEAR)	PEAK DISCHARGE (m 3/s)	CHANNEL BED SLOPE	VALLEY SLOPE	CHANNEL BOTTOM WIDTH (m)	CHANNEL SIDE SLOPE (H:V)	CHANNEL LENGTH/ VALLEY LENGTH (SINUOSITY)	CHANNEL FLOW DEPTH (m)	CHANNEL FLOW VELOCITY (m/s)
C3	6.2	5	0.0274	2 10 100 PMF	0.21 0.44 0.79 6.4	0.0013	0.002	4.0	3:1	1.5	0.15 0.23 0.38 0.58	0.32 0.41 0.43* 0.43*
C4	7.5	5	0.0368	2 10 100 PMF	0.21 0.44 0.79 3.1	0.0013	0.002	5.0	3:1	1.5	0.13 0.20 0.29 0.53	0.30 0.39 0.47 0.48*

NOTE: *BANKFULL FLOW VELOCITY

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DESIGN OF MAIN CHANNELS C3 AND C4

21 JAN 98	FIG. No. 6	DRAWN BY: TM

Alternative Drainage Routes

routes B5 and B6 were not selected because the recommended routes provide larger residence time

As shown in Figure 4, runoff from Cell 4 could alternatively be routed via route B5, discharging directly to the end pit lake. This would allow shorter drainage path and lower elevations of the final topography at Cell 6. However, this would largely reduce the residence time of the water discharged to the end pit lake. Therefore, the route to the north end of the end pit lake was selected, even though this would require placement of a larger volume of reclamation materials in Cell 6, resulting in a slightly higher cost for reclamation. Similarly, route C4 is preferred to route B6, because route C4 would provide for a longer residence time in the end pit lake than route B6.

4.2.4 Main Drainage System for Cell 5

Proposed System

proposed drainage systems for Cell 5 and design drawings

The proposed drainage system for Cell 5 includes a main drainage channel C5 and a shallow wetland/lake. The main channel C5 collects runoff from a drainage area of 3 km^2 before discharging to the end pit lake. Figure 7 presents the design of the main drainage channel C5 and shows the plans of the channel alignment, profile, typical cross section and a summary of channel design parameters. The proposed valley slope for the C5 is 0.2% and channel slope is 0.13%, allowing for a channel sinuosity of 1.5. The calculated channel flow velocity is less than 0.4 m/s, even for the extreme PMF event. As illustrated in Figure 7, the channel width, depth, width-depth ratio, meander wave length and sinuosity were selected based on the regime equations discussed in Section 2.

Alternative Drainage Routes

routes B5 and B6 were not selected because the recommended routes provide larger residence time

As shown in Figure 4, runoff from Cell 5 could be routed directly to Muskeg River. This direct release of the surface water from the reclaimed CT areas would result in a discharge of water of less desirable water quality directly to the Muskeg River. Routing the flows to the end pit lake would allow bioremediation of the CT porewater and the runoff from the reclaimed surfaces. Therefore, routes C1 and C2 are preferred to the alternative routes B1 and B2.

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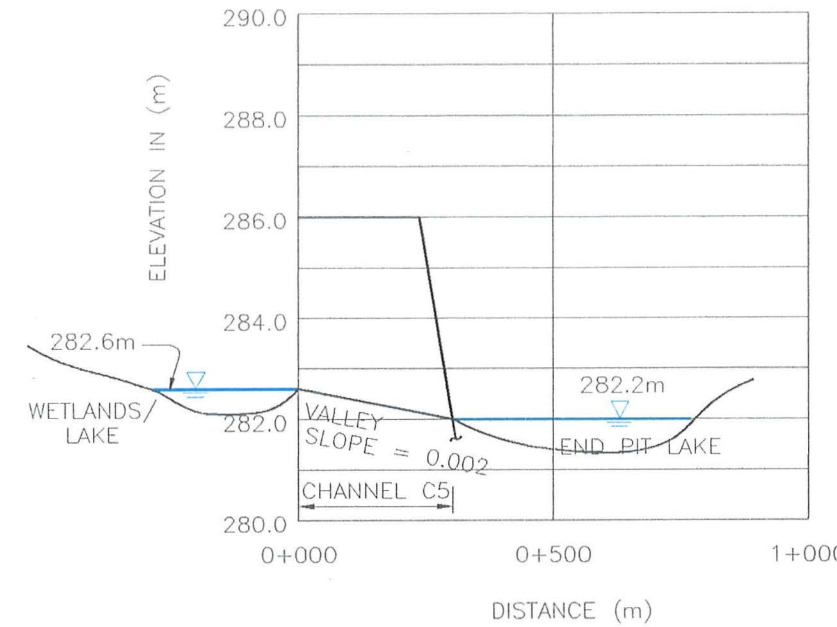
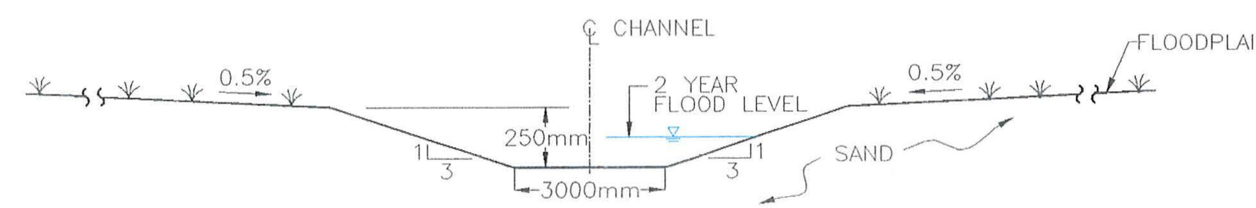
PLAN OF MAIN DRAINAGE CHANNEL FOR CELL 5

SCALE 1:25,000



PROFILE OF MAIN DRAINAGE CHANNEL C5

SCALE H=1:15,000 V=1:150



TYPICAL CROSS SECTION FOR MAIN CHANNEL C5

NTS

SUMMARY OF CHANNEL DESIGN PARAMETERS

CHANNEL	DRAINAGE AREA (km²)	ASSUMED SILT/CLAY CONTENT OF CHANNEL BED (%)	AVERAGE ANNUAL FLOW (m³/s)	RETURN PERIOD (YEAR)	PEAK DISCHARGE (m³/s)	CHANNEL BED SLOPE	VALLEY SLOPE	CHANNEL BOTTOM WIDTH (m)	CHANNEL SIDE SLOPE (H:V)	CHANNEL LENGTH/ VALLEY LENGTH (SINUOSITY)	CHANNEL FLOW DEPTH (m)	CHANNEL FLOW VELOCITY (m³/s)
C5	3.0	5	0.0104	2 10 100 PMF	0.09 0.22 0.46 1.67	0.0013	0.002	3.0	3:1	1.5	0.11 0.18 0.32 0.41	0.25 0.35 0.40* 0.40*

NOTE: *BANKFULL FLOW VELOCITY

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DESIGN OF MAIN CHANNEL C5

21 JAN 1998	Figure 7	DRAWN BY: TM

4.2.5 Proposed Secondary Drainage Systems

there are two types of secondary drainage systems for the in-pit storage areas

There are two types of secondary drainage systems proposed for the in-pit CT storage areas, depending on the capping materials used to raise the final elevations of the reclaimed surfaces. The two types of systems are described below:

- **Sand Cap on CT:** A system of sand ridges will be developed by controlled placement of tailings sand. Secondary drainage channels are expected to form naturally as surface runoff concentrates between the sand ridges. The proposed sand ridges will be located to encourage the development of a dendritic drainage system which is a characteristic of natural systems. The advantage of this configuration is to enable leaching of the salts from the soils caused by the upward flux of CT porewater during CT consolidation, and planting of upland vegetation on the sand ridges.

- **Overburden Cap on CT:** The secondary drainage system will develop on a network of sand trenches placed between blocks of overburden materials. The sand trenches are needed to provide for release of CT porewater during CT consolidation. The secondary drainage channels are expected to form naturally as surface runoff concentrates in the low land areas at the sand trenches.

layout of secondary drainage systems for storage areas with sand cap on CT

A schematic layout of the secondary drainage systems at the storage areas with sand cap on CT is shown in Figure 8. The sand ridges are approximately 5 m high with 50 m top widths and side slopes of about 15H:1V. They will be constructed of tailings sand. The typical spacing of the sand ridges ranges from 500 to 700 m.

secondary drainage channels will be naturally formed

Drainage ditches between the sand ridges are expected to develop naturally during the initial period of CT upward flux after construction. This natural evolution will facilitate the development of regime channel pattern and cross-sectional shape. The resulting secondary drainage system is expected to be stable over the long term, following the reduction of CT upward flux.

design of secondary drainage systems for CT storage areas with overburden caps

A schematic layout of the secondary drainage systems at CT storage areas with overburden cap is shown in Figure 9. The typical spacing of the sand trenches ranges from 400 to 500 m. The sand trenches will be placed on top of CT materials allowing release of CT porewater to the sand surface. The bottom width of the sand trenches will be about 20 m and the side slopes will be about 3H:1V. The secondary drainage channels will form naturally in a manner similar to those at the CT storage areas with sand caps.

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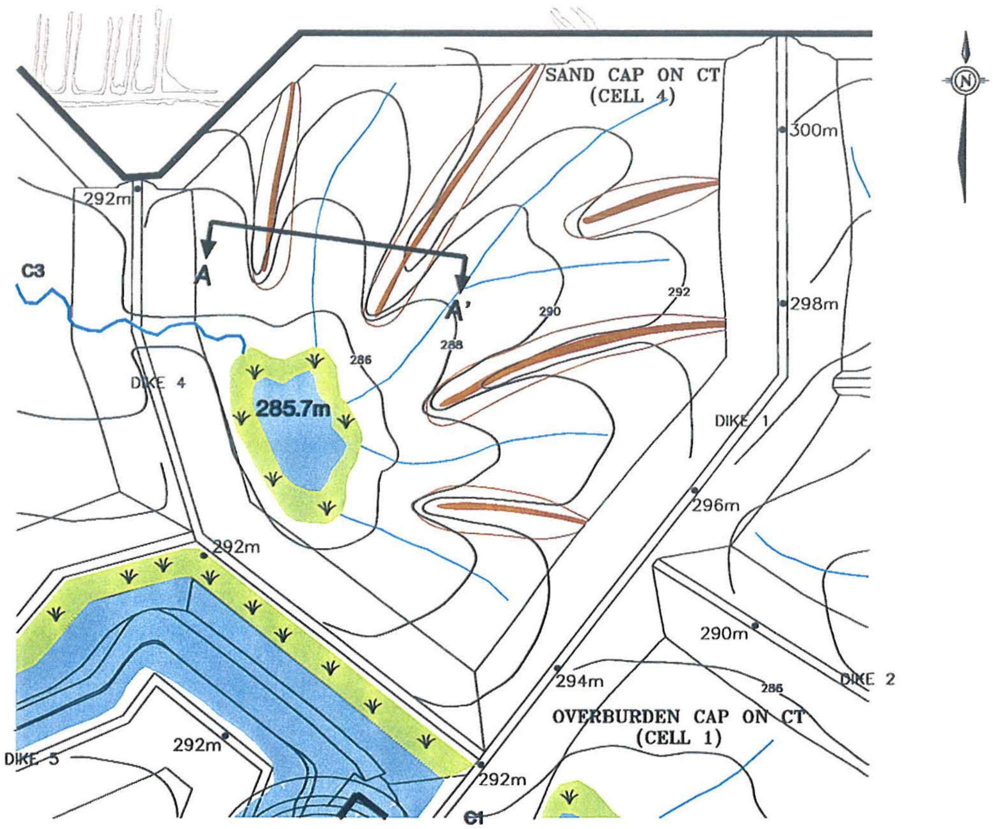
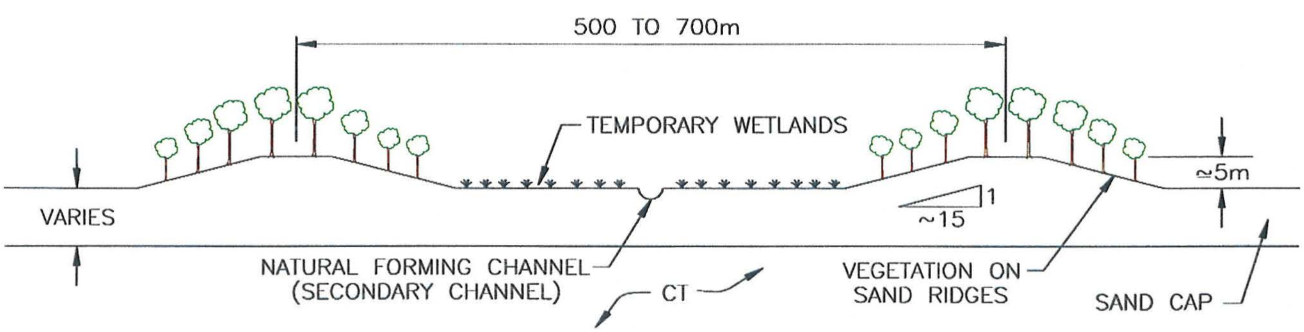


SECONDARY DRAINAGE CHANNELS AT STORAGE AREAS WITH SAND CAP ON CT
SCALE 1:25,000



SECTION A-A'
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Golder Associates	SHELL CANADA LIMITED
SCHEMATIC LAYOUT OF SECONDARY DRAINAGE CHANNELS AT STORAGE AREAS WITH SAND CAP ON CT	
13 JAN 1998	Figure 8
DRAWN BY: TM	

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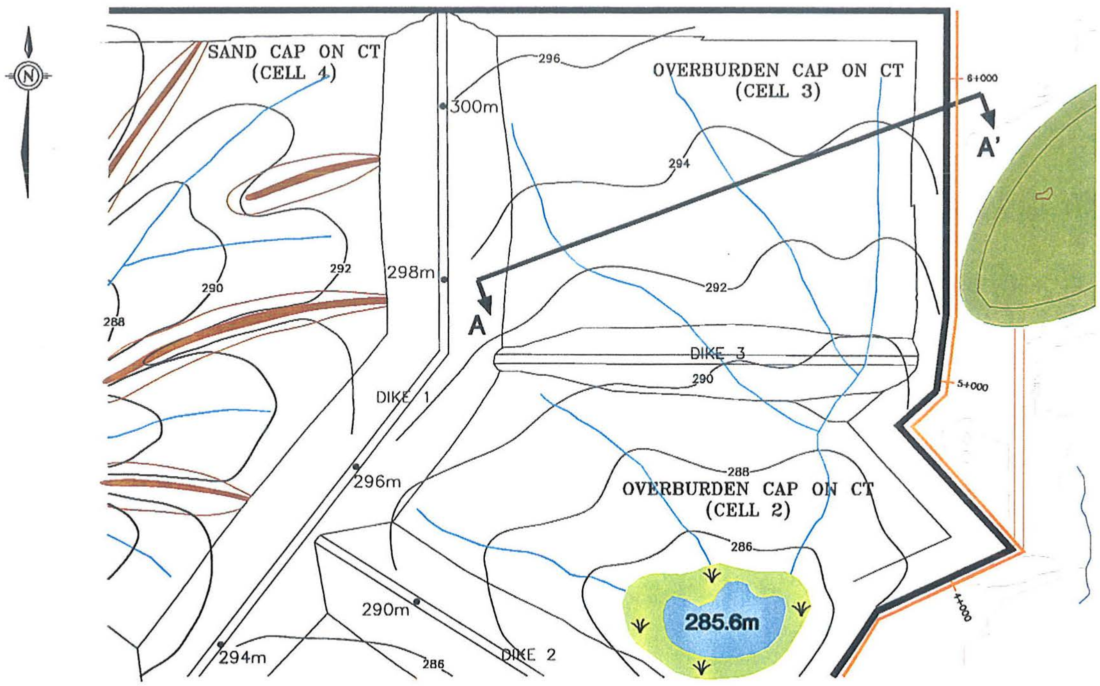
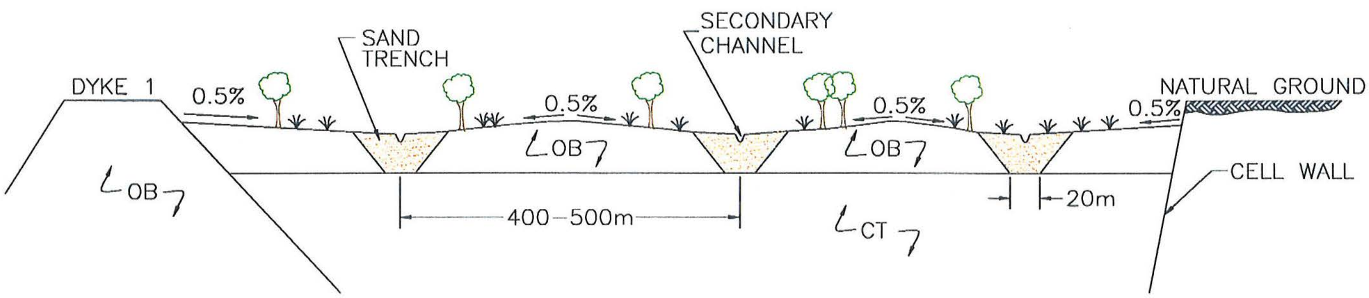


SECONDARY DRAINAGE CHANNELS AT STORAGE AREAS WITH OVERBURDEN CAP ON CT

SCALE 1:25,000



SECTION A - A'

NTS

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SCHEMATIC LAYOUT OF SECONDARY CHANNELS AT STORAGE AREAS WITH OVERBURDEN CAP ON CT

13 JAN 1998	Figure 9	DRAWN BY: TM

4.3 DRAINAGE SYSTEMS FOR RECLAIMED TAILINGS SETTLING POND

4.3.1 MAIN DRAINAGE SYSTEM

Proposed System

proposed topography of the reclaimed tailings settling pond

The reclaimed tailings settling pond has a foot-print area of about 10.4 km^2. The facility will be built above the original ground level with an average outside side slope of 5H:1V and an average inside side slope of 25H:1V. The crest level will be about 325 m, which is a maximum of 45 m above the ground elevation at the northeast toe.

design of the main channel C7

The main drainage system includes a shallow wetlands/lake and a channel to the end pit lake. Figure 10 presents the design of the main outlet channel C7 and shows the plans of the channel alignment, profile, typical cross section and summary of channel design parameters. These parameters are selected based on the regime equations discussed in Section 2.

Alternative Drainage Routes

route B9 was not selected because route C7 offers the opportunity for bioremediation and increases the drainage area of the end pit lake

As shown in Figure 4, surface runoff from the reclaimed tailings settling pond could alternatively be discharged directly to the Muskeg River via route B9. This would eliminate the opportunity for bioremediation in the end pit lake, of surface runoff and CT porewater seepage discharges. Route C7 is also preferred, because it will increase the drainage area contributing runoff to the end pit lake with a relatively large surface area.

route B10 was not selected because this would require a large excavation

Another alternative is to convey the surface runoff from the sand tailings area directly to Athabasca River via route B10. This would require a large excavation down the valley wall alongside the Athabasca River and would result in a much larger construction cost. Therefore, this route was not selected.

4.3.2 Perimeter Collector System

purpose of the perimeter collector system

A collector system, composed of drainage ditches and shallow wetlands/lakes, will be built at the perimeter of the reclaimed tailings setting pond to collect surface runoff from the outer side slopes of the reclaimed tailings settling pond and seepage discharge from the sand structure. The shallow wetlands/lakes are needed for bioremediation of the seepage water, before discharging to the receiving stream.

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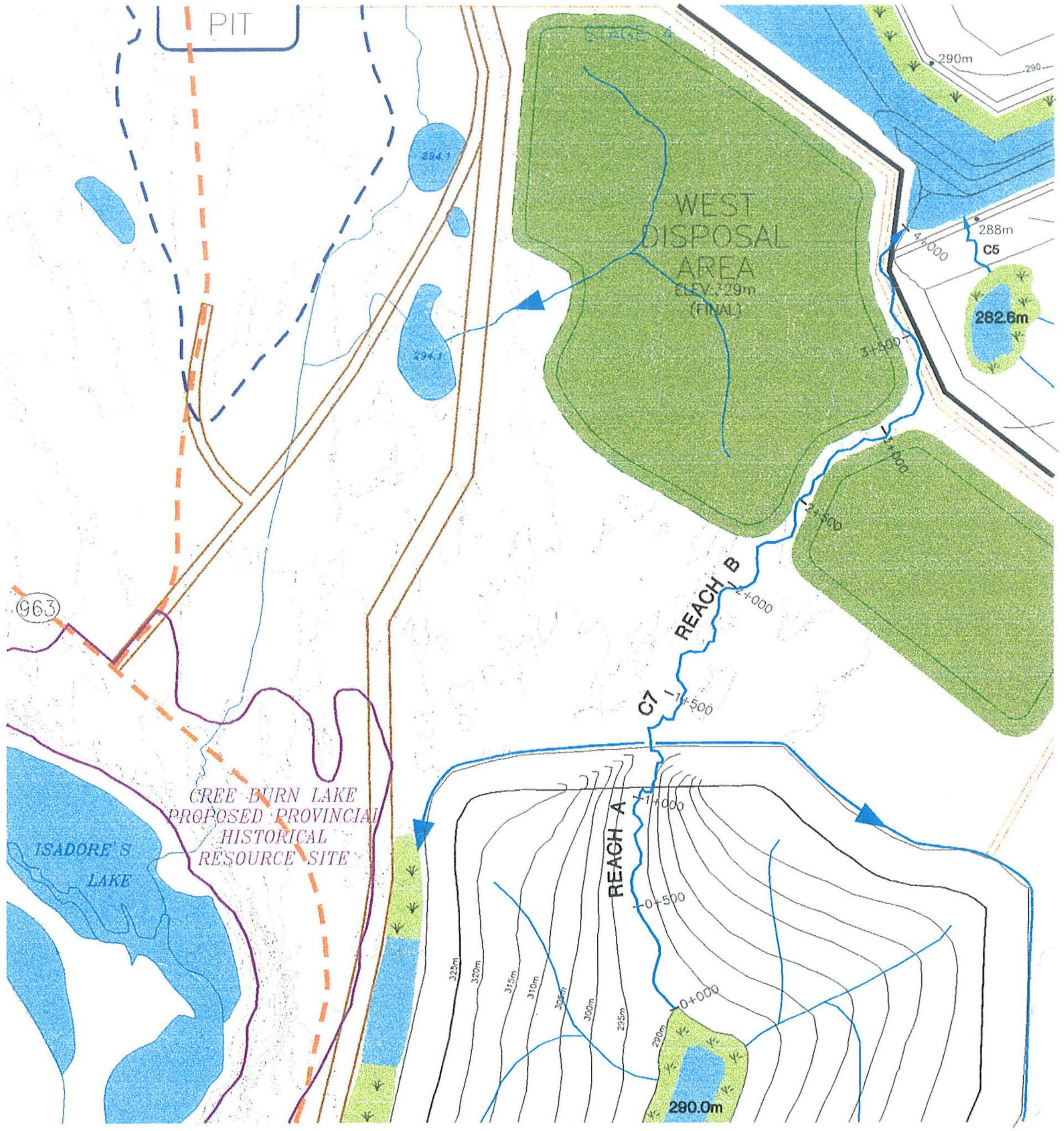
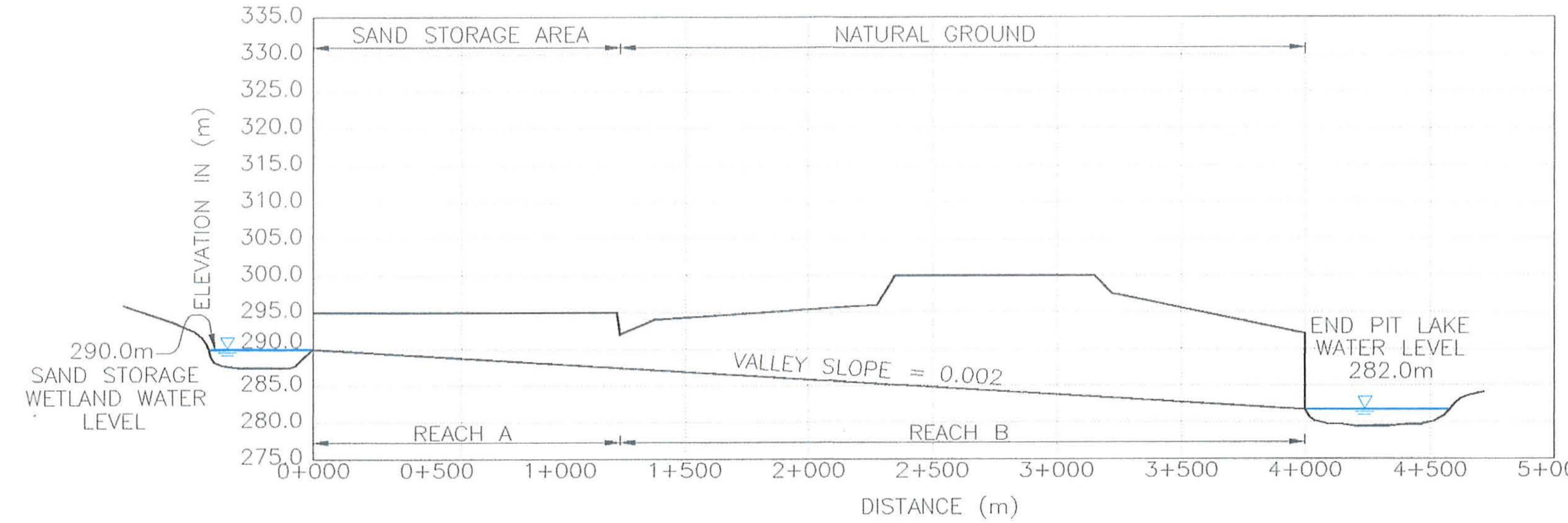


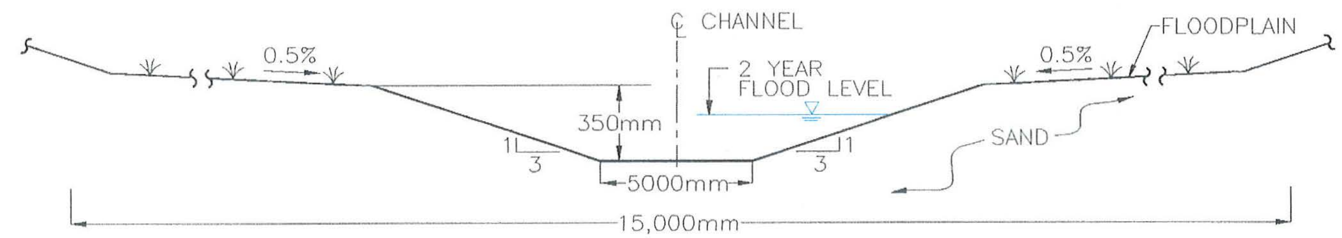
PLAN OF MAIN DRAINAGE CHANNEL (C7) FROM RECLAIMED TAILINGS SETTLING POND TO END PIT LAKE

SCALE 1:30,000



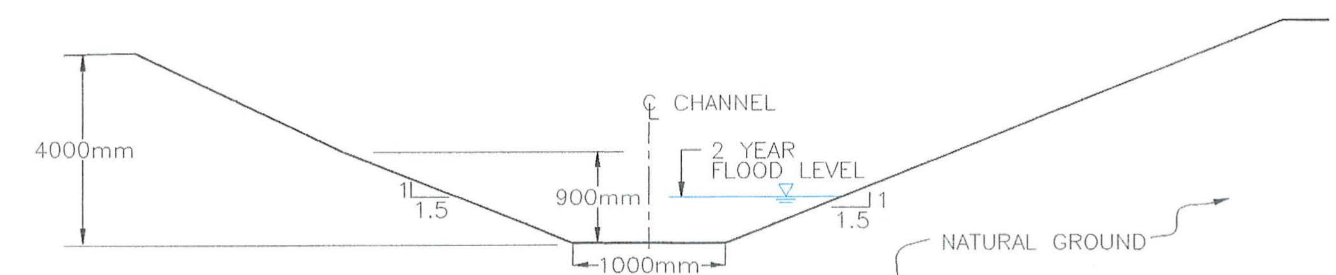
PROFILE OF MAIN DRAINAGE CHANNEL C7

SCALE H=1:30,000 V=1:1000



TYPICAL CROSS SECTION FOR REACH A

NTS



TYPICAL CROSS SECTION FOR REACH B

NTS

SUMMARY OF CHANNEL DESIGN PARAMETERS

CHANNEL REACH	DRAINAGE AREA (km²)	ASSUMED SILT/CLAY CONTENT OF CHANNEL BED (%)	AVERAGE ANNUAL FLOW (m³/s)	RETURN PERIOD (YEAR)	PEAK DISCHARGE (m³/s)	CHANNEL BED SLOPE	VALLEY SLOPE	CHANNEL BOTTOM WIDTH (m)	CHANNEL SIDE SLOPE (H:V)	CHANNEL LENGTH/ VALLEY LENGTH (SINUOSITY)	CHANNEL FLOW DEPTH (m)	CHANNEL FLOW VELOCITY (m/s)
A	7.6	5	0.0429	2 10 100 PMF	0.19 0.36 0.59 4.91	0.0013	0.002	5.0	3:1	1.5	0.13 0.20 0.29 0.53	0.3 0.35 0.47 0.48*
B	7.6	80	0.0931	2 10 100 PMF	0.19 0.36 0.59 4.91	0.001	0.002	1.0	1.5:1	2.0	0.33 0.46 0.59 1.16	0.39 0.46 0.53 0.65*

NOTE: * BANKFULL FLOW VELOCITY

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DESIGN OF MAIN CHANNEL C7

21 JAN 1998	Figure 10	DRAWN BY: TM

design considerations

Figure 11 presents the design of the proposed collector system for the reclaimed tailings settling pond. The figure shows the plan view of the east and west interceptor ditches, profiles, and typical ditch cross sections. The ditches have an average depth of about 5 m to maximize interception of the seepage water from the sand structure. An embankment will be constructed along the collector channel of excavated materials from the ditches provide a barrier between the Muskeg River and the collector system to prevent the Muskeg River from spilling into the collector ditch during extreme flood events.

4.4 SHALLOW WETLANDS AND LAKES

purposes of shallow wetlands and lakes

Shallow wetlands and lakes will be built into each drainage and collector system to provide hydrological and environmental benefits. They are needed to attenuate flood peak discharges and provide flow releases with less fluctuation. By providing storage and long residence times, these wetlands and lakes will help improve water quality through biological treatment of the drainage from the reclaimed areas.

design of shallow wetlands and lakes

The shallow wetlands and lakes shown on the plans, provide a surface area of about 5% of the local contributing drainage area. Each shallow wetlands and lake system will consist of about 50% wetlands and about 50% lake areas. The depths of wetlands will range from 0 to 1 m and the depths of lakes will range from 1 to 2 m. A schematic representation of the shallow wetland and lake system is shown in Figure 12. Table 7 summarizes the relevant design parameters of the proposed shallow wetlands and lakes.

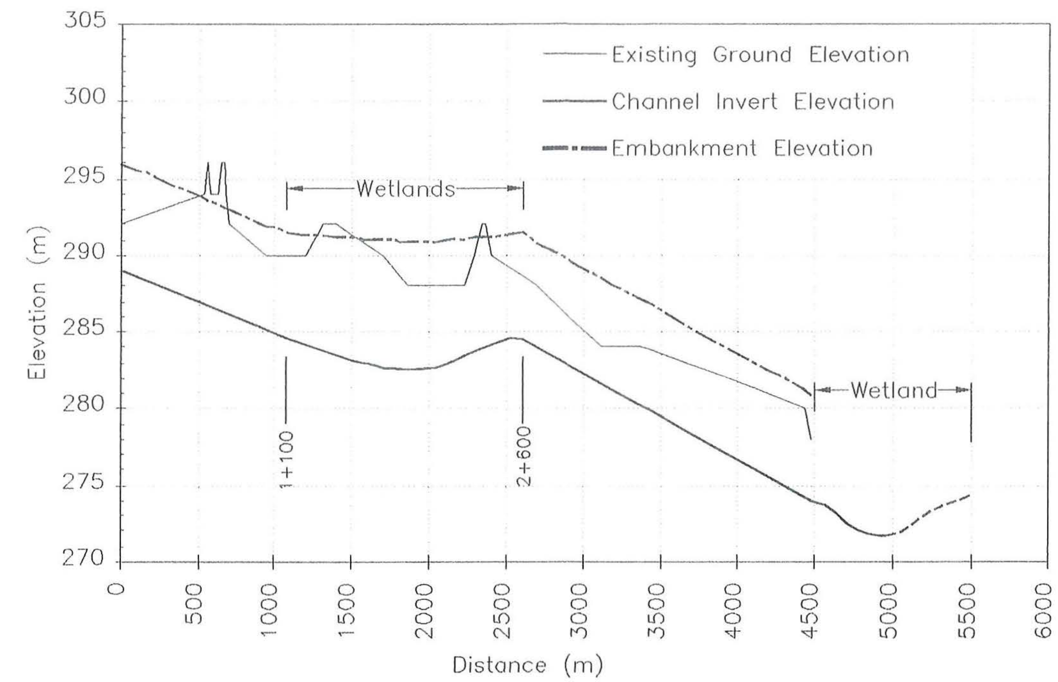
Table 7 Design Parameters of Proposed Shallow Wetlands and Lakes

Contributing Drainage Basin			Shallow Wetlands and Lake System			
Location of Basin	**Drainage Area (km^2)**	**Mean Annual Flow (m^3/s)**	**Design Water Level (m)**	**Surface Area (km^2)**	**Volume ($1000\ m^3$)**	**Residence Time[(a)] (months)**
Cell 1	2.77	0.023	282.7	0.134	139	2.3
Cell 2/3	3.95	0.019	285.6	0.180	158	3.2
Cell 4	3.79	0.027	285.7	0.176	165	2.3
Cell 5	2.97	0.010	282.6	0.134	114	4.2
Cell 6	3.75	0.037	282.5	0.216	202	2.1
Tailings Settling Pond	7.60	0.043	290.0	0.380	296	2.6

(a) Equivalent to the ratio of storage volume divided by mean annual inflow.

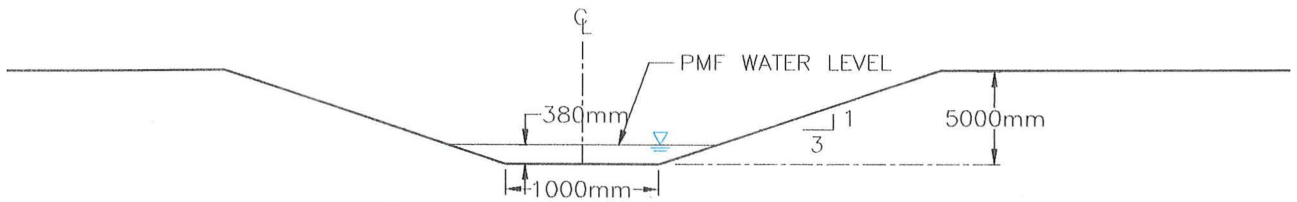
PLAN OF RECLAIMED TAILINGS SETTLING POND

SCALE 1:50,000



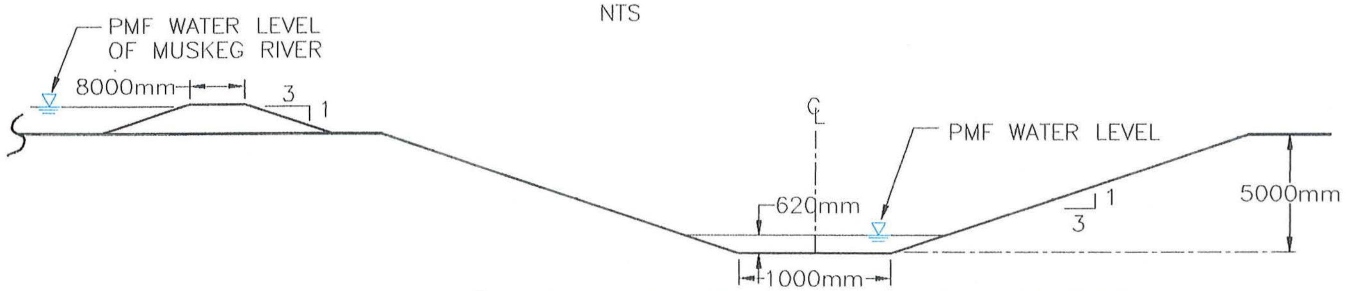
PROFILE OF WEST DITCH

SCALE H=1:50,000 V=1:5,000



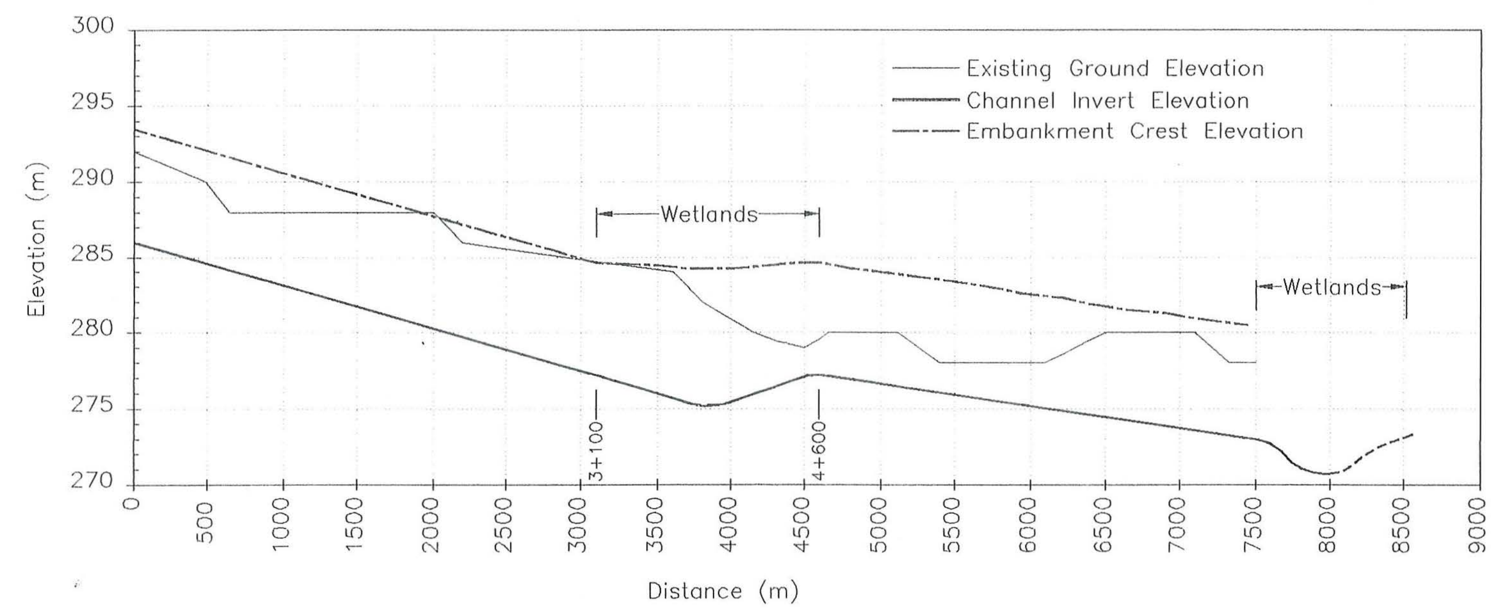
TYPICAL CROSS SECTION OF WEST DITCH

NTS



TYPICAL CROSS SECTION OF EAST DITCH

NTS



PROFILE OF EAST DITCH

SCALE H=1:50,000 V=1:5,000

SUMMARY OF CHANNEL DESIGN PARAMETERS

CHANNEL	DRAINAGE AREA (km^2)	ASSUMED SILT/CLAY CONTENT OF CHANNEL BED (%)	AVERAGE ANNUAL FLOW (m^3/s)	RETURN PERIOD (YEAR)	PEAK DISCHARGE (m^3/s)	CHANNEL BED SLOPE	VALLEY SLOPE	CHANNEL BOTTOM WIDTH (m)	CHANNEL SIDE SLOPE (H:V)	CHANNEL LENGTH/ VALLEY LENGTH (SINUOSITY) (m)	CHANNEL FLOW DEPTH (m)	CHANNEL FLOW VELOCITY (m/s)
EAST DITCH	1.4	100	0.014	2 10 100 PMF	0.049 0.081 0.124 0.937	0.0013	0.0014	1	3:1	2900	0.15 0.19 0.24 0.62	0.2 0.3 0.3 0.5
WEST DITCH	0.6	100	0.0063	2 10 100 PMF	0.0209 0.0339 0.0529 0.401	0.0021	0.0023	1	3:1	1880	0.08 0.11 0.14 0.38	0.2 0.2 0.3 0.5

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DESIGN OF COLLECTOR DITCH FOR RECLAIMED TAILINGS SETTLING POND

21 JAN 1998	Figure 11	DRAWN BY: TM

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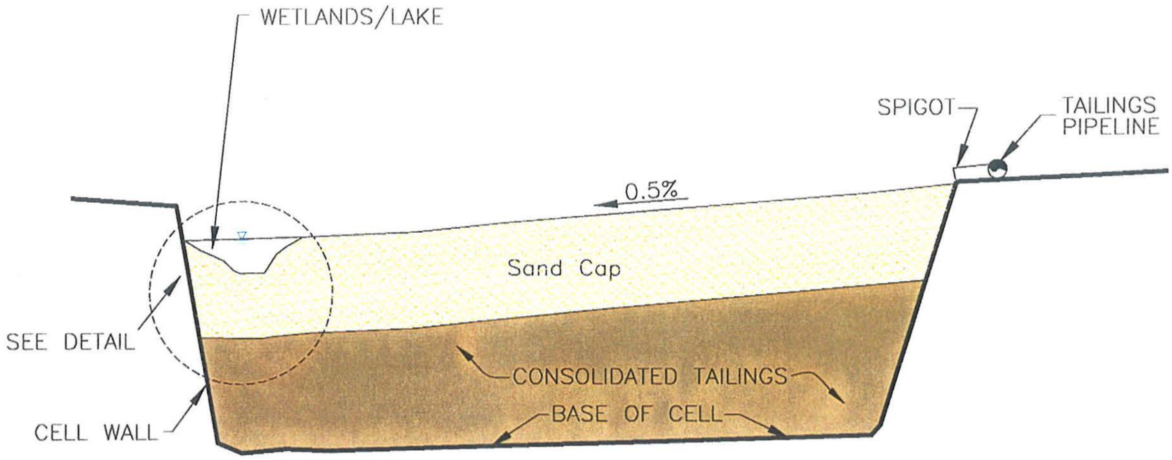
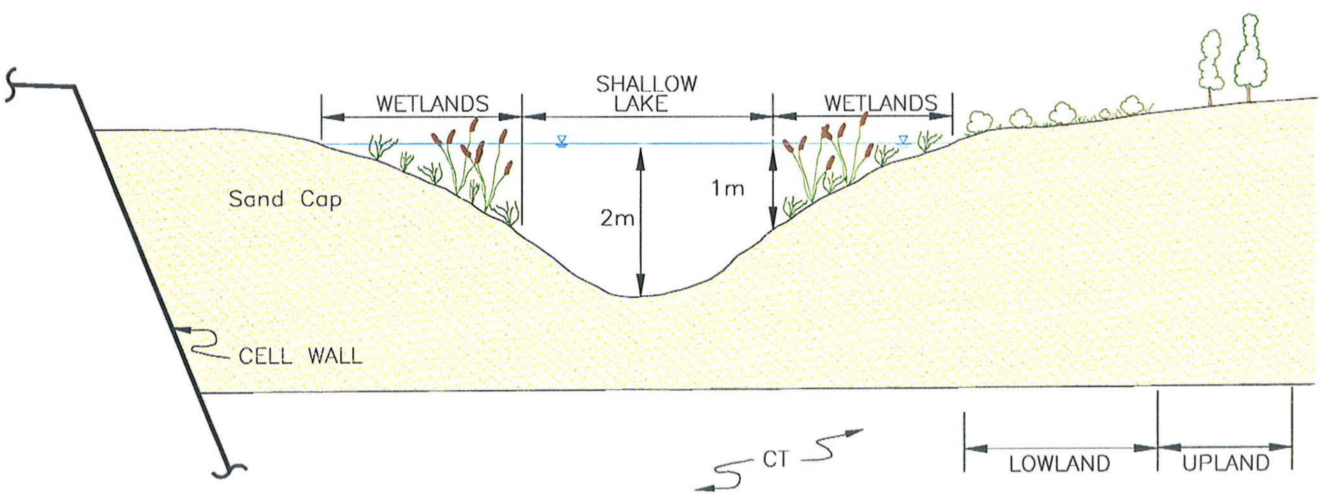


TYPICAL SAND CAP AT CT DISPOSAL SITE



DETAIL OF SHALLOW LAKE / WETLANDS

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SCHEMATIC LAYOUT OF
SHALLOW WETLANDS AND LAKE

21 JAN 1998	Figure 12	DRAWN BY: RFM

4.5 END PIT LAKE

4.5.1 General Configuration of the End Pit Lake

relevant design parameters of the end pit lake

The end pit lake will occupy the last mined-out pit, the crusher pit area and a deep ore conveyance route which connects the last mined-out pit with the crusher pit. Accordingly, the lake will form an elongated water surface along the west and south sides of the mined areas. The lake level will be 12 m to 18 m below original ground level and will therefore become a seepage discharge area with seepage entering the lake from the adjacent natural terrain on the west side, the Aurora mine on the north side and CT storage areas on the east side. MFT from the tailings settling pond will be transferred to the end pit lake over a period of about four years from 2027 to 2030.

Design parameters of the end pit lake are listed below.

MFT Volume Stored in the End Pit Lake after initial filling:	66 million m^3
MFT Surface Elevation at Closure:	263 m
Water Volume Stored in the End Pit Lake after initial filling:	64 million m^3
Normal Lake Water Level:	282 m
Water Depth above MFT Surface after initial filling:	19 m
Total Lake Surface Area:	4.4 km^2
Wetland Surface Area:	1.0 km^2
Average Residence Time of Lake Inflows:	20 years
Mean Annual Lake Outlet Discharge:	0.1 m^3/s

The average residence time of the lake inflows is estimated by dividing the lake water volume by the mean annual lake outlet discharge.

lake water cap and long-term lake water balance

The initial water cap of about 32 m deep at the end pit lake will be supplied by a transfer of tailings porewater from the tailings settling pond, porewater released from the CT consolidation, and surface runoff from reclaimed surfaces during the reclamation period from 2023 to 2030. Combined with residual MFT transferred from the tailings pond, these sources of water are sufficient to raise the lake water level to 282 m during the post-closure management period. Therefore, diversion of fresh water from the Athabasca River will not be required to raise the lake water level and to enable positive drainage of lake water to the Muskeg River at closure. In the far future, the end pit lake water balance will be largely maintained by runoff inflows from its drainage area. A lake water balance simulation was conducted based on 43 years of climate record. It shows that the lake would have an average outflow of 0.1 m^3/s during the 43 year simulation period.

4.5.2 Design of Outlet Channel

Proposed Design

relevant design parameters of the end pit lake

The end pit lake receives surface runoff inflows from reclaimed surfaces, seepage discharges from adjacent terrain and direct precipitation onto the lake surface. Overflow from the end pit lake will be released to the Muskeg River via an outlet channel. Figure 13 presents the design of the outlet channel C6 and shows the plan of the channel alignment, profile, typical cross sections and summaries of channel design parameters. These parameters were selected based on the regime equations discussed in Section 2.

the end pit lake is a reclamation facility which would not be construed as an engineered reservoir

The end pit lake is a sustainable feature of the reclamation landscape and not subject to risk of uncontrolled, catastrophic release of the contained water and MFT. It is not an engineered reservoir and is not contained by man-made dams. It is fully contained by natural ground and the lake level is well below original ground level. It will be separated from the Muskeg River by a width of at least 1.2 km of undisturbed soils. The outlet channel has a mild bed slope of 0.1% and is designed to minimize channel erosion during floods. The maximum channel flow velocity during the PMF event is estimated to be about 0.8 m/s. This will cause a minimum level of erosion in a channel constructed mainly in natural overburden soils.

the end pit lake would have no risk of direct spillage to Athabasca River

The maximum lake water level during the PMF event is estimated to be 283 m, which is well below original ground level of 298 m on the west side of the lake. Potential blockage of the lake outlet by beaver dams and channel icing would pose no risk of direct spillage of lake water to the Athabasca River, which is separated from the end pit lake by a minimum distance of 4.6 km, with ground levels up to 12 m.

Alternative Outlet

alternative route B11 was not selected based on cost and hydrologic considerations

The proposed lake outlet to the Muskeg River could be replaced by the alternative route labelled B11 in Figure 4, which would enable direct discharge to the Athabasca River. This alternative outlet is feasible, but the excavation would be far more costly than the proposed outlet. Alternative route B11 would also be less preferable because it would reduce the drainage area and surface runoff to the Muskeg River.

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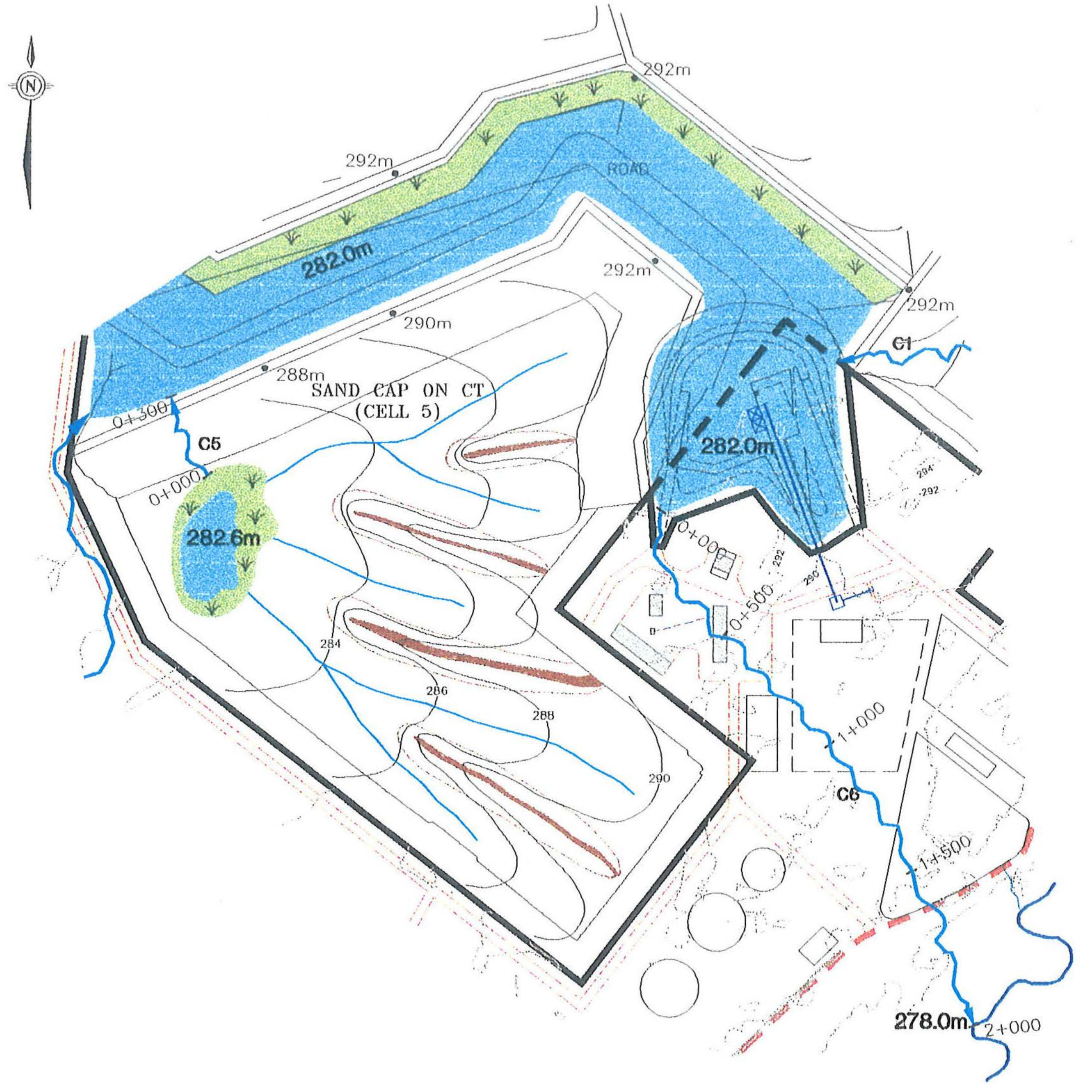
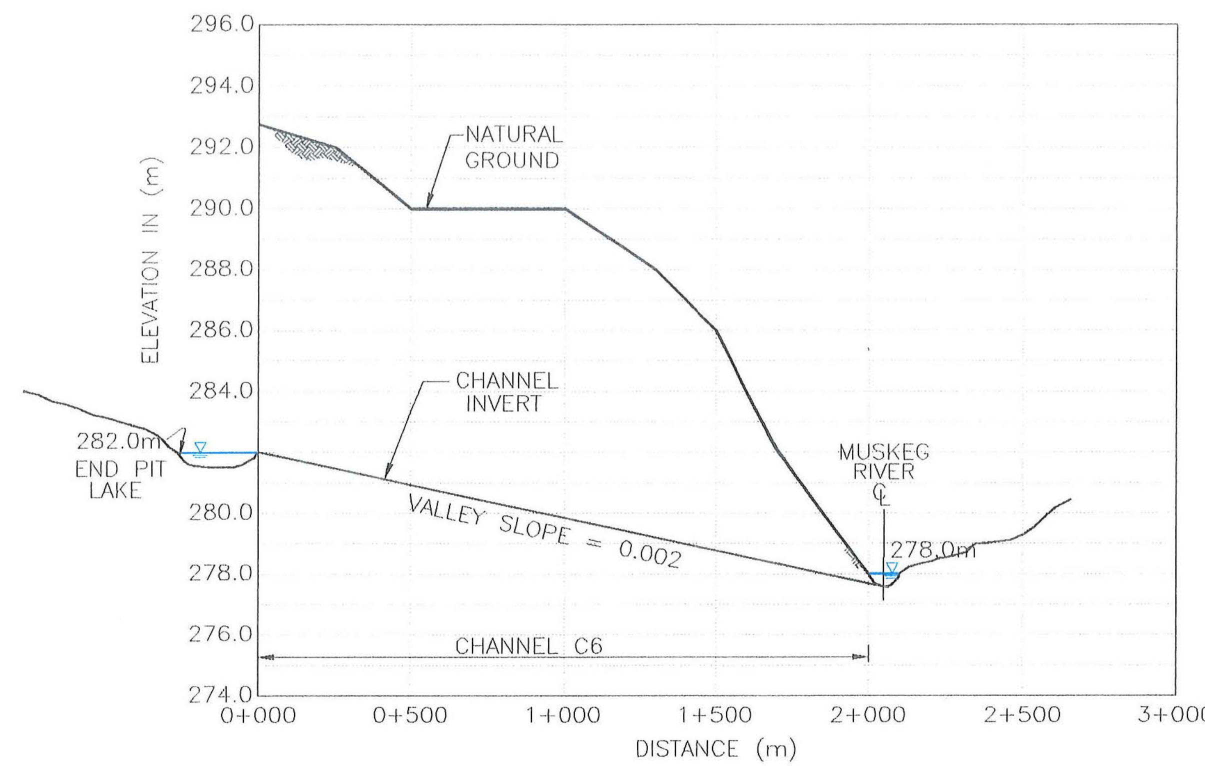


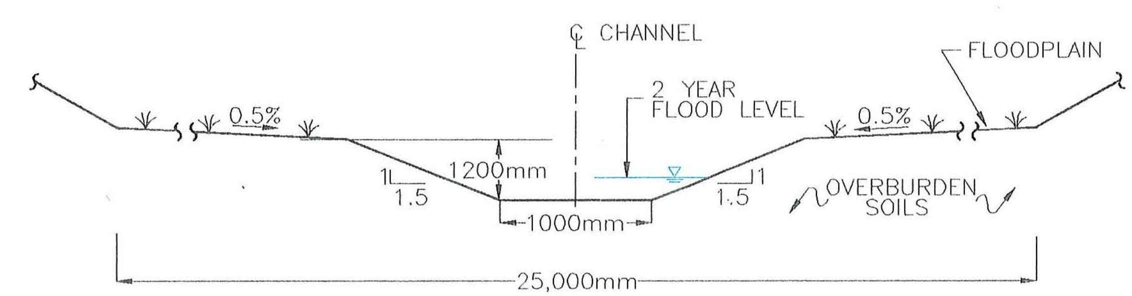
PLAN OF END PIT LAKE OUTLET CHANNEL (C6)

SCALE 1:25,000



PROFILE OF MAIN CHANNEL C6

SCALE H=1:25,000 V=1:250



TYPICAL CROSS SECTION FOR MAIN CHANNEL C6

NTS

SUMMARY OF CHANNEL DESIGN PARAMETERS

CHANNEL	DRAINAGE AREA (km^2)	ASSUMED SILT/CLAY CONTENT OF CHANNEL BED (%)	AVERAGE ANNUAL FLOW (m^3/s)	RETURN PERIOD (YEAR)	PEAK DISCHARGE (m^3/s)	CHANNEL BED SLOPE	VALLEY SLOPE	CHANNEL BOTTOM WIDTH (m)	CHANNEL SIDE SLOPE (H:V)	CHANNEL LENGTH/ VALLEY LENGTH (SINUOSITY)	CHANNEL FLOW DEPTH (m)	CHANNEL FLOW VELOCITY (m/s)
C6	29.3	80	0.10	2 10 100 PMF	0.33 0.70 1.21 2.48	0.001	0.002	1.0	1.5:1	2.0	0.44 0.64 0.84 1.36	0.45 0.55 0.64 0.75*

NOTE: * BANKFULL FLOW VELOCITY

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DESIGN OF MAIN CHANNEL C6

13 JAN 1998	FIG. No. 13	DRAWN BY: TM

4.5.3 Design of Littoral Zone and Shoreline Protection

littoral wetlands will be provided along the east shoreline of the end pit lake

The end pit lake will have littoral area wetlands occupying about 20% of the total lake surface area to ensure biological productivity. The average water depth of the littoral zone will be about 0.5 m. The littoral area wetlands will be constructed along the east shoreline of the end pit lake as shown in Figure 14.

considerations of lake level fluctuation for design of the rock breakwater

As shown in Figure 14, the littoral zone will be protected by a rock breakwater to minimize wave erosion. The breakwater is designed based on the extreme wind events of a 100 year recurrence interval. The estimated wave height caused by the 100-year westerly hourly wind is 0.8 m and the 100-year flood lake level is estimated to be 282.5 m. The maximum elevation of the rock breakwater is designed to be 282.9 m, equal to the 100-year flood level plus 100-year wave height. The 100-year drought lake level is estimated to be 281.7 m. The base of the rock breakwater is 281.3 m, equal to the 100-year drought level minus 100-year wave height.

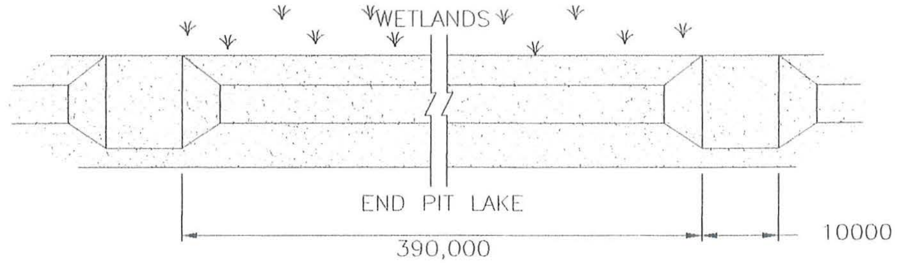
rock sizes and other considerations for design of the rock breakwater

The riprap breakwater is designed to prevent damage from wave erosion by the 100-year extreme hourly wind and 5% damage by the 1000-year extreme hourly wind. This results in a design with reasonable sizes of rocks (D_{50}=330 mm) for the breakwater. The breakwater is discontinuous with small openings as shown in Figure 14 to allow passage of fish between the lake and the littoral zone for food supply and spawning.

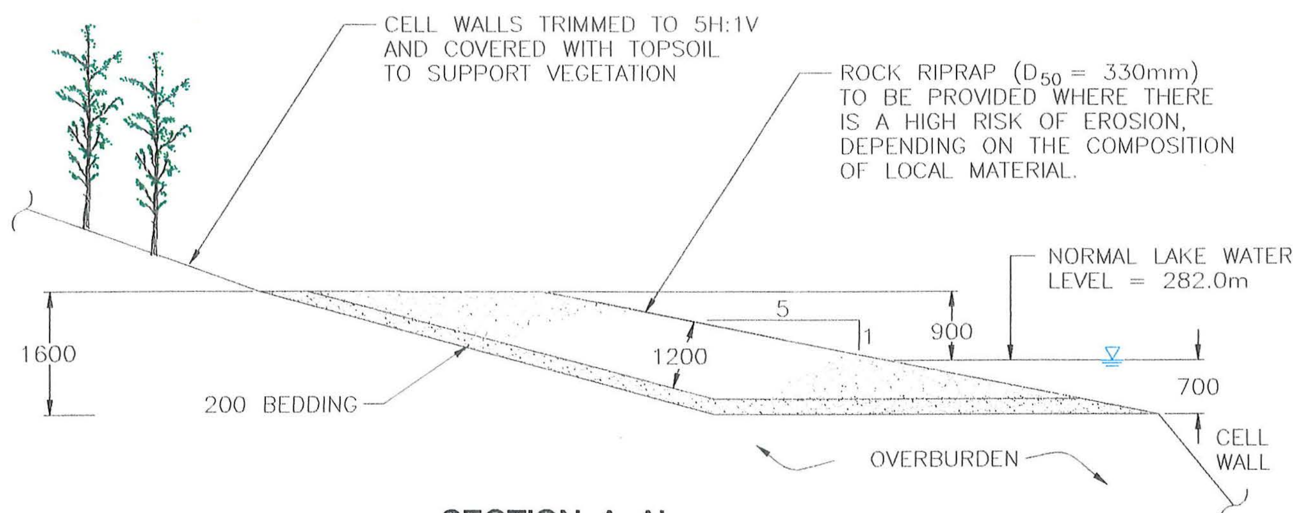
gradual shoreline erosion will not affect long-term sustainability of the end pit lake

Shoreline erosion is not a threat to the physical sustainability of the lake because of the large land area between the lake and surface water outlet. Without erosion protection, a stable beach profile would eventually form after a period of gradual wave erosion and occasional slumping of shore materials. The fetch is relatively small because of the elongated variable, shape of the lake and consequently the potential wave energy is relatively small. Shore erosion is expected to be relatively slow because of the presence of gravel size materials in the overburden and because of the oil sand which will eventually harden into a non-erodible material.

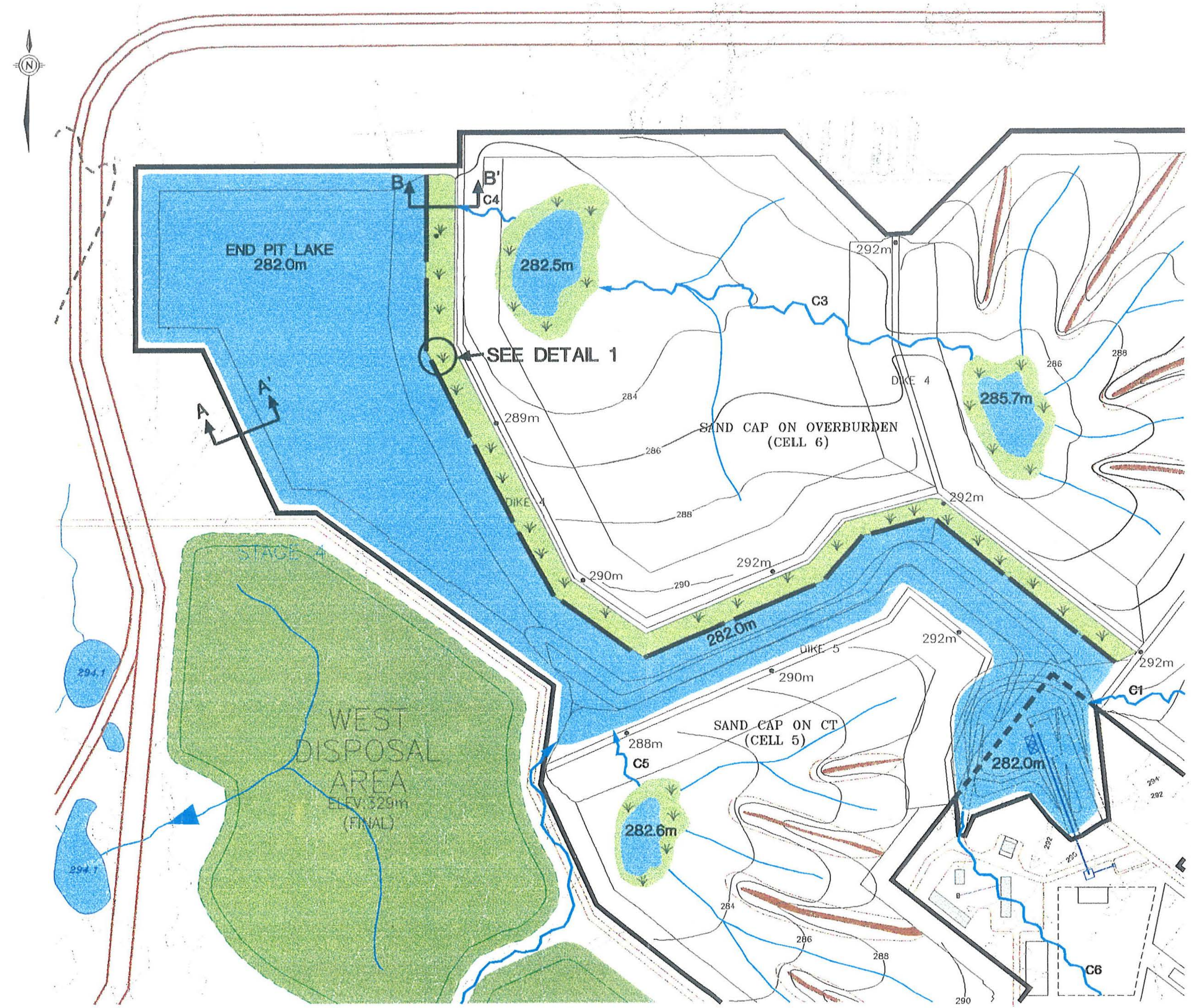
Accordingly, the lake shoreline does not require erosion protection, except for isolated locations of highly erodible soil materials and also the littoral zone areas or the east side of the lake. Without the breakwater, the littoral zone area would probably not support littoral vegetation because of exposure to waves. Also, the east shore is more vulnerable to erosion because it is formed by an earth embankment, which contains CT and sand material on the east side.



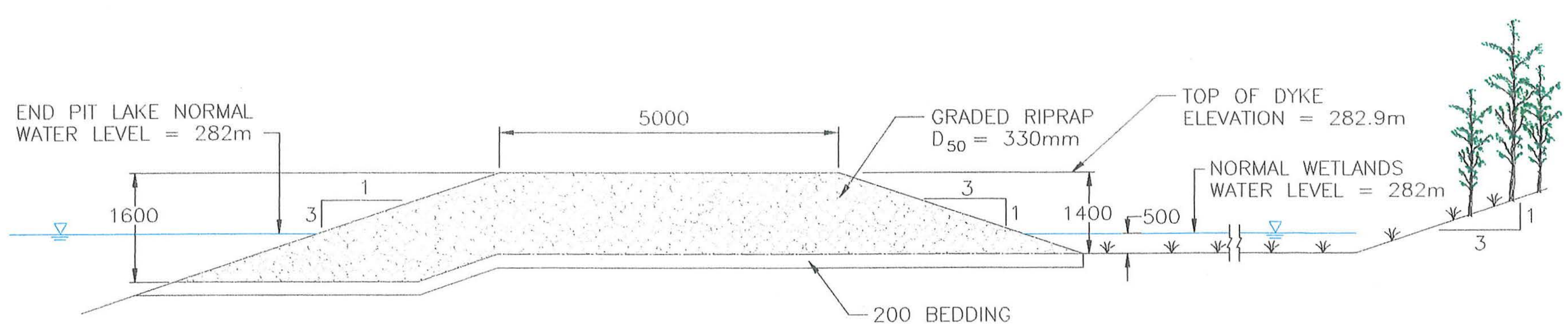
DETAIL 1 - PLAN OF END PIT LAKE
SCALE 1:1,000



SECTION A-A'
SCALE 1:100,000



PLAN OF END PIT LAKE
SCALE 1:25,000



DYKE SECTION B-B'
SCALE 1:100,000

NOTE
ALL UNITS ARE IN mm UNLESS OTHERWISE NOTED

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SHORELINE PROTECTION FOR END PIT LAKE

21 JAN 1998	Figure 14	DRAWN BY: TM

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5. CONCLUSIONS

this investigation demonstrates the technical feasibility of the proposed drainage systems

This investigation shows that sustainable closure reclamation drainage systems for the Muskeg River Mine Project are technically feasible. Closure drainage systems can be designed to achieve similar level of stability, safety, sustainability and robustness as the natural drainage systems. The proposed drainage systems are designed to accommodate a degree of channel evolution over geologic time frames similar to natural drainage systems.

The design criteria and specifications contained in this report are preliminary and subject to revision during the life of the Project. Final design will be based on a detailed analysis of actual conditions and on monitored performance of pilot reclaimed areas.

6. CLOSURE

This report presents the feasibility design of the closure reclamation drainage systems for the Muskeg River Mine Project. The results of analysis indicate that it is possible to develop a sustainable reclamation drainage facility for the Muskeg River Mine Project. The proposed feasibility design presents a sound basis for identification and assessment of the environmental impacts of the project.

Respectfully submitted by:

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