Kinross Gold Corporation

LUPIN OPERATION

CLOSURE PLAN FOR

TAILINGS CONTAINMENT AREA

JANUARY 2005

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Lupin Operations, now part of Kinross Gold Corporation, has operated a gold mine on the northwest side of Contwoyto Lake, Nunavut, since 1982. It is presently operating on a renewed Water License NWB1LUP0008 that extends until June 30, 2008. This report presents the history of the tailings containment area, the proposed remediation of this area and supporting information for the proposed esker covered tailings design. It is presented in support of the 2004 Abandonment and Restoration Plan submitted by the Lupin Operations (Lupin) to the Nunavut Water Board in January 2005.

A Tailings Containment Area (TCA) was developed in a rolling topography approximately 6 km south of the Lupin mine and mill complex. This site was selected after Kilborn and Geocon (Geocon 1980a & 1980b) had conducted two site selection exercises that showed the existing site had the largest storage capacity requiring limited dam construction. After about 10 years of operation the other areas would have required much larger dams and considerably longer dams extending along its perimeter.

It was created in 1981 by the construction of four small height dams and two smaller divider dikes creating a self-contained watershed from where excess water is discharged annually under controlled conditions.

The TCA was operated as a contained water facility until 1985. Increased production of ore resulted in the adoption of a tailings management strategy that deposits the tailings within cells (Wilson 1989). Excess water from these cells is directed into two ponds in tandem within the TCA that improves the water quality before the water is discharged. Since 1985, water was discharged from a downstream polishing pond to control the water level within ponds. This tailings management strategy has been in practice to this date. The mine was shutdown during 1998 and 1999 for a shorter period over the winter months in 1993/94.

Progressive reclamation was started in 1988, when one of the filled cells (Cell 1A) was covered with 0.5 m of sand and gravel from a nearby esker. An additional 0.5m of esker cover was placed on Cell 1A in 1995, and a 1.0 m esker cover was placed on Cell 1 and most of Cell 2 during the same period. Cells 3A and 3B, two small contained areas within Cell 3, were covered by 1.0 m of esker in 2003. Approximately 60% of the remainder of Cell 3 was covered during 2004.

This report presents the background information of the TCA, the proposed closure plan of the TCA and back-up information for the proposed tailings cover design that has been collected over many years of monitoring.

The report contains large quantity of information that is given within the main text of this report and four Appendices. The main report contains key photos and figures that provide an overview of the Lupin site, extensive monitoring that has been done and all the tables. The Appendices provide more detailed information as follows:

Appendix A. - Photographs
Appendix B –Supporting figures
Appendix C – Ground temperature profiles
Appendix D – Stability analysis results

In the text, photos that are given in Appendix A are listed as Photo 1 etc and all figures that are located given in the Appendices B, C and D are given as Figure 1B, Figure 1C or Figure 1D respectively.

2.0 TAILINGS AREA BACKGROUND

2.1 Geomorphology and geology

The Contwoyto Lake area lies within the Upland unit of the Kazan physiographic region of the Canadian Shield. The area was glaciated during the Pleistocene Epoch (Blake 1963). The area is overlain by predominantly a silty sand till, with gravel and boulders, occasionally overlain by glacio-fluvial and glacio-lacustrine sand and gravel deposits. Esker and abandoned beaches are common landforms. Bedrock belongs to the Yellowknife Super group of the Achaean Epoch. The rock consists of a mixture of low grade metamorphosed argillite, siltstone, slate, greywacke and quartzite; generally described as phyllite.

2.2 Climate

Contwoyto Lake area is located in the continuous permafrost region with mean annual air temperature (MAAT) being –12.0ºC based on 1951 to 1980 Canadian Normals (Environment Canada 1982). Monitoring was conducted at the Contwoyto Lake climate station at 65º 29’ N and 110º 22’ W from 1959 to 1981, and subsequently at the Lupin mine weather station at 65º 47’ N and 111º 12’ W from 1982 to the present.

The MAAT has been rising since the first measurements were taken in 1951 and the rate of increase has amplified since 1980 as has been observed in Alaska and the Northern Global hemisphere (Anisimov & Fitzharris 2001). The combined MAAT measurements from the Contwoyto Lake and Lupin climate stations are shown in Figure 2-1. Based on a general relationship observed between ground temperature and MAAT (Smith & Burgess 2000), a ground temperature of 0º C is observed at a MAAT of –4.4º C. Based on the two trend lines, one for 1960 to 2004 data and the second for the 1980 to 2004 data, the MAAT of –10.3ºC at 2004 will warm to
-4.4º C in about 110 years based on the long-term temperature records but only about 30 years based on the MAAT trend since 1980.

The thawing index that largely governs the thaw depth, or thickness of the active zone, has been increasing correspondingly with the MAAT, as shown on Figure 2-2. The trend shown on Figure 2-2 indicates that the thawing index increased from about 850 C-degree-days to nearly 1000 C-degree-days from 1980 to 2004. The cumulative number of degree-days above 0ºC during one year provides thawing index. The trends of the MAAT and thawing index indicate that the durability of using permafrost encapsulation for the Lupin tailings has a limited lifespan between 30 to 110 years.

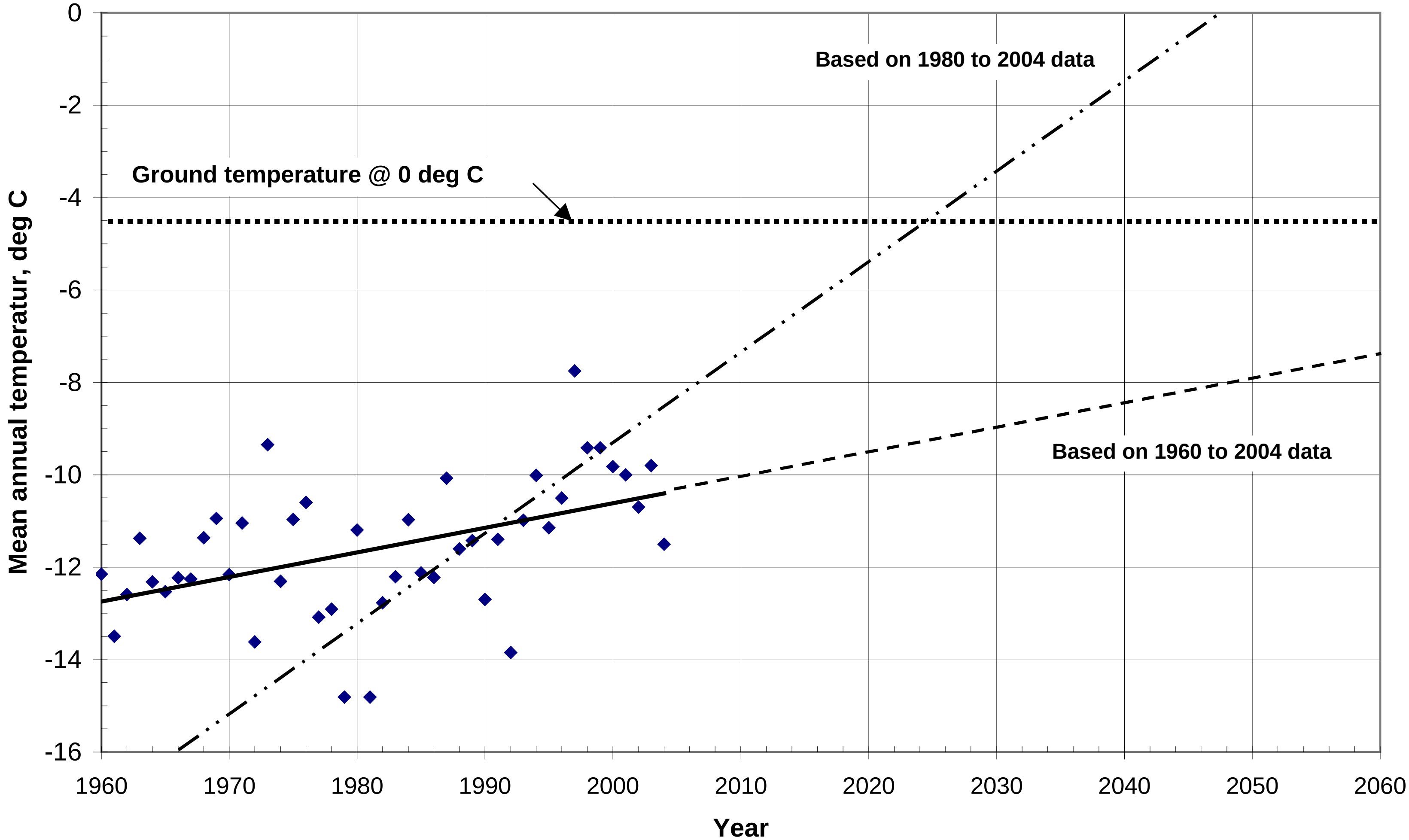

Figure 2-1. Mean annual air temperature trend at Lupin

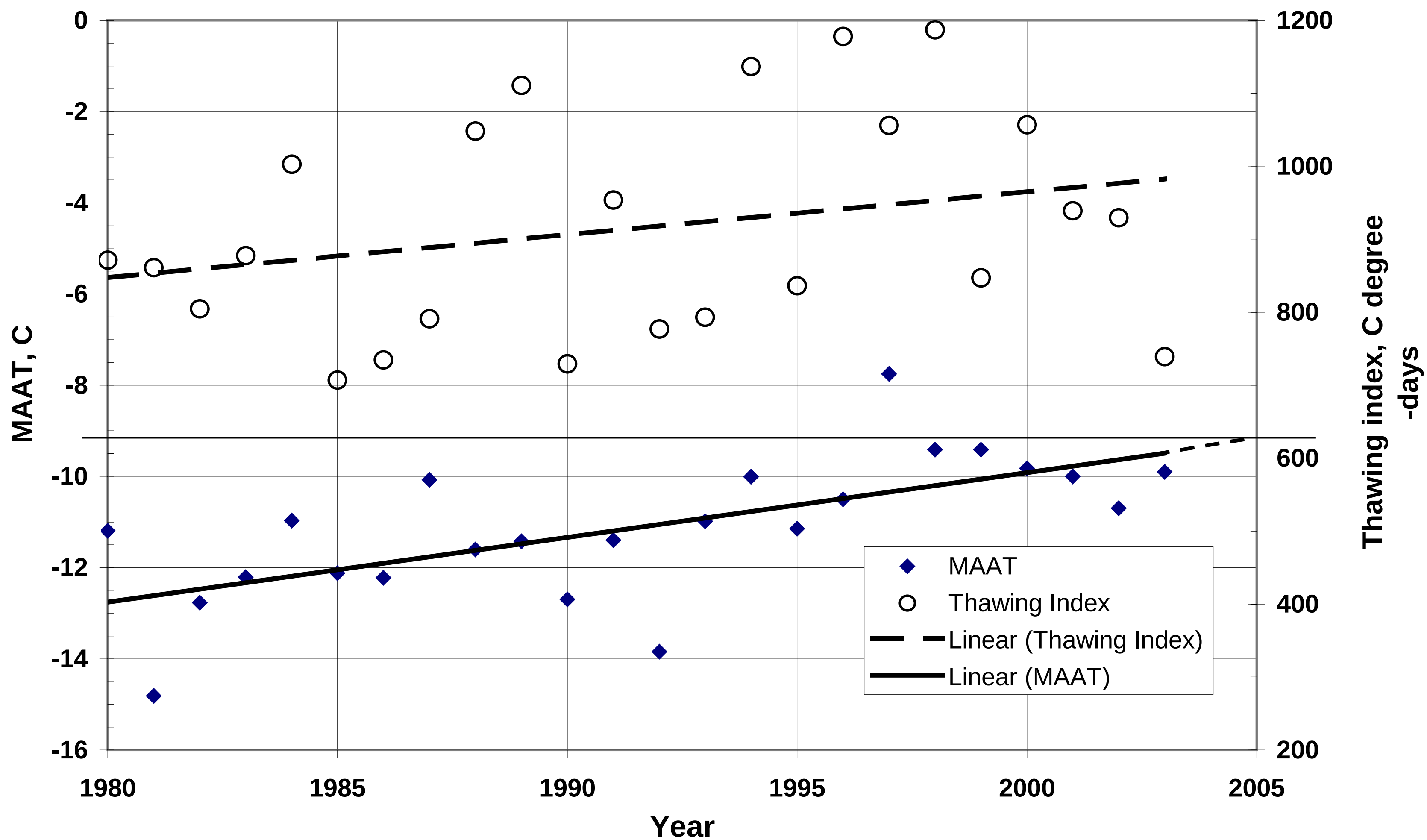

Figure 2-2. MAAT and Thawing Index trends since 1980

Precipitation at Lupin has experienced a smaller change over the mine operation period from 1982 to 2004. The total precipitation has been about 303 mm distributed about equally between rain (163 mm) and snow (140 mm). The variation in precipitation over the project time is shown in Figure 2-3.

Monthly air temperatures, rainfall and snow averages for the initial and final 10 year periods are given in Table 2-1.

Table 2-1. Two Ten year averages for air temperature, rainfall and snow, Lupin

Air Temp. C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1983 - 1992	-30.4	-29.5	-25.9	-16.0	-6.6	**5.9**	**10.8**	**8.5**	**1.4**	-9.1	-22.2	-27.1	-11.7
1994 - 2003	-29.1	-28.0	-24.0	-15.4	-5.1	**7.2**	**12.6**	**9.3**	**3.2**	-7.9	-18.0	-25.4	-10.0

Rainfall	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1983-1992					6	26	44	51	25	3			154
1994-2003				0	6	23	43	67	32	1			172

Snow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1983-1992	13	9	10	15	11	3	1	4	16	26	17	12	138
1994-2003	6	6	15	14	16	4	0	2	17	29	17	16	142

Rain + Snow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1983-1992	13	9	10	15	17	29	45	55	41	29	17	12	291
1994-2003	6	6	15	14	22	27	43	69	49	31	17	16	314

2.3 Watershed Description

The area has numerous shallow lakes and marsh-like depressions. The drainage pattern is deranged or poorly defined but ultimately, the streams drain to Contwoyto Lake. Water within these lakes generally varies between 1 to 6 m.

The TCA was developed in a rolling topography with majority of the terrain lying between El 480 m and 490 m and the high ground being on the north side with maximum elevation being about at El 505 m. The construction of two relatively small dams on the west side and a saddle dam on the east side created an enclosed watershed with an area of 616 ha. The watershed contained 18 small lakes varying in surface area from about 0.6 ha to 19.7 ha illustrated in pre-construction air photo shown on Figure 2-4.

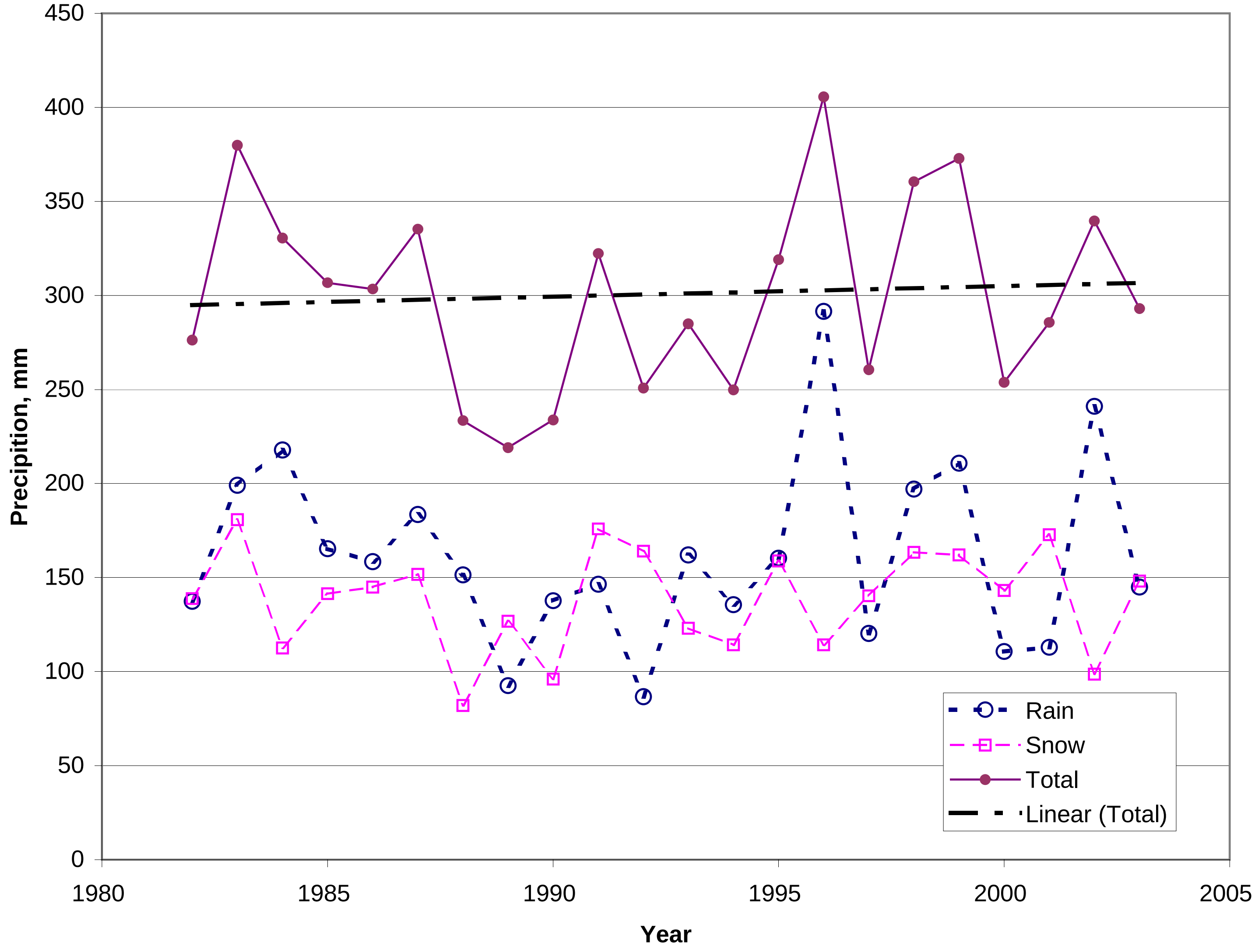

Figure 2-3. Annual rain, snow and total precipitation from 1982 to 2003, Lupin

The contained watershed was created by the construction of Dam 1a between lakes ‘a’ and ‘r’ shown on Figure 2-4 and the saddle Dam 4 between lakes ‘x’ and ‘l’. Before the construction of the saddle, lake x was part of the watershed contained by Dam 1a.

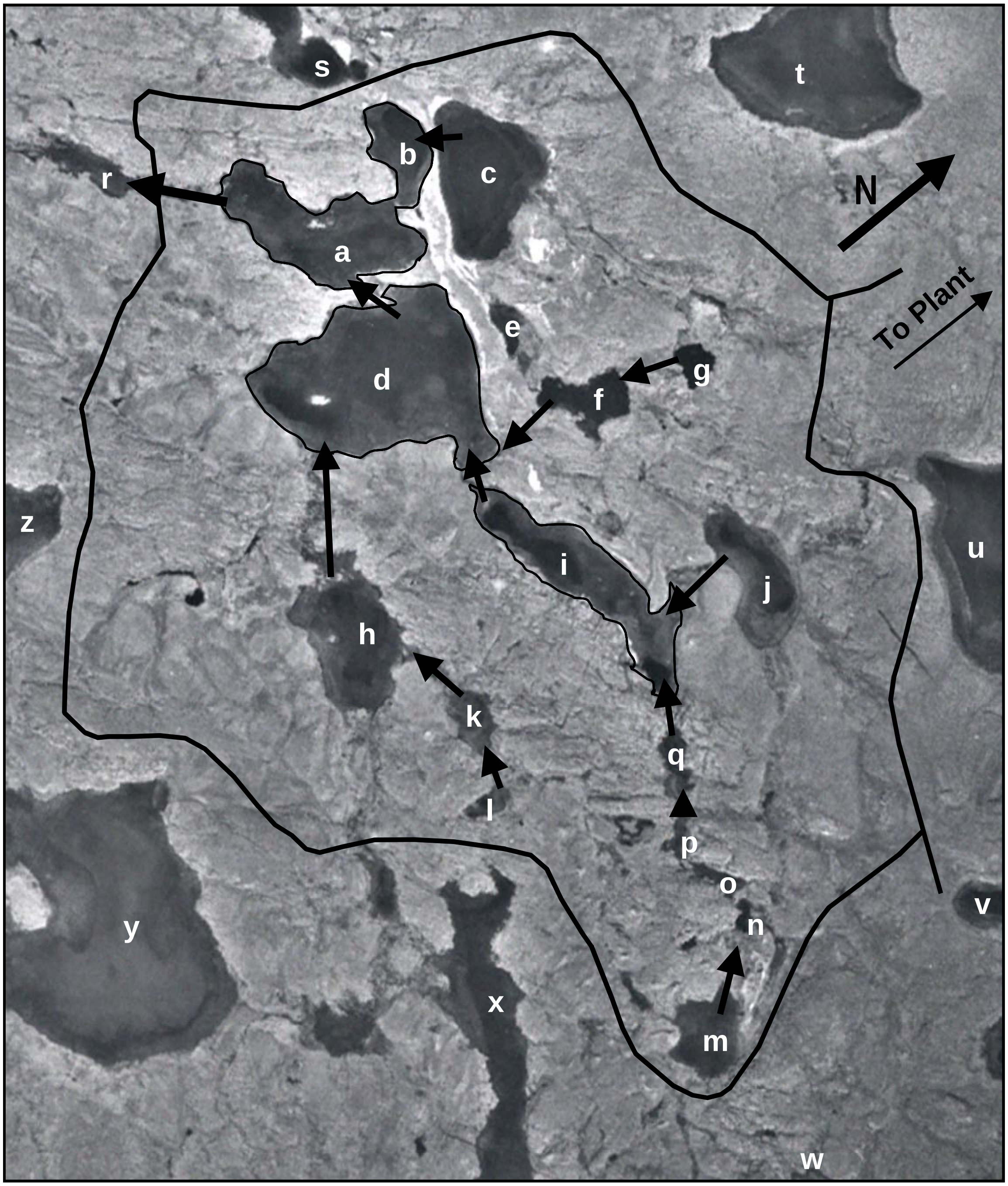

Figure 2-4. Tailings Area watershed and historic lakes and drainage

The areas and before construction water elevations of the lakes and the flow pattern is given in Table 2-2.

Table 2-2. Lakes, elevations and areas of lakes

Lake	WL, El. m	Area, ha	Lake	WL, El m	Area, ha
l	480.4	0.9	m	485.9	4.7
k	480.2	2.0	n	484.4	0.6
h	479.8	11.5	o	484.0	0.9
d	477.9	19.7	p	484.0	1.2
			q	483.9	1.4
g	482.6		i	478.0	12.1
f	481.9				
d	477.9		j	478.5	7.1
			i	478.0	12.1
e	479.5	1.0	d	477.9	19.7
c	477.8	11.7	Lakes outside of watershed		
b	477.8	4.1	s	478.2	
a	477.8	13.9	t	494.0	
Downstream of outlet			u	484.5	
r	477.7		w	482.7	
			x	482.8	
			y	481.7	

2.4 Tailings Deposition History

The Tailings Containment Area (TCA) was developed in 1981 by the construction of two main dams, Dam 1a and Dam 2, on the west side of the tailings watershed (Holubec et al 1982). Dam 1a was constructed across the watershed outlet stream and Dam 2 across an adjacent low saddle. The plan for the TCA was to operate it as a contained facility for the first few years. This would provide an opportunity to establish the tailings pond excess water quality and determine any need for treatment before discharge would commence.

Ore milling commenced in 1982 and the tailings slurry was discharged from the northern edge of the TCA to form one large pond against Dams 1a and 2 as shown in a photograph in Figure 2-5. This operation strategy continued until 1985. Increased production of ore resulted in the adoption of a revised tailings management strategy that deposits the tailings within cells. Excess water from these cells is directed into two ponds in series within the TCA that improves the water quality before the water is discharged. Since 1985, water has been discharged from a downstream polishing pond to control the water level within ponds.

This tailings management strategy has remained in practice to this date. Progressive reclamation of the filled cells started in 1988, when Cell 1A was covered with a layer of esker sand.

Figure 2-5. Photo of initial TCA in 1983, looking northeast

The history of the construction of dams, filling of the cells and placing covers over the cells is in Table 2-3. The location of perimeter and internal dams, ponds and the identification of the cells is provided on Figure 2-6.

The initial discharge of tailings occurred from an elevated point along the perimeter of the TCA that was closest to the Plant. The tailings were discharged over sloping ground that is labeled as Cell 5 and all excess water was contained within the TCA impoundment.

Due to increased ore milling and the need to discharge excess water from the TCA, Lupin mine decided to encourage natural contaminant degradation by settling out the tailings solids within cells and passing the excess tailings slurry water through two ponds in a series before discharge out of the TCA. This was accomplished by constructing an internal Dam 3C to form an initial Cell 1a, subsequently replaced by constructing a larger internal Dam 3D downstream to form the larger Cell 1, and the internal Dam J to create Pond 1 and Pond 2. This allowed the tailings to be settled in first Cell 1a and then Cell 1, and excess water to be held during the operating year in Pond 1. After checking the water quality in Pond 1, the excess water was siphoned into Pond 2. If the Pond 1 water quality did not meet design conditions at this time, iron salt solution was injected into the siphon between the two ponds. After allowing the water to improve for one more year in Pond 2, and checking that it met discharge water quality criteria, the excess water in Pond 2 was discharged annually across Dam 1a.

This concept of storing the tailings in internal cells and passing the excess water through Ponds 1 and 2 before discharging continued from 1985 onwards. The only changes were that as Cell 1, and subsequently Cell 2, were filled, additional Cells 3, 5 and N were constructed.

Cell 3 was developed in 1990 by the construction of internal Dam K. In this case, as the tailings were settled out in Cell 3, water was allowed to flow into Cell 4 from where it progressed into Ponds 1 and 2. Cell 4 provided an additional clarification pond. A small dike and a gated culvert at its north perimeter controlled its water level, before discharging excess into a natural channel and small lakes flowing into Pond 1.

In 1992, internal Dam L was constructed to prevent tailings in Cell 3 from contaminating Cell 4 as Cell 3 was being filled. Furthermore, Dam M was constructed to allow tailings to be discharged again in Cell 5, where the earliest tailings discharge occurred. Dam M would contain the tailings within a controlled area, prevent the encroachment of the tailings on Pond 2 and cover the original placed tailings in this area.

Finally, internal Dam N was constructed in 1997 to allow the containment and covering of a small area of tailings from the initial years that were located on the Pond 2 side of Dam M, to be covered.

Placing of a gravelly sand esker cover over the tailings commenced in 1988 by the covering of Cell 1a. In 1995 Cell 1 and part of Cell 2 were covered. In 2003 Cells 3a and 3B, 2 mini-cells in the westerly section of Cell 3, were covered. In 2004, the remainder of Cell 2 and about half of the remaining exposed tails in Cell 3 were covered. It is planned to complete covering of all the exposed tailings in 2005 and 2006.

The physical condition of the TCA in 2004 is illustrated in Figure 2-7.

Table 2-3. TCA development and tailings disposal history

Year	Tailings	Disposal in Cells, in months					Operation Notes
	in m^3	1	2	3	5	N	
1981							Construct Dams 1a & 2
1982	202,000				12		Construct Dam 3
1983	354,000				12		
1984	257,000				12		
1985	254,000	12					Construct internal dams 3C & J
1986	263,000	12					
1987	276,000	12					
1988	277,000	6	6				Cover Cell 1A
1989	281,000	6	6				
1990	282,000	6	6				Construct internal Dam K
1991	296,000	2		10			
1992	309,000	2		10			Construct perimeter dams 4, 5 & 6
							Internal dams L & M
1993	341,000			8	4		
1994	332,000	1		10	1		Cover Cell 1 partially (waste rock)
1995	156,000		2	10			Cover Cell 1 & part of Cell 2
1996	201,000		2	9	1		
1997	216,000			10	2		
1998	9000				1		Shut down in January
1999	4,000						Closed
2000	173,000			3	9		Resume in April, raise Dam M
2001	212,000			4	8		
2002	209,000			6	6		
2003	13,000				8	2	Reopen March, Cover Cells 3a and 3b
2004	68,000			7	3	2	Complete cover Cell 2 & start Cell 3
Total	5,120,000						

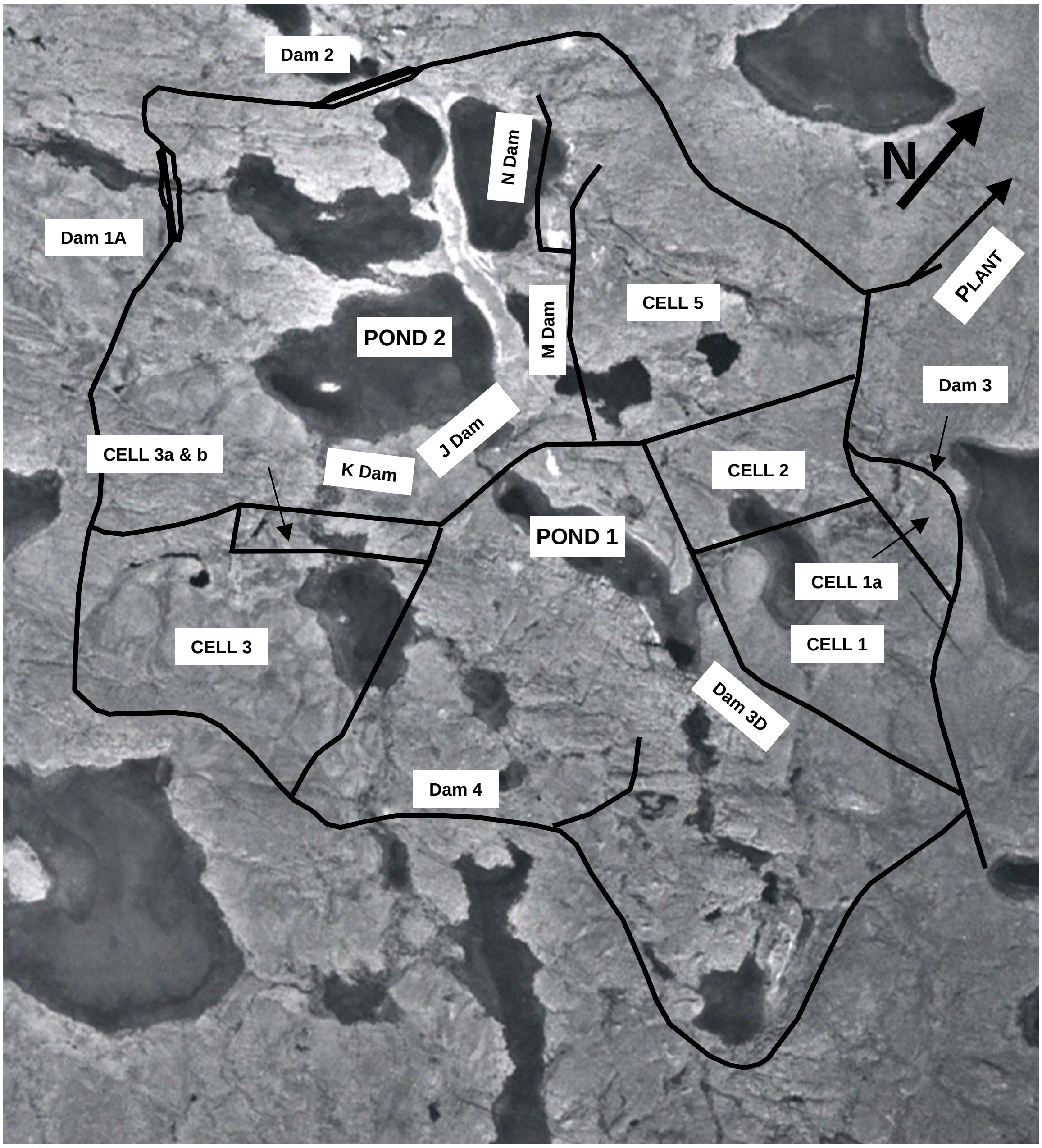

Figure 2-6. Locations of TCA dams, ponds and cells

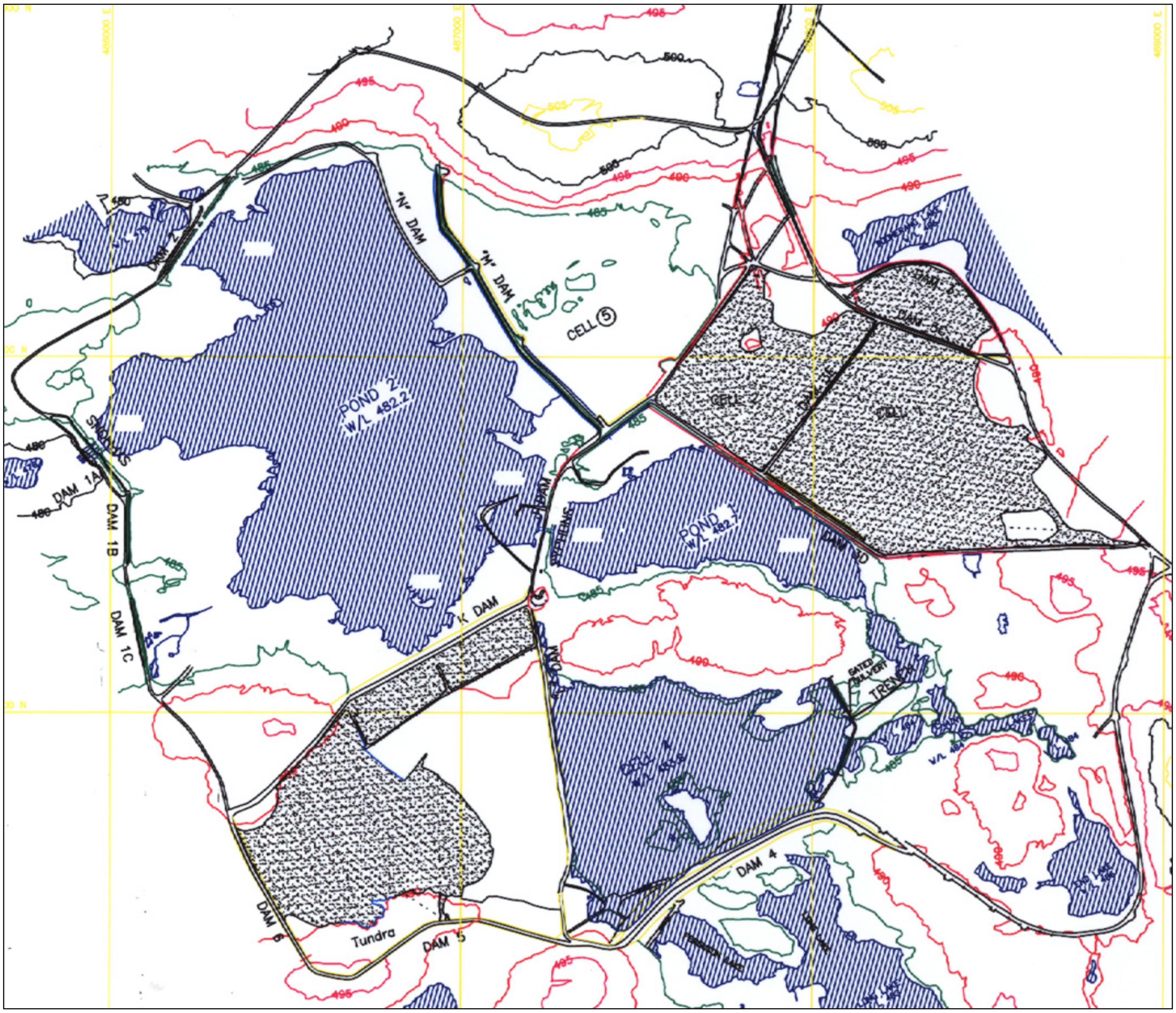

Figure 2-7. TCA Plan 2004

3.0 DAMS

3.1 General

Lupin TCA was created by the construction of 18 dams as given in Table 3-1 and shown on Figure 2-6 and Figure 2-7. The dams can be characterized as 6 main perimeter dams that contain either water or tailings within the TCA, 2 small saddle dams that were constructed to contain Pond 2 water in case of high water levels within Pond 2 and 9 internal dams to form cells that store tailings. All these dams have presently a frozen dam structure that is founded on frozen foundations. The perimeter and internal dam design section differ in that the perimeter dams include an internal liner that was incorporated to prevent internal seepage during the first years after construction and also acts as a design backup for the frozen dam section. The internal dams do not have a liner since some seepage during the development of the frozen zone was acceptable since any seepage was contained within the TCA area.

The foundation conditions, design, construction and performance are briefly discussed in the following sections. Photos of the tailings area with cells and major dams are provided in Appendix A; dam profiles and design sections are given in Appendix B and ground temperature profiles through the major dams are given in Appendix C.

Table 3-1. List of Lupin TCA perimeter and internal dams

Perimeter Dams

Dam	Year built	Crest El	Ground El	Ht, m	Design
1a	1981	485.0	478.5	6.5	Esker gravely sand with liner
	1984	486.4	478.5	7.9	“ – “
2	1981	485.5	480.2	4.7	Esker gravely sand with liner
	1984	486.1	480.2	5.9	“ – “
3	1983	490.2	486.9	3.3	Esker gravely sand with liner
4	1992	489.5	485.6	3.9	Esker gravely sand with liner
5	1992	491.6	489.7	1.9	Esker gravely sand with liner
6	1992	490.3	489.3	1.0	Esker gravely sand with liner

Small Perimeter Saddle Dams

Dam	Year built	Crest El	Ground El	Ht, m	Design
1b	1981	485.8	483.135	2.5	Esker gravely sand with liner
1c	1981	485.7	483.5	2.2	Esker gravely sand with liner

Internal Dams

Dam	Year built	Crest El	Ground El	Ht, m	Design
3C	1985	491.2	485.5	5.7	Esker, tailings on both sides
3D	1986	487.5	480.0	7.5	Esker, tailings on cell side
	1988	490.5	480.0	9.5	
3E	1985	491.2	480.0	11.2	Esker, tailings on both sides
J	1985	490.5	481.4	9.1	Esker, tailings on cell side
K	1990	490.7	480.0	10.7	Esker, liner with tailings on cell side
L	1992	490.8	479.8	11.0	Esker, tailings on cell side
M	1992	488.8	481.8	7.0	Esker, tailings on cell side
N	1997	483.9	478.0	5.9	Esker, tailings on cell side

3.2 Perimeter Dams

3.2.1 Basic Design

The design concept for all perimeter dams is illustrated on Figure 3-1. It consists of a low permeability of homogeneous dam with a liner on the pond side anchored in a trench on the pond side. The dams were constructed in the summer. Since it was difficult to predict if the dam section would freeze completely over the first winter, a liner was provided to stop seepage until the main dam section developed permafrost. The dam section was armoured against erosion with mine rock on either the pond side only or both the pond and downstream sides.

Dams constructed in 1981 used local thawed silty sand till for the main zone and a gravelly sand esker material to cover the liner on the pond side. The remainder perimeter dams were constructed solely from gravelly sand esker material and they have an internal liner.

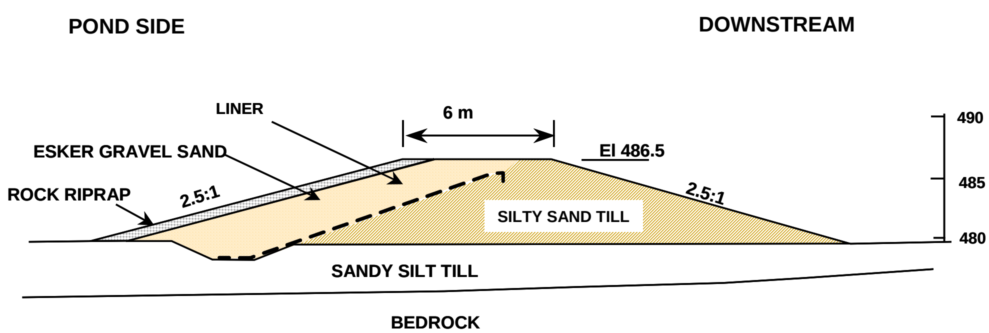

Figure 3-1. Design concept of perimeter dams

The internal dams were constructed from a gravelly sand esker material. Minor content of silt in the esker material and the fact that tailings a beach was developed against the upstream dam face, created low permeability dams. The low seepage, that did not pose any water quality problems since it was trapped within the TCA and improved before discharge, allowed the gradually freezing of the dam cross sections as discussed in detail in the next sections.

Both the perimeter and internal dams were armoured with mine rock on sides that has water ponding.

All perimeter dams were constructed on natural ground consisting of either silty sand till or bedrock. With the exception of Dams 1a and 2, the foundation consisted of relatively thin till, less than 2 m thick, underlain by bedrock. The silty sand till, below the active layer that existed during the summer, had little or no excess ice and thereby formed competent foundations in either frozen or thawed state. Water content of thawed till was measured to be between 14 and 18 percent.

3.2.2 Perimeter Dams 1a and 2

The main and first dams constructed at the site were Dams 1a and 2. They were constructed at the west end of the TCA watershed that drained towards the west at Dam 1a. The outlet stream at Dam 1a controlled the water level at the three adjacent lakes at El 478.5 m. The base of Dam 2 was about 1.7 m higher at El 480.2 m. The locations of these dams are illustrated on Photo 8 in Appendix A.

The presence of relatively deep silty sand till foundations at Dams 1a and 2, led to designing the dams with a homogeneous low permeability core that would freeze and coalesce with the frozen foundations. Since it was anticipated that the dam fill material could take one to two years to freeze completely, an impermeable liner, anchored into permafrost, was included with the dam section. These dams were constructed in two stages: in 1981 the dam crests were built to El 485.0 and El 485.5 m (Dams 1a and 2 respectively) and then raised in 1984 to El 486.4 and El 486.1 m respectively. The cross sections are shown in Figures B 2 and B 3 and soil conditions along the dam profiles of the dams are shown in Figures B 4 and B 5 respectively in Appendix B.

The dams experienced two minor problems during the initial years. Dam 1a showed some seepage near the north abutment in 1982, likely due to excessive thaw during the summer construction in an area with smaller depth of the silty sand over bedrock. This was managed by adding some low permeability silty sand on the upstream slope of the dam.

In 1984 seepage was observed at the abutments of Dams 1b and 1c. The reason was that the water level against the dam had risen above the elevation of the annual thaw depth within the bedrock in the abutments of the dams. Lowering Pond 2 water level by siphoning over Dam 1a and stricter control of the reservoir water level thereafter stopped the seepage.

Both dam sections and the foundations froze completely by the second year (1983) and the ground temperature below the dam crest has remained stabile at around –3.5 ºC for the past 20 years. No other seepage was reported aside of the two instances during the initial years.

3.2.3 Saddle Dams 1b and 1c.

Saddle Dams 1b and c were constructed along the drainage divide to contain Pond 2 water in case of high water level conditions. The dams are 2.5 and 2.2 m high respectively.

Their design is similar to the basic homogeneous low permeability section with a liner illustrated in Figure 3-1.

3.2.4 Dam 3

Dam 3 was constructed in 1983 to reduce the main watershed area of the TCA and to create Cell 1a for tailings storage. Dam 3 rerouted the drainage from adjacent Boomerang Lake. The drainage from this sub-watershed was routed by the construction of a 1 m deep outlet channel towards the east. Design of this dam again was the same as in Figure 3-1.

3.2.5 Dam 4

This dam is located at the watershed divide of the TCA. While a permanent dam was constructed at this location in 1992, a temporary dam was in existence since 1983. The initial dam was constructed using a homogenous silty sand design because only a small height of water would be impounded on the downstream side. This dam experienced annual sloughing of the downstream slope and required continuous maintenance.

In 1992, a permanent 3.9 m high dam with the common design was constructed as shown in Photo 8. The design is shown in Figure 6 B. Both the upstream and downstream faces of the improved dam were armoured with development waste to prevent the sloughing problem of the previous years.

3.2.6 Dams 5 and 6

These two dams are low height dams constructed along the drainage divide at the southwest side of the TCA. They are about 1.9 and 1.0 m high respectively. The design sections of these two dams are shown on Figures B 7 and B 8 respectively.

3.3 Internal Dams

3.3.1 General

Internal dams were constructed within the TCA watershed boundary and therefore any seepage occurrence would not be critical since all water was being retained. Some of these dams were constructed using an esker homogenous zone only and some included a liner within the esker zone.

3.3.2 J Dam

Through a pilot plant study in 1984 and 1985, it was determined that prolonging the retention of excess water within ponds could enhance that natural degradation process. As a result, it was decided to collect tailings within cells and provide two ponds in series to provide up to two years retention of water before discharge. This would lower cyanide and metal concentrations to Water License limits. To further enhance the lowering of arsenic concentration, an iron salt solution was introduced during the transfer of water between Ponds 1 and 2 (Wilson 1989).

To create the two ponds, J Dam was constructed between two original Lakes ‘d’ and ‘i’ shown on Figure 2-4. The proposed route of the dam was on land that had a thin till cover over bedrock. It did cross a small stream that drained Lake ‘i’ into Lake ‘d’ shown on Figure 2-6. At this time, the original proposed alignment of Dam J was already flooded by the filling of the TCA reservoir as shown in Figure 2-5.

Dam J was built from minus 150 mm mine waste rock that was dumped through ice during the winter of 1985. Since the rock-fill dam section was relatively permeable, the upstream side of the dam was covered with a layer of gravelly sand esker followed by tailings during the summer. Some seepage through the Dam J was acceptable since this dam was within the TCA. The southern section of Dam J, including the siphons used to transfer water from Pond 1 to Pond 2, can be seen in the lower left corner of Photo 4.

Dam J section is shown in Figure B-9 and the foundation profile in Figure B 10. Figure B 10 shows that at the lowest valley point, the dam base is at the same elevation as former Lake ‘d’.

3.3.3 Cell 1 Dams

Along with the construction of Dam J, cells started to be constructed on the north side of TCA to store tailings. The cells were formed by the construction of the TCA perimeter Dam 3 and internal dams 3A, 3B, 3C, 3D and 3E to form Cells 1a, 1 and 2 shown in Figure 2-7. Dams 3A and 3B are not shown in this figure since these were intermediate small dams that were covered with tailings in Cell 1a. Also, no dam is identified between Cells 2 and 5 because the division between these two dams is formed by high ground. A road indicates the boundary between these two cells.

General arrangement of the dams bounding Cells 1a, 1 and 2 is shown on Photo 3 in Appendix A. In this photo, Pond 1 is in the foreground, Cells 1 and 2 are shown on right and left respectively and Cell 1a and Boomerang Lake are visible in the top of this photo.

The major internal dam in this area is Dam 3D built in 1986 to create Cell 1. It has a maximum final height of 9.5m. It was built across internal higher ground as shown in Figure 2-6 with the exception of a small length that crosses the outflow of former Lake ‘j’ Figure 2-4.

The dam was constructed from a gravelly sand esker to form a homogenous cross section. Seepage occurred through the dam during operation as expected since the gravelly sand was relatively permeable. As the operation continued, sloughing of the downstream slope and the need to increase storage capacity of Cell 1, resulted in buttressing the downstream slope of Dam 3D with about 10 m of mine rock on the downstream side and adding additional esker material on top of the dam to raise its final elevation to El 490.4 in 1988. Photo 9 in Appendix A shows the downstream rockfill zone of Dam 3D.

The geometry of Dam 3D is shown on Figures B 11, B 12 and B 13. These show the massive esker & rock-fill construction of the dam in Figure B11; the foundation profile in Figure B 12 and an exaggerated vertical to horizontal section normal to the Dam 3D in Figure B 13. This shows that on an average Dam 3D is about 9.5m high and presently its downstream slope is submerged in Pond 1 water to a depth of about 5 m. Presently Dam 3D is frozen as measured by thermistor 3D3-1 discussed in the following section.

Internal Dam 3E has ceased to exist since it is buttressed by tailings on both sides as illustrated on Photo 4.

3.3.4 Dam K

Dam K was built in 1990 to develop new tailings storage area. It was constructed from esker and tailings on competent dry ground. Pond 2 water level did not cover the dam route during construction. The design consists of building a gravelly sand esker embankment that is buttressed by a 100 m wide tailings zone on the upstream side. The tailings buttress was created by means of discharging tailings from both Dam K edge and a berm constructed on the upstream side as shown on Figure B 14 in Appendix A. The upstream berm was constructed and over time raised from settled tailings. The area between Dam K and the downstream berm is called Cells 3a and 3b. The tailings beach formed by Cells 3a and 3b form a wide low permeability zone. The downstream slope was covered with mine rock for erosion protection.

Dam foundation profile is shown on Figure B 15 and the dam along with the upstream contained tailings are shown in section in Figure B 16. Dam K along with the tailings cells 3a, 3b and 3 are shown in Photo 4 and the Dam K downstream slope in Photo 10, Appendix A.

3.3.5 Dam L

Dam L was constructed in 1992 to contain tailings within Cell 3 and create an additional water treatment pond in Cell 4. Dam L is shown on the left side in Photo 4 in Appendix A. The dam was constructed in two stages from esker material. Upstream and downstream slopes of this dam were protected by mine rock riprap as shown in Figure B 17. A small dike and a gated culvert on the northeast side of Cell 4 have regulated the water level in Cell 4. However, the difference in water levels between Cells 3 and 4 is small. Foundation profile of this dam is shown on Figure B 18.

3.3.6 Dam M

Dam M was constructed in 1992 to provide additional tailings storage in Cell 5 without compromising the water quality of Pond 2. It also provides greater operational flexibility in allowing the discharge of tailings closer to the plant during winter. Dam M, with tailings beach in the background, is shown in Photo 2.

The dam was constructed from gravely sand esker material and the downstream slope adjacent to Pond 2 was covered with a thick layer of mine rock riprap as shown in Photo 11. A section view of the dam, with the contained tailings and the dam foundation profile, is shown on Figures B 19 and B 20 respectively.

3.3.7 Dam N

Dam N was constructed to allow the covering of a small area of exposed tailings beyond Dam M alignment with an esker cover. This dam, in section, consists of a homogenous esker zone covered with mine rock riprap on the downstream side. Photo 5 in Appendix 5 shows Dam N on the right side.

4.0 TAILINGS STORAGE

4.1 General

From the start of the Lupin operation in 1982 to end of 2004, approximately 1,770,000 tonnes or 5,120,000 m^3 of tailings were stored in within the TCA. The tailings were stored in four major cells (Cells 1, 2, 3 and 5) and one smaller Cell N according to the disposal history given in Table 2-3. These cells occupy an area of about 145 ha within the total TCA watershed area of about 616 ha. Estimated statistics of the cells and contained tailings are given in Table 4-1.

Table 4-1. Statistics of cells and contained tailings

Cell	Cell's Watershed, ha	Tailings surface area ha	Mean tailings depth, m	Tailings volume stored, m3
Cell 1a	6	6.3	1.7	107,000
Cell 1	41	36.1	3.5	1,263,000
Cell 2	21	15.0	3.0	450,000
Cell 3	67	50.0	4.0	1,724,000
Cell 5	56	34.3	4.5	1,544,000
Cell N	3	3	1.0	32,000
Totals	194	144.7		5,120,000

The tailings volumes were estimated from production records as given in Table 2-3, Specific Gravity of 2.90 and an estimated void ratio of the deposited tailings of 0.70.

4.2 Cell 1

Cell 1 was developed in two stages. First a small Cell 1a was constructed against Boomerang Lake on the north side of the main Cell 1. It was formed by the small perimeter Dam 3 and a small internal Dam 3E.

Cell 1 was created by the construction of internal Dam 3D. This dam was constructed northeast of Lake i (Figure 2-4) that became Pond 1. It created a suitable storage area by its topography and its enclosure of Lake j. While the depth of tailings over the whole Cell 1 surface area averages about 3.5m, the actual depth varies greatly as can be seen from Figures B12 and B13. The maximum depth against Dam 3D is approximately 6 metres and in the area occupied by the previous Lake j it is about 11m.

Deposition in Cell 1a and 1 was started in 1985 and continued until 1992. The areas were covered with a gravelly sand esker material in 1988 and 1995.

4.3 Cell 2

Cell 2 is an extension of Cell 1 towards the west. It was constructed by extending internal Dam 3D. The depth of tails in Cell 2 is not as high as in Cell 1, containing about 6 m of tailings. Cell 2 was used between 1988 and 1990, and in 1995 and 1996. The bulk of the cell was covered with esker material in 1995, with the remainder covered in 2004.

4.4 Cell 3

Cell 3 was constructed at the most southerly location of the TCA and it stores the greatest volume of tailings. It was developed by the construction of K Dam in 1990 and was used from that time until 2004. To allow additional the raising of K Dam and increase the massiveness of this dam, sub Cells 3a and 3b were developed upstream of the main K Dam. The berm upstream of K Dam that contained the tailings within Cells 3a and 3B was constructed predominantly from settled tailings. These sub cells can be seen in Photo 4 in Appendix A.

Cell 3 area contained a large Lake h that enhanced its storage capacity. While K Dam is about 9 m high, depression of Lake h created a sizeable bowl where up to 10 m of tailings could be stored. The tailings were discharged from a berm forming the southeast side of Cells 3a and 3b and from the southeast high ground. A section through this cell can be seen in Figure B16. Cell 3 stores about 1,724,000 m^3 of tailings.

Reclamation of Cell 3 began in 2003, when Cells 3a and 3b were covered with esker sand and gravel. The reclamation continued in 2004, with over half of the exposed tailings being covered during this year. It is planned to complete covering the tailings in this cell in 2005.

4.5 Cell 5

Cell 5 has the most varied use history of the four main tailings cells. It was the main tailings storage area during the start up years from 1982 to 1984. During this period, Lupin operated the TCA as a single storage pond with the tailings being discharged from the northern perimeter of the TCA. About one third of the tailings stored in this cell were discharged in the first 3 years. From 1985, the TCA operation changed to storing the tailings within discreet cells and improving the decant water quality by means of extended storage in two polishing ponds.

Storage in Cell 5 did not restart until 1993. From this point on, the cell was mainly used during the wintertime because of its proximity to the plant. Tailings have been discharged into this area until 2004. Aside from the proximity of this cell, tailings also have been discharged to level the cell for a final cover and to cover the older tailings with fresh tailings.

Cell 5 area is generally sloping towards the south and previously contained several small lakes that increased its storage capacity. The cell was created by the construction of M Dam, which is about 5m high with the exception of a section across the outlet of the closest former lake, where the dam height is about 8m.

It is planned to cover Cell 5 in 2005 and 2006.

4.6 Cell N

Cell N is a northerly extension of Cell 5 and was formed by the construction N Dam in 1997 to cover a small exposed tailings beach that was created during initial operation between 1982 and 1984. The construction of Dam N allowed the placement of fresh tailings over the old tailings beach, so that the water quality of Pond 2 would not be compromised. The exposed tailings in Cell N will be covered in 2005.

5.0 PERMAFROST WITHIN DAMS AND TAILINGS

5.1 General

Permafrost is defined as a thermal condition in soil or rock with a temperature below 0ºC that persists over at least two consecutive winters and the intervening summer (Everdingen 1998). Moisture in the form of water or ground ice may or may not be present. The definition does not include the presence of frozen soil or rock within the stratigraphy, its temperature, or water/ice content that may determine physical and chemical properties. Nor does it consider the depression of the freezing point that may be relevant to the oxidation of reactive tailings.

Two parameters that are important to the evaluation of the permafrost conditions at the TCA are the annual depth of thaw (active layer) and the ground temperature at zero annual amplitude (MAGAT). These parameters and the ground temperature regime is illustrated in Figure 5-1.

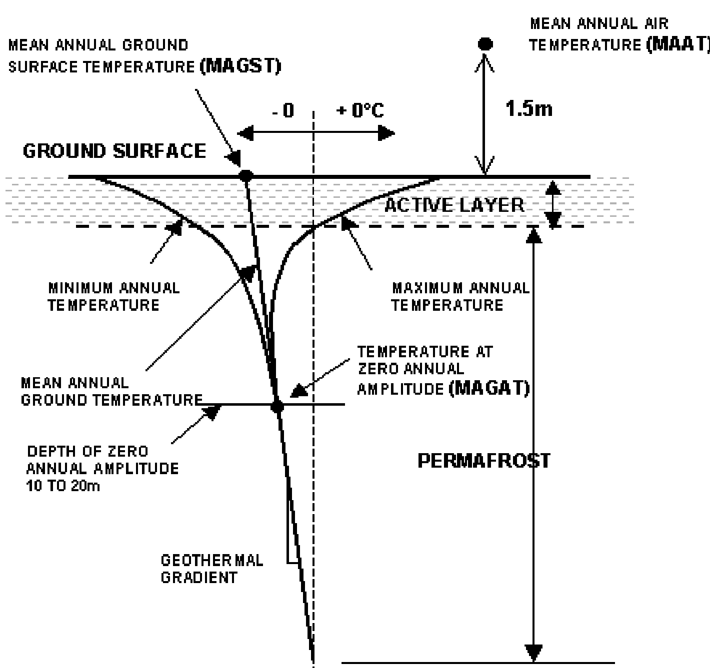

Figure 5-1. Ground temperature regime in permafrost

The thickness of the active layer or thaw depth is important in the stability of dams and the design of the tailings cover if permafrost encapsulation is the closure design for the tailings.

In case of the dams, the thaw depth indicates the zone of thawed material below the dam crest that could allow seepage during the summer thaw period if water level rises above the thaw elevation and a liner is not provided. Critical areas could be in the abutments if the liner is not extended far enough into the abutments.

In case of tailings encapsulation, the thaw depth determines the design and thickness of the cover to ensure that the thaw remains within the cover.

MAGAT provides an indicator that the dam core and foundations are frozen and thereby prevent seepage that may not be acceptable because of water quality or that could undermine the stability of the dam. Also the changes of the MAGAT can be used to evaluate the changes of permafrost temperature over time. MAGAT occurs normally at a depth of about 15 m. At locations with no organic cover, the MAGAT may be located at a greater depth; then the mean annual ground temperature (MAGT) at depths greater than 10 m provides a similar value.

Lupin has been monitoring the ground temperatures in dams since 1982 and in covered cells since 1985. The results of this monitoring have been provided annually to the Water Board and have been published in several papers. This chapter summarizes the most recent permafrost conditions at the site. These are based on relatively deep thermistor cables, 12 to 20 m, located at thirteen locations as shown in Figure 5-2. Four of these thermistor cables were installed in the summer of 2004 and therefore do not provide reliable MAGT values. Plans where the ground temperatures were measured, and last years temperature profiles, are given in Appendix C. Ground temperature profiles are not shown for 3 thermistors: D1-00-02n and D2-0003s because of malfunction of two temperature sensors near the ground surface and TC 3-1 because of recent installation.

5.2 Thaw Depth

Thaw depths were determined from ground temperature profile fluctuations as shown in Figures C9 to C18 in Appendix C. Note that the thaw depths could not be determined at 2 of the 13 thermistors because of the malfunction of some of the near ground surface temperature sensors. The determined thaw depths are summarized on Table 5-1.

The temperature records show that the thaw depths below the dam crests varied from 2.0 to 3.1 m. (average 2.5 m) and below the covered tailings area, including in one thermistor installed in the esker borrow area, from 1.3 to 1.6 m (average 1.4 m). Different thaw depths were obtained below the dam crests and below the covered cells due to moisture content of materials at these locations. The geometry of the dam sections and the presence of the liner at Dams 1a, 2 and 3 keep the ground below the dam crest relatively dry that encourages thick active layer or large thaw depth. Dam safety in Dams 1a, 2 and 4 is maintained by the presence of a liner within the dam section and keeping sufficient freeboard. Dams 3D, M and

N, do not have liners but are internal dams with massive, relatively low permeability, esker zones that buttress tailings. Dam K also buttresses tailings but contains a liner.

The thaw depth in the covered tailings cells and in the esker borrow area is shallower than in the dams because of the flat geometry in these areas. The flat geometry and the underlying permafrost keep the groundwater high which in turns limits the annual thaw. As a result the maximum thaw depth averages 1.4 m, with a range of 1.3 to 1.6 m.

Table 5-1. Summary of thaw depths and MAGT

Dams Thermistors	Max'm Depth	Thaw D m	MAGT @ Max d	Note
D1-1s	20	3.0	-4.1	
D1-2n	20.3	na	-3.9	
D2-3s	20	na	-3.5	
D2-2n	20	2.3	-4.5	
D4-1	12	2.4	-4.3	
D4-3	12	2.7	-3.6	
D4-4	12	2.2	-4.5	
DK-3	19.6	3.1	-2.9	Fall 2004
D3D	20	2.0	-2.1	Fall 2004
	Avg	2.5	-4.1	Exclude
	Range	2.0 - 3.1		Fall 2004

Tails & Esker Thermistors	Max'm Depth	Thaw D m	MAGT @ Max d	Note
TC1-3	13	1.2	-5.2	1995
TC3-1	20	1.4	-3.9	Fall 2004
TC1-6	20	1.3	-5.1	2003
Esker	14.3	1.3	-6.5	
TC1-7	20	1.6	-4.3	Fall 2004
	Avg	1.4	-5.8	Exclude
	Range	1.3 - 1.6		Fall 2004

5.3 Mean Annual Ground Temperature (MAGT)

The presently monitored thermistors provide a good picture of the permafrost conditions within the dams and covered cells because of their large depths ranging from 12 to 20 m. Nine of the 13 thermistors were used to assess the MAGT because 4 of the thermistors were installed only in the summer of 2004. These four most recent installations do not have temperature records for the whole year to determine the mean annual ground temperatures.

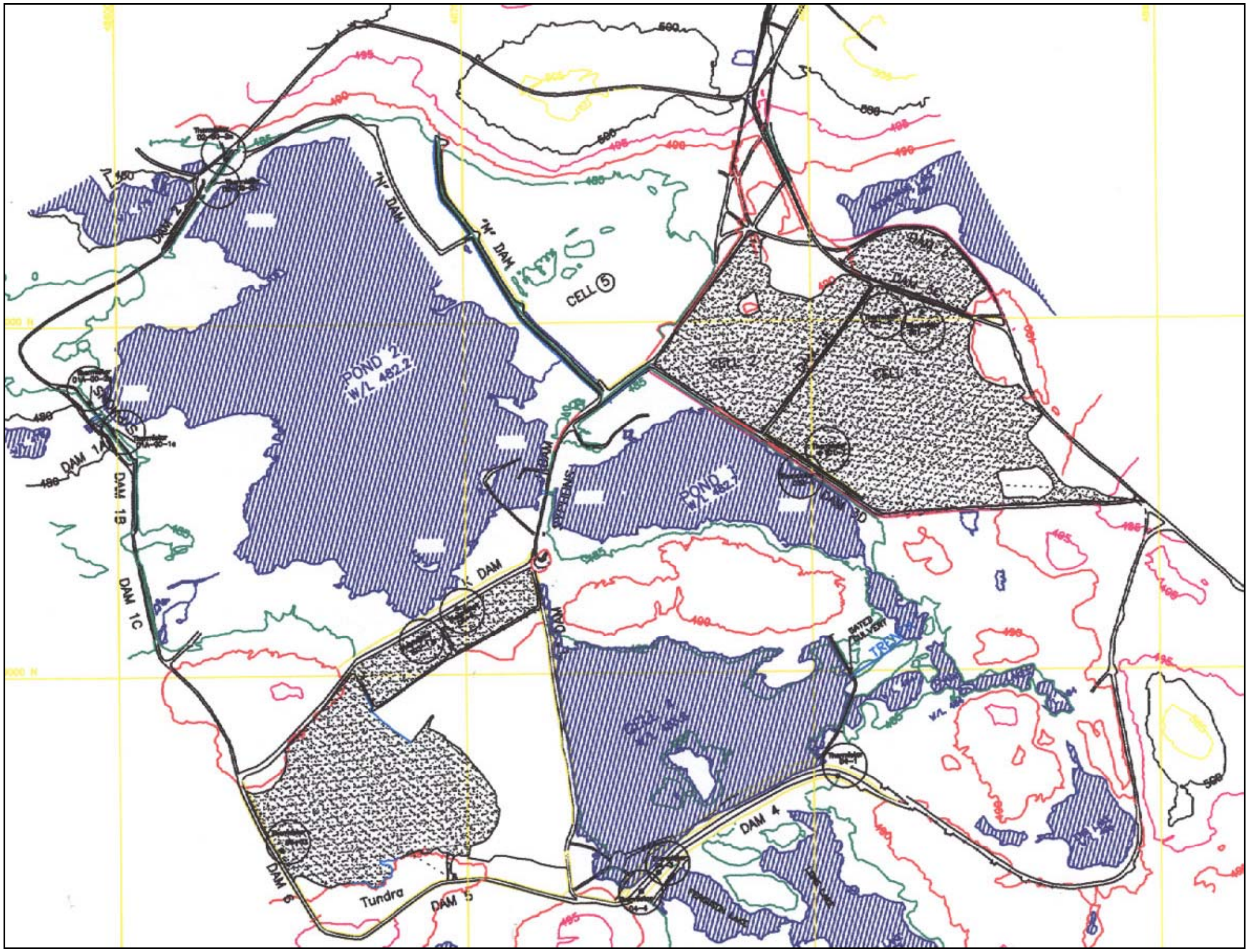

Figure 5-2. Locations of active thermistors

Estimated MAGT below Dams D1a, D2 and D4, average at –4.1ºC and range from –3.5ºC to –4.5ºC. The warmer MAGT as compared to the thermistors in the tailings and the thermistor installed in the esker with an average of -5.8ºC is due to the presence of water in the adjacent ponds.

It is of interest to view the ground temperature changes at 20 m depth measured in Dams 1a and 2 shown on Figure C-7 in Appendix C. The coldest MAGT (-4.5ºC) was measured in thermistor D2–02n that is furthest from Pond 2 water, being located at the abutment. It can be concluded that all dams have sufficiently cold permafrost regimes to prevent seepage or pose stability problems in the TCA operating phase.

The variation of MAGT at the tailings can be explained by several facts. MAGT below Cell 3b tailings, thermistor TC3-1 is the warmest at –3.9ºC because of the influence of the most recent tailings deposits and possibly the proximity to Pond 2. Similarly the warmer MAGT at TC1-7 is likely due to the proximity to Pond 1.

The coldest MAGT in the tailings cells was observed at the northeast part of Cell 1, at thermistor TP1 that is located within a recently installed test pad. The colder MAGT in Cell 1 (–5.1ºC) can be explained by the fact that the tailings disposal was completed in 1985 and the tailings at the location of the thermistor are only about 3 m deep and therefore the ground would have cooled relatively rapidly. The magnitudes and changes with time of ground temperatures between the depths 13 to 20 m at five of the thermistor locations can be seen on Figure C-8 in Appendix C.

Adjacent to the Test Pad in Cell 1 is another relatively deep thermistor, TC1-3, that has been monitored since 1996, thereby providing MAGT information for 9 years. The MAGT from 1996 to 2004 shown in Figure 5-3 shows the ground at 13 m depth has warmed from -6.7ºC to –5.2ºC in the nine years. To see how the permafrost warming corresponds to the mean annual air temperature (MAAT), MAAT from 1980 to 2004 is also shown in this figure. Furthermore, since Sharon and Burgess (2000) have shown a direct relationship between MAAT and MAGT that is offset by 4.4ºC, a 4ºC offset was added to the MAAT from 1980 to 1995 and plotted on Figure 5-3.

Reviewing the three curves in Figure 5-3 show:

- A good relationship between MAAT and MAGT
- MAGT has been following the same warming trend as the MAAT.
- During the last 5 years MAAT has been cooling and this cooling trend has stopped the warming of the MAGT trend during the last two years.
- However, the last five year MAAT trend is not significant enough to discount global warming.

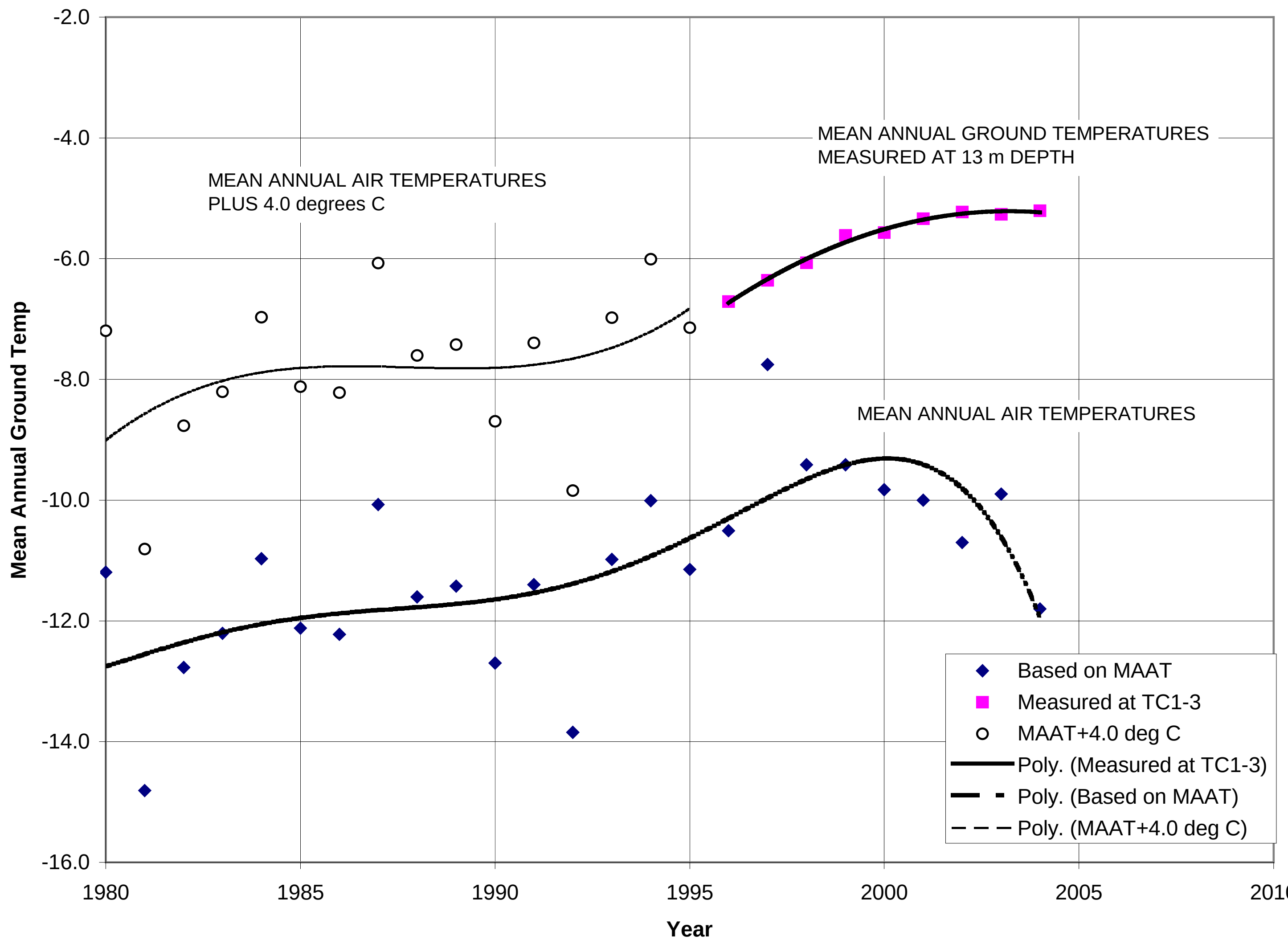

Figure 5-3. Mean annual ground temperatures in Cell 1 from 1980 to 2004

6.0 SURFACE WATER

6.1 General

The TCA is located within a relatively large watershed of about 616 ha that contained about 18 small lakes with a total area of about 974 ha before the construction of the TCA. It is located near the headwater of watershed draining into the West Arm of Contwoyto Lake as shown in Figure 6-1. An easterly area containing Long Lake was also contained originally within the TCA watershed but was redirected to flow eastward into Shallow Bay and subsequently to Contwoyto Lake by the construction of a saddle dam at Dam 4 location.

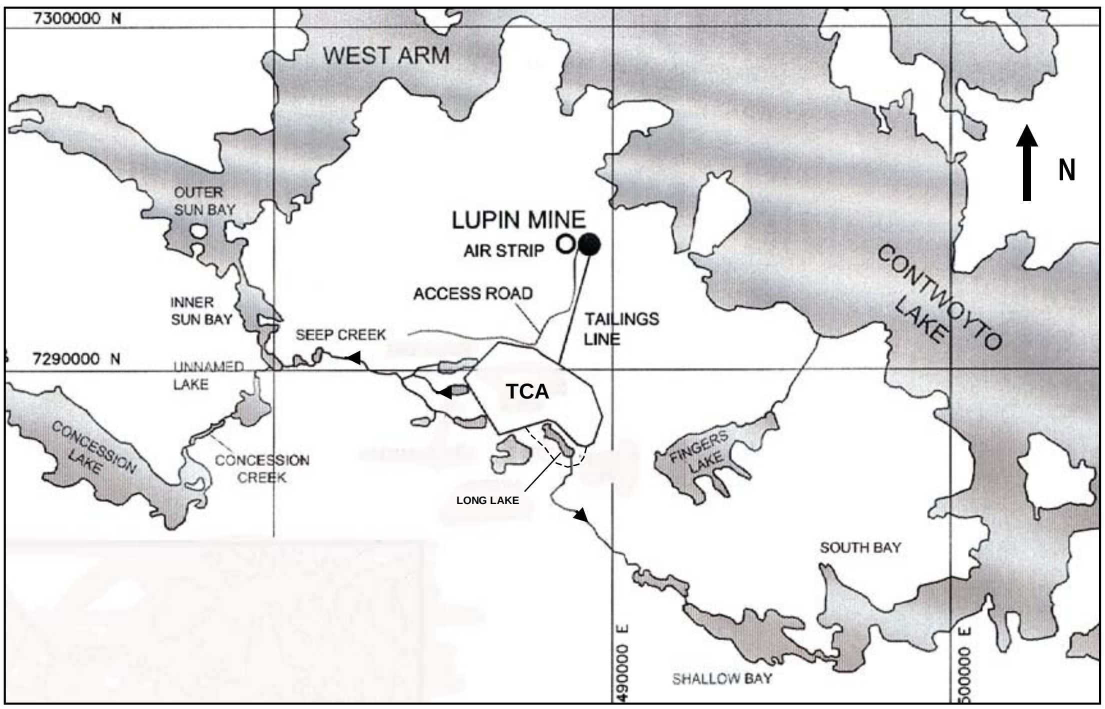

Figure 6-1. Location of TCA within Contwoyto drainage system

The construction and operation of the TCA has changed the water flows from this area and will change again upon closure. The water surfaces and flows within the TCA are shown in Figure 2-4 (before), Figure 2-7 (during operation in 2004) and Figure 6-7 (after closure). The mean annual water balances, and therefore the flows out of the TCA, were estimated for: before, during operation, and after closure.

The water balance is a function of the annual precipitation, runoff from the land areas, evaporation from water surfaces, excess water from tailings slurry and outflow from the TCA if there is excess water. The climate and a description of the TCA watershed were provided in

Sections 2.2 and 2.3. Precipitation values used in the water balance are the mean values for the before and closure conditions as given in Table 6-1.

Table 6-1. Mean annual precipitation and evaporation

Item	Value
Annual rainfall	165 mm
Annual snowfall	140 mm
Total annual precipitation	305 mm
Lake water evaporation	280 mm

For operational water balance, the water balance for the years of 1985 to 2004 was estimated and for this estimate the actual annual precipitation values shown in Figure 2-3 were used.

The land and water surface areas are different for the three stages of the TCA. The estimated areas that were used in the calculations are given in Table 6-2.

Table 6-2. Land and water areas during three stages of TCA

Type	Pre TCA	Operation	After Closure
Land area, ha	519	281	543
Water area, ha	97	335	73
Total TCA, ha	616	616	616

Different runoff coefficients of 0.50 and 0.60 were used for the before and operation stages respectively of the land area. The reason being that before TCA, the land area contained low-lying areas with swamp vegetation that would retain water. These low areas were covered with tailings and subsequently covered with esker sand that would promote higher runoff.

The volumes slurry water and water that was trapped within the tailings were calculated using the values as given in Table 6-3.

Table 6-3. Tailings slurry and tailings properties

Tailings properties	
SG	2.90
Void ratio	0.77
Slurry ratio	0.40

It should be noted that normally a small watershed in the Lupin area experiences two runoff periods. The first runoff period, representing the largest concentrated flow, takes place during the spring snow melt, occurring generally in late May. Snow melt occurs over a short period of about a week, naturally depending on the air temperature changes. The second runoff period occurs during rainfall events, and is the greatest in July and August and trailing off into September. The snowmelt produces the largest flows but the flows within small watersheds occur over frozen ground. Runoffs from rainfall over small watershed produce smaller flows with a relatively small erosion.

6.2 Water balance before TCA construction

The initial watershed area of the TCA before the construction the diversion of the easterly portion of the watershed was about 710 ha. Diversion of the Long Lake watershed reduced the TCA watershed to 616 ha. The small lakes within the TCA represented about 97.4 ha of water surface. The pre-TCA lakes and water flow directions are shown on Figure 2-4 and the areas of these lakes and the elevations of the water surfaces (based on 1980 survey) are given in Table 2-2.

The water balance of this area is illustrated in Figure 6-2...

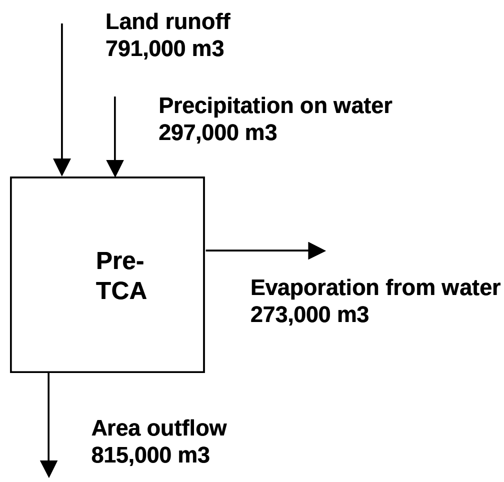

Figure 6-2. Pre TCA construction water balance

Before TCA operation, the area had an inflow of 791,000 m^3 from runoff and 297,000 m^3 total precipitation on the lake surfaces. The latter assumed that the greater snow accumulation on the low lying area was about equal to snow sublimation. The lake water surface lost about 273,000 m^3 of water due to lake evaporation, thereby leaving 815,000 m^3 of water to flow out of the TCA area.

6.3 Water management during operation

Construction of Dams 1a, 2 and 4 changed the water management of TCA. During the initial 5 years, all water inputs into the TCA, precipitation and slurry water were retained within the TCA. This resulted in forming a large pond against Dams 1a and 2 as illustrated in Figure 2-5. From 1985, Lupin began storing the tailings in cells and managing excess water by passing it through a series of ponds to improve the water to meet discharge quality before siphoning the water over Dam 1a annually. Layout of the TCA during 2000 is portrayed in an aerial photo taken in 2000 in Figure 6-3.

During 2000 and the years to the present the tailings were discharged into either cells 2, 3 or 5 (including N) and all excess water, from both precipitation and excess slurry reported to Pond 1, from where it was siphoned annually to Pond 2 and finally after about two years residency in Pond 2, excess water was siphoned over Dam 1a into the West Arm of Contwoyto Lake. Water from individual cells was transferred into Pond 1 as follows:

- Excess precipitation water from Cell 1 flowed through a small channel and culvert located at the easterly end of Dam 3D into the adjacent small lakes and then to Pond 1.
- Excess precipitation and tailings water from Cell 2 seeped through Dam 3 into Pond 1.
- Excess precipitation and tailings water from Cell 3 was siphoned over Dam L into Cell 4 pond from where it was allowed to flow under controlled conditions into the adjacent small lake system that directed the water into Pond 1.
- Excess precipitation and tailings water from Cell 5 was pumped into Pond 1.

The large Ponds 1, 2 and Cell 4 pond increased the water surface of the TCA and inversely decreased the land surface. This in turn increased the precipitation on water surface and correspondingly evaporation from the water. The water balance was further changed by the introduction of tailings slurry water and subsequent storing some of this water within the tailings pores.

Excess water within the TCA was stored temporarily within Ponds 1 and 2. When water levels became high in these ponds and water quality within Pond 2 met the discharge quality criteria, some of the excess water within Pond 2 was siphoned out. The changes in the water levels in Ponds 1 and 2 are given in Figure 6-4.

Figure 6-3. Aerial view of TCA in 2001

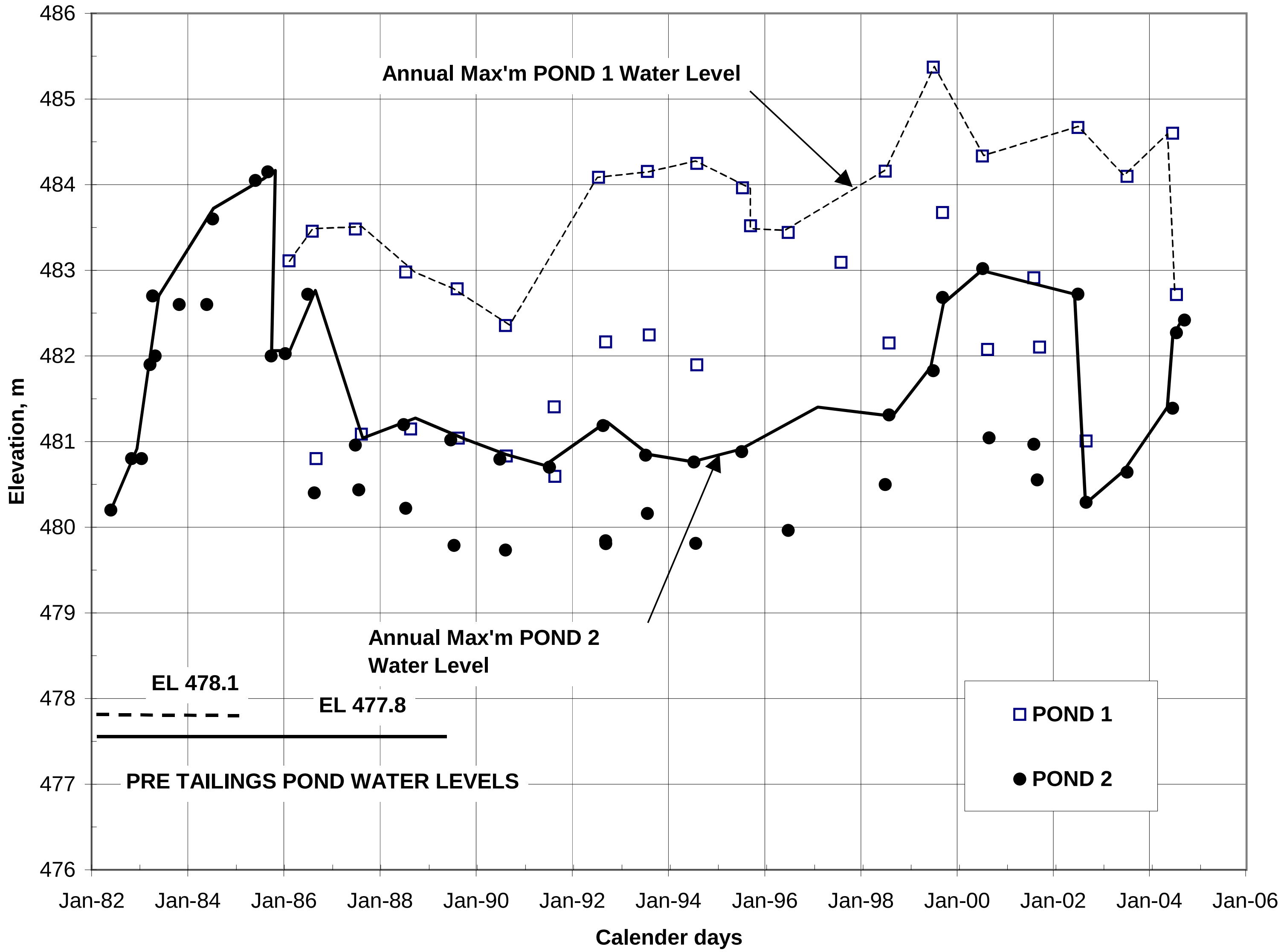

Figure 6-4. Water level fluctuations in Ponds 1 and 2

Water balance analysis over the period from 1985 to 2004 was performed in order to calibrate the parameter used for the water balances before and after construction. A long period of tracking of water in and out of the TCA was necessary because of large fluctuation of tailings production and water discharge from Pond 2 over the years. Tailings discharge into the TCA varied from a maximum of 248,000 and 239,000 tonnes in 1983 and 1993 respectively to minimum values of 6,400 and 3,000 tonnes in 1998 and 1999 respectively. Correspondingly the volume of water that was discharged from Pond 2 varied from 4,400,000 m^3 and 3,100,000 m^3 in 1985 and 2002 respectively to no water discharge in 1998, 1999, 2001, 2003 and 2004.

To obtain the mean annual water balance at the TCA during operation, a spreadsheet calculation was used to follow the continuous water balance from 1982 to 2004. In this calculation, an initial water volume of 2,000,000 m^3 was assumed stored within the existing and the various water balance components were calculated using the actual annual total precipitation, tonnes of tailings solids discharged into the TAC and water volumes that were siphoned out of the TCA.

The results given in Table 6-3 show the final accumulated volume of water over the original lake to be 4,900,000 m^3. This volume corresponds to the increased water level in Pond 2 that is about 5 m above the original water level. This means that the water balance assumptions and parameters that were used in the before and after TCA water balance are realistic. The mean annual water balance at the TCA during operation is shown in Figure 6-5.

The water balance shows that on an mean annual basis, Pond 2 accumulated water at a rate of 212,600 m^3. This resulted in the accumulation of excess stored water volume of 4,900,000 m^3 that will have to be discharged to restore to original water level at Pond 2 and before Dam 1a is breached.

6.4 Surface water after closure

At closure the surface water flows will be returned to pre-TCA construction period as much as possible. This will be done by completing the covering of all tailings with esker sand to prevent potential oxidation of the tailings, breaching Dams 1a and J to re-establish the pre-TCA lakes as far as possible. Erosion of the covered tailings cells will be eliminated by the fact that each cell represents a small watershed, and therefore it will produce only small water flows. Channels through bedrock will direct these flows to the re-established lakes. Lakes and flows of water after closure are illustrated on Figure 6-7.

Year	Total	Precip	Land	Lake	Tails solids	Slurry	Storage	Net	Accumulated	Discharge	Net
	Precip	water	Runoff	Evaporation		water	in tails	water, m3			Accumulated
	mm	m3	m3	m3	tonnes	m3	m3	2,000,000	water	m3	Water, m3
1982	305	1,022,885	1,127,285	939,042	141,734	212,601	37,633	1,386,097	3,386,097		3,386,097
1983	379.9	1,274,078	1,404,117	939,042	247,960	371,940	65,838	2,045,256	5,431,353		5,431,353
1984	330.5	1,108,404	1,221,534	939,042	***180,000***	270,000	47,793	1,613,104	7,044,457		7,044,457
1985	306.7	1,028,586	1,133,569	939,042	178,018	267,027	47,267	1,442,873	8,487,330	4,413,507	4,073,823
1986	303.4	1,017,519	1,121,372	939,042	183,764	275,646	48,793	1,426,702	9,914,032	4,126,199	1,374,326
1987	335.2	1,124,167	1,238,905	939,042	193,204	289,806	51,299	1,662,538	11,576,570	1,142,687	1,894,177
1988	233.4	782,758	862,651	939,042	193,592	290,388	51,402	945,353	12,521,923	1,163,214	1,676,316
1989	219.1	734,800	809,798	939,042	196,509	294,764	52,177	848,143	13,370,066	1,162,239	1,362,220
1990	233.8	784,100	864,129	939,042	197,318	295,977	52,391	952,773	14,322,839	837,246	1,477,747
1991	322.3	1,080,904	1,191,227	939,042	206,893	310,340	54,934	1,588,495	15,911,334	771,280	2,294,962
1992	250.7	840,778	926,592	939,042	216,302	324,453	57,432	1,095,349	17,006,682	1,214,636	2,175,674
1993	285	955,810	1,053,365	939,042	238,696	358,044	63,378	1,364,800	18,371,482	704,575	2,835,899
1994	249.8	837,759	923,265	939,042	232,189	348,284	61,650	1,108,616	19,480,098	863,868	3,080,647
1995	319	1,069,837	1,179,030	939,042	130,930	196,395	34,764	1,471,456	20,951,554	938,715	3,613,388
1996	405.7	1,360,604	1,499,475	939,042	141,013	211,520	37,441	2,095,115	23,046,669	1,139,233	4,569,270
1997	260.5	873,644	962,813	939,042	151,240	226,860	40,157	1,084,118	24,130,788	2,892,289	2,761,100
1998	360.4	1,208,681	1,332,045	939,042	6,381	9,572	1,694	1,609,561	25,740,349		4,370,661
1999	372.8	1,250,267	1,377,876	939,042	2,993	4,490	795	1,692,796	27,433,144		6,063,456
2000	253.8	851,174	938,049	939,042	120,831	181,247	32,083	999,346	28,432,490	2,701,360	4,361,442
2001	285.6	957,822	1,055,583	939,042	148,355	222,532	39,391	1,257,505	29,689,996		5,618,948
2002	339.6	1,138,923	1,255,168	939,042	146,022	219,033	38,771	1,635,311	31,325,307	3,102,895	4,151,364
2003	293.1	982,975	1,083,303	939,042	88,620	132,930	23,530	1,236,637	32,561,943		5,388,000
2004	337.8	1,132,887	1,248,515	939,042	47,359	71,039	12,575	1,500,824	34,062,767		6,888,824
Total					3,589,923			32,062,767		27,173,943	
Avg	303.55	1,018,233	1,122,159	939,042	156,084	234,125	41,443	1,394,033		1,181,476	
									Annual	Average	212,558
									Total water volume differer		4,888,824

Table 6-4 . Spreadsheet of annual water balance components at TCA from 1982 to 2004

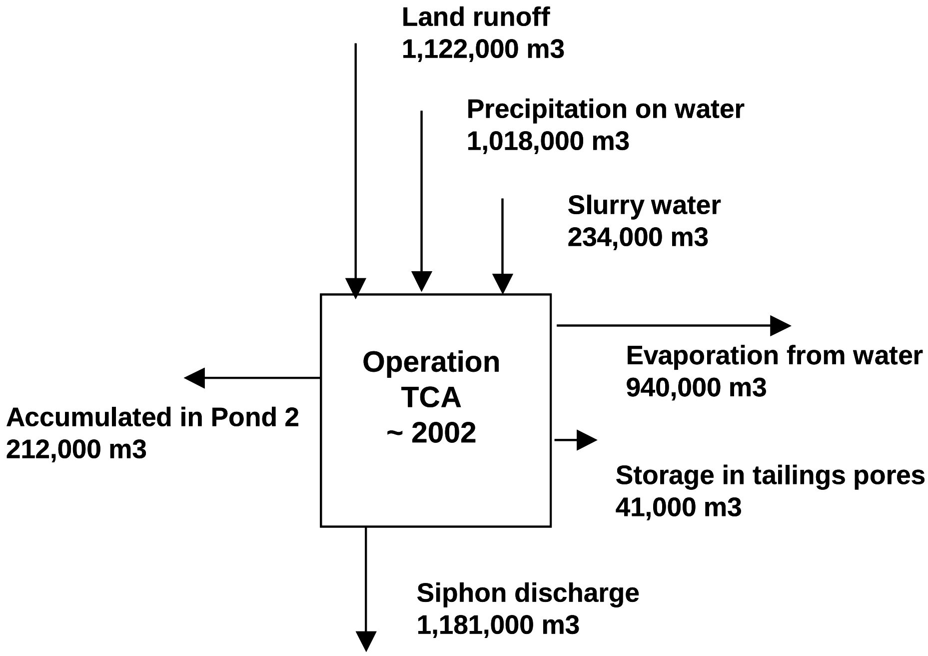

Figure 6-5. Mean TCA water balance during operation

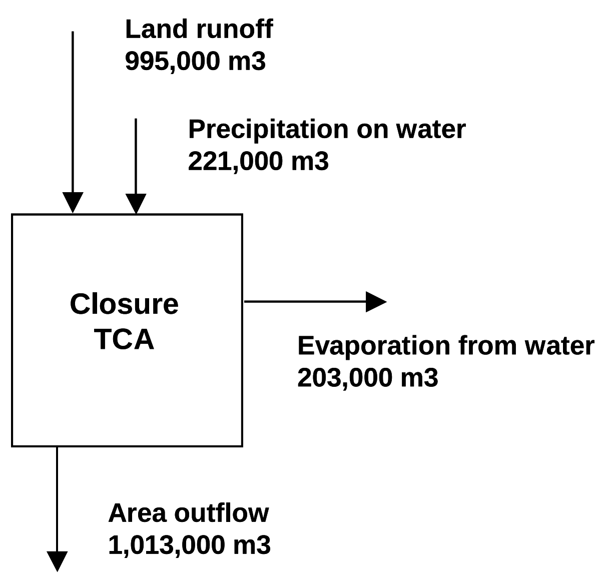

Figure 6-6. TCA water balance after closure

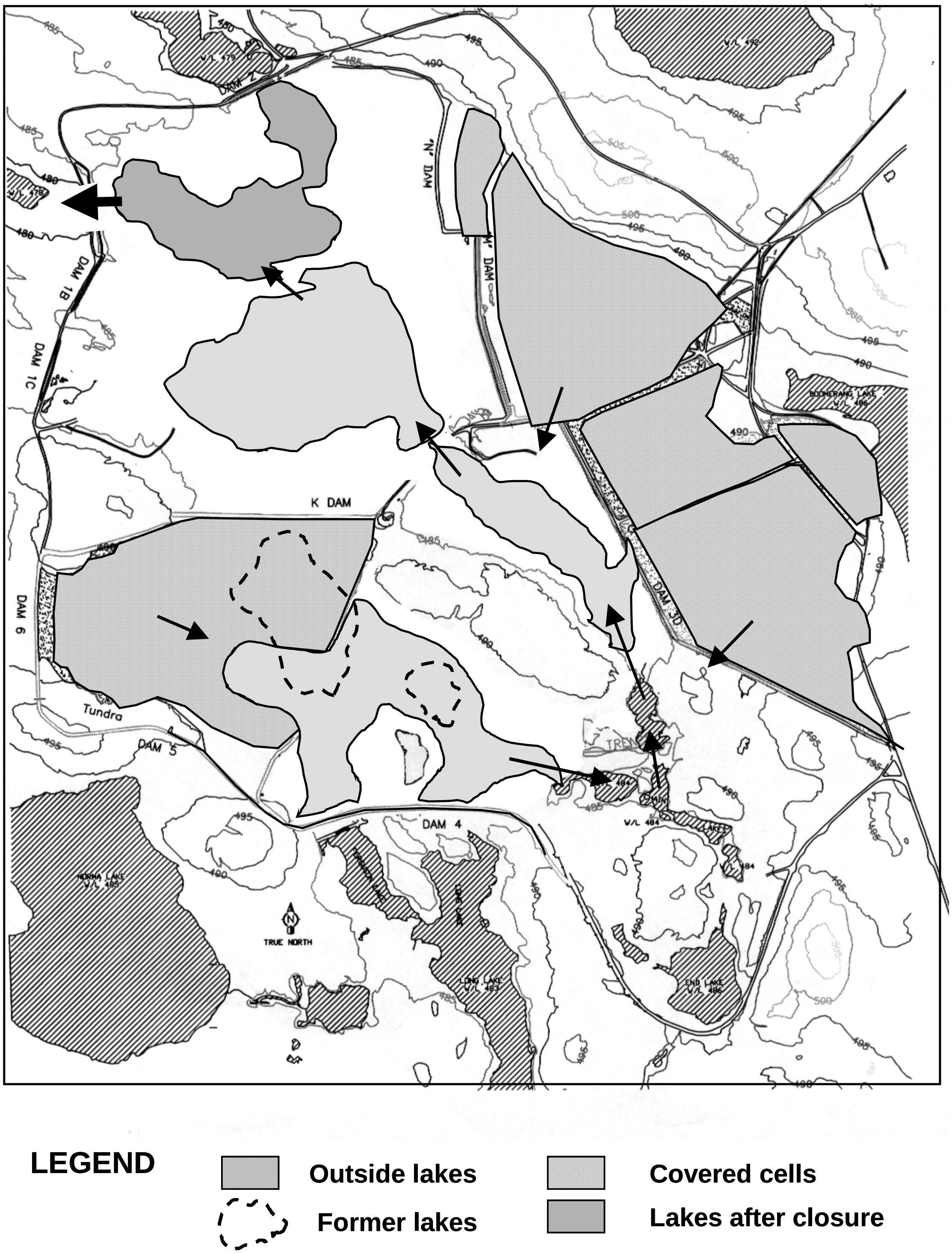

Figure 6-7. Surface water management after closure

6.5 Observations

The results of the annual water balance before, during operation and after closure at the TCA are summarized in Table 6-5.

Table 6-5. Summary of annual water balance before, during operation and after closure at the TCA

WATER TO TCA	Pre tailings	Operation ~2002	After Closure
Precipitation land runoff	790,870	1,122,159	994,427
Precipitation on water	297,070	1,018,233	221,430
Slurry water		234,125	
Total in	1,087,940	2,374,518	1,215,857
WATER LOSS			
Evaporation from water	272,720	939,042	203,280
Storage in tailings pores		41,443	
Mean annual syphon out		1,181,476	
Mean TCA outflow	815,220		1,012,577
Total out	1,087,940	2,161,960	1,215,857
Annual water accumulation in Pond 2		212,558	

The observations that can be made from these results are:

- The operation phase experience much greater water inflows into the TCA and this was compensated by much larger evaporation from water surfaces; the total water surface being more than three times the before TCA and storage of water within the tailings pore space.
- After closure, the TCA will discharge about 12 percent more water from the same watershed as before TCA construction. The reason for this is that there will be correspondingly smaller water surface for evaporation.

7.0 LONGTERM STABILITY OF EARTH STRUCTURES

7.1 General

The TCA contains a number of earth structures that are referred to as dams. The dams were classified as perimeter dams, small perimeter saddle dams and internal dams in Table 3-1. The purpose, physical structure and condition of these dams are different for the perimeter and internal dams.

7.2 Perimeter Dams

Perimeter dams were constructed to retain water during the operation phase and it is proposed to terminate their function as water retention structures at the closure of TCA. Dams 1a and 2 are the largest of the 8 perimeter dams, including the two small perimeter saddle dams 1b and 1c. The maximum height of these two dams is 7.9 m and 5.9 m respectively. After closure of operations, and after water quality within Pond 1 and Pond 2 meets discharge limits, water will be lowered in the two ponds to about pre-project levels by breaching both Dam 1a and J Dam. Lowering of the water level in Pond 2 will result in Dam 2 becoming an earth berm resting on ground above the pre-project water level.

Dam 3 was constructed to isolate Boomerang Lake from the TCA. In 1985, the area behind Dam 3 was developed as a tailings storage cell (Cell 1a), filled with tails, then capped with an esker cover to Dam 3 crest level. The Dam 3 section has become an earth buttress containing a small height (about 2m) of tailings.

Dam 4 was constructed to redirect the flow of water from Long Lake watershed eastward. It acts as a saddle that causes water to flow either west to Pond 1 or east towards Contwoyto Lake. Dam 4, which is 40 to 50 m wide toe to toe, will be left in place between the two adjacent watersheds.

Dams 5, 6, 1b and 1c are small perimeter dams with total height varying between 1 and 2.5 m. They are located along the TCA watershed perimeter and were constructed to contain water in case of extreme water level rise within the TCA. There will be no need to provide high water level protection once Dam 1a is breached. After closure these dams will become higher ridges along the watershed divide.

7.3 Internal Dams

There were eight perimeter dams (Table 3-1) during the operation of the TCA.

- Two of these dams (3C and 3E) have been absorbed within tailings and esker cover material when these materials were placed on both sides of these dams.
- Two dams (J and L) will be breached upon closure of the TCA.
- Remaining dams 3D, K, M and N will be converted into earth buttresses containing solid tailings; without any ponded water.

7.3.1 3D Dam

This dam is a massive earth berm that retains tailings. Figure B 11 illustrates the cross section of this dam. It consists of a gravelly sand (esker) berm with a crest of more than 10 m buttressed by about 10 m of mine rock. Tailings and an esker cover were placed to be level with the dam crest. Presently Pond 1 water saturates the downstream face of 3D Dam. However, upon closure when J Dam and Dam 1a are breached, the Pond 1 water level will drop to just above the toe of the remaining structure with the exception of a short distance that was the outlet of a small lake that was covered by Cell 1 tailings.

The proposed closure plan of the Cell 1 tailings area is to keep draining the surface water from Cell 1 by means of a channel through bedrock at the east end of Dam 3D and grade small part of the mine rock zone to ensure long-term stability of the Dam 3D structure. Since this dam will not retain water, it can be considered as an earth structure.

7.3.2 K Dam

This dam was constructed as a wide earth structure, with an upstream liner, from which tailings were discharged into Cell 3. The resulting tailings Cell 3 is shown in Figure B 16.

Upon closure, Pond 2 water level will drop by about 2 m and thereby resulting in the entire K Dam downstream slope being above water. Tailings within Cell 3 are being presently covered. Figure B 16 shows that the K Dam earth structure will be more than 400 m from any upstream water.

It is proposed to place a rock fill blanket/buttress, at a 2.5H:1V slope, on the downstream side of K Dam to ensure long-term physical and erosion stability of this earth structure. The geometry of the rock fill was developed by slope stability analyses discussed in a subsequent section.

7.3.3 M Dam

This dam was constructed to contain tailings within Cell 5. It consists of gravelly sand fill lined with rock fill riprap on the downstream side. The profile of this dam with contained tailings is shown on Figure B 19. At closure the remaining water upstream of M Dam will be replaced by tailings and gravelly sand cover. All surface water will be discharged from Cell 5 by a channel constructed through bedrock located at the southeast corner of Cell 5. The downstream slope of M Dam will be covered with blanket/buttress of rock fill, at a final 2:1 slope.

At closure of the TCA, M Dam will become an earth zone that provides physical and erosion stability for Cell 5 tailings. The long-term stability is discussed in a later section.

7.3.4 N Dam

This dam is the smallest of the internal dams containing tailings. It will receive similar closure treatment to the M Dam and become a buttressing berm to M Dam.

7.4 Stability of internal dams

7.4.1 General

The physical stability of the four internal dam structures will change as operation phase changes to reclamation and abandonment, and as the effect of global warming will likely thaw the permafrost. Presently all four internal dams (3D, K, M and N) are frozen. This results in the foundation and dam section to be impermeable and creating strong physical stability due to high strength of the frozen materials. Lupin has chosen to consider the likelihood that global warming may thaw the permafrost at the site and will modify the downstream slopes of the internal dams to be physically stable in the unfrozen condition. To develop the final geometry design of these dams, thawed dams were first analyzed with existing geometry and than a final geometry was developed based on long-term physical and erosion stability.

7.4.2 Dam Safety

Dam Safety Guidelines were developed by the Canadian Dam Association (1999) to apply to dams that are at least 2.5 m high and which have at least 30,000 m^3 of reservoir capacity. The guidelines also apply to tailings dams if the reservoir contents could be released and have an unacceptable impact on the environment.

If a dam falls under the dam safety guidelines, it has to meet the physical stability criteria given by a minimum factor of safety for static conditions of 1.5, and generally 1.1 for seismic conditions. It also has to be able to pass maximum flood flows and have a minimum freeboard. Dams require annual geotechnical inspections (required by Water Boards) and Dam Safety Reviews every 5 to 10 years depending on consequence category given by the Dam Safety Guidelines.

The above dam safety requirements are practically impossible to meet at a closed facility on a long-term basis because of access and unknown changes. Therefore it is highly preferable not to leave any dams behind once a mine site is closed.

The internal Dams 3D, K, M and N do not fall under the Dam Safety Guidelines because they do not, and will not, store any water behind the earth structure after closure, and a physical failure of any of these structures will have practically no environmental impact. Dams 3D, M and N will not have any reservoirs since all surface water will be directed out of the watershed areas by channels.

The physical stability of the 3D, K, M and N earth structures do not have to meet the minimum Factor of Safety for static assessment of 1.50 since they will not fall under the dam classification (retaining water) after abandonment. The Lupin earth structures, that are now buttressing tailings with no pond, correspond to earth embankments that are designed with smaller minimum factors of safety than 1.5. For instance, highway embankments with similar height are normally designed with a minimum Factor of Safety greater than 1.3 (author's experience). Another argument for smaller minimum factor of safety is obtained from Dam Safety Guidelines recommending that the dam embankment, at the end of construction before reservoir filling, should have a minimum of 1.3.

Lupin has adopted a minimum Factor of Safety for the long-term stability of earth structures, such as the 3D, K, M and N, which will be equal to or greater than 1.50.

7.4.3 Stability conditions and assumed material properties

Stability conditions of 3D, K, M and N earth structures have been analyzed for three conditions, namely:

- Present, frozen core and foundation.
- Existing structures, thawed core and foundation due to global warming
- Closure design, thawed core and foundation due to global warming.

Selection of strength parameters of frozen materials for the slope stability analyses is difficult because the frozen strengths are dependent on particle matrix, ice content and temperature of the frozen material and the selected design creep rate. The frozen materials with high ice content creep under stress and therefore a creep frozen strength based on a creep rate has to be used. Because of the difficulty to determine appropriate frozen strength, normal practice is to base the frozen strength on a broad spectrum of published test results and confirmed with some creep strength testing. This method was adopted in the Diavik PKC (tailings) dams that were constructed on ice rich soils and will have a final height of 42 m. A relationship between frozen creep strength of three types of soils and different ice contents is shown in Figure 7-1.

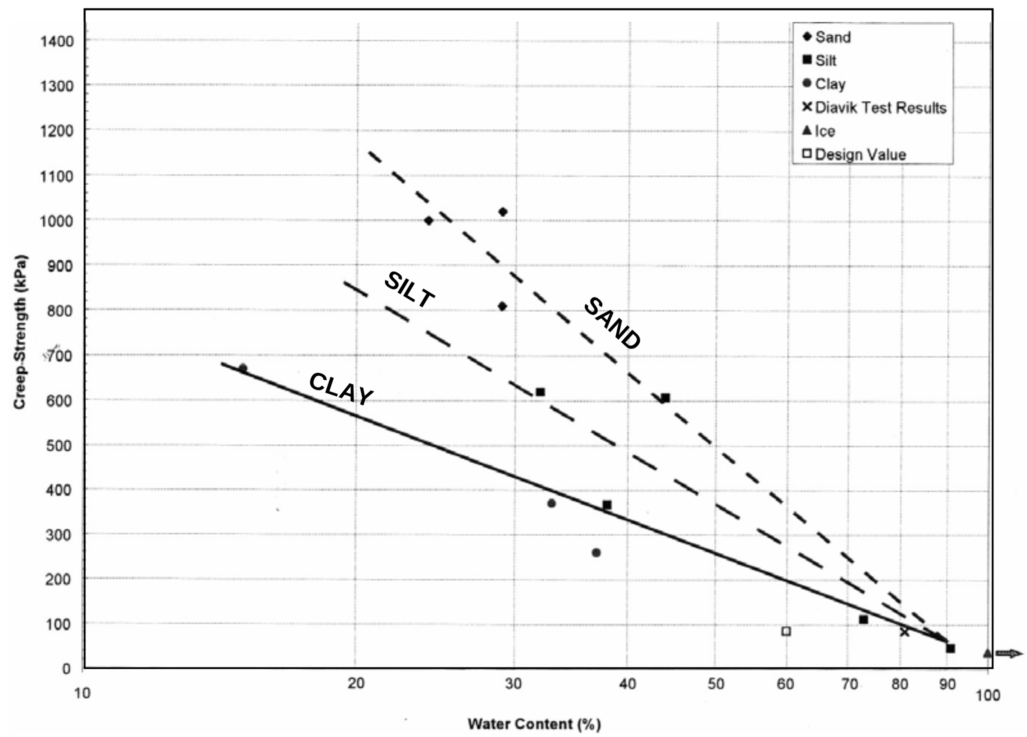

Figure 7-1. Frozen creep strength at –2º C versus ice content given in terms of water content (Diavik 1999)

For the stability analyses of the Lupin earth structures, the earth structures can be represented by three materials: a) sandy esker dam core and the underlying thin silty sand foundation as one material, b) tailings and c) downstream rock fill zone as rockfill. These structures are founded on bedrock that is assumed infinitely strong. The frozen strength is based on the mean temperature of the earth structure during summer to be –2º C and the creep rate is 1 m over a 10-year period. The frozen creep strength (very conservative) and strength properties selected for the three materials are given in Table 7-1.

Table 7-1. Parameters selected for stability analyses

Material		Frozen		Thawed	
	Unit Weight kN/m^3	Cohesion kPa	Friction angle degrees°	Cohesion kPa	Friction angle degrees
Rockfill	20	0	40	0	40
Tailings	16	200	0	3	30
Esker & silty sand	20	300	0	0	33
Bedrock		Infinitely strong			

7.4.4 Stability analyses results

Stability analyses of the three main earth structures (3D, K and M dams) were conducted for the three conditions (frozen, thawed and closure design, thawed). The analyses were conducted using the G Slope program prepared by Mitre Software Corporation. The results are given in Appendix D and summarized in Table 7-2.

Table 7-2. Summary of stability analyses

Dam	Existing frozen dam		Thawed dam with different GWL			Closure geometry Berm slopes		
	Thru Rock berm	Thru Esker Section	HWL	LWL	Likely	Static		Seismic
						2h:1v	2.5h:1v	2.5h:1v
K Dam		8.8	0.96	1.21		1.63	2.11	2.02
3D Dam	1.4	8.5			1.51		2.04	1.95
M Dam		8.1			1.32	1.62	1.91	1.82

Comments of the results are:

7.4.5 K Dam earth structure

The existing structure has a very high minimum factor of safety (8.8) under the existing frozen condition. However, if the geometry of the K Dam was left as it exists, it would have poor stability under thawed conditions that would develop under a global warming condition. Depending on assumed groundwater surface within the dam, the minimum factor of safety would be between 0.96 (high groundwater level) and 1.21 (low groundwater level).

Placing a rockfill stabilizing berm on the downstream face will raise the minimum factor of safety to 1.63 for a downstream slope of 2 horizontal to 1 vertical, and to 2.11 for a slope of 2.5 horizontal to 1 vertical. Both downstream slopes are satisfactory. Final closure slope will be between 2H:1V and 2.5H:1V to be determined by the construction equipment.

As with K dam, the existing 3D Dam under the present frozen condition has a very high minimum factor of safety of 8.5. Upon global warming thawing, the stability of the dam will decrease to a minimum factor of safety of 1.51 that would be adequate for an earth structure. However, because of the presence of a 10 m wide rockfill berm on the downstream side, it is proposed to re-grade this berm to form a slope of 2.5H:1V which will raise the minimum factor of safety to 2.04.

7.4.6 M Dam earth structure

As with K and 3D dams, the existing dam under the present frozen condition has a very high minimum factor of safety of 8.1. Upon global warming thawing, this earth structure will have a marginal minimum factor of safety of 1.32 for the long-term closure condition. It is proposed to place a rockfill zone on the downstream face. A rockfill zone of 2H:1V will produce a minimum factor of safety of 1.62, and a 2.5H:1V slope will raise the minimum factor of safety to 1.91. Final closure slope will be between 2H:1V and 2.5H:1V to be determined by the construction equipment.

7.4.7 Seismic Conditions

Seismic stability analyses were conducted on the final closure design geometry. The results shown for final slopes of 2.5H:1V show the static minimum factors of safety to drop about 5% when earthquake acceleration is applied to these earth structures. Considering that much lower minimum factors are accepted for earthquake loading, the final closure design structures will have very satisfactory minimum factors of safety.

8.0 TAILINGS COVER

8.1 General

Tailings at Lupin were observed to have a potential for acid drainage, if the tailings were exposed to prolonged weathering (Klohn-Crippen 1995). Lupin started to cover exposed tailings in completed cells in 1988 and monitoring the covered tailings to assess the effectiveness of the covers. As a result, Lupin has collected the most extensive and longest observed performance records of covered cells in permafrost areas.

Data collected includes ground temperatures, water levels within the cover, water quality within the cover, slope of tailings surface, thickness of tailings deposition, moisture content of the cover, and particle size analyses of tailings and cover materials. Various studies have determined the durability (physical and chemical) of the cover material, water balance within the cover during drought conditions, and pore water expulsion potential from the compacted tailings during thaw conditions (Golder 2004). Test pits excavated through the cover to the tailings surface were examined for evidence of cryoturbation, oxidation at the tailings interface, presence of ice lenses, and condition of the tailings/cover interface.

Based on this data and research on tailings covers in southern areas, Lupin proposed to place a p*artially saturated granular cover* over the tailings. The concept was described in a paper (Holubec, 2003a) and as a report (Partially Saturated Granular Cover for Lupin Mine Tailings, Holubec 2003b) transmitted to Nunavut Water Board in March 2004 as an Appendix to the *2004 Lupin TCA Management Report*. Since the submission of that report, the name of the cover has been modified to *saturated zone cover,* which represents a more accurate description of the design.

In 2004, Lupin continued to monitor the various covered cell instrumentation, and has collected additional information to validate the effectiveness of the saturated zone cover.

8.2 Saturated Zone Cover

Oxidation of potentially acid drainage tailings needs to be prevented to avert metal loading into receiving waters. In southern regions with no permafrost, this is accomplished with dry or water covers. Since these are not viable in continuous permafrost regions, such as exist at Lupin, many mines in continuous permafrost have been adopting the concept of encapsulating tailings in permafrost. This involves placing a granular cover over the tailings that will maintain the annual thaw zone (active layer) within the cover. Field test cover trials at 3 mines in Nunavut and northern Quebec (Holubec 2004) have shown that increased saturation within the cover will decrease the required cover thickness. The saturation within the cover provides the same benefit as a water cover, whereby tailings oxidation is prevented even if the tailings are unfrozen. While I. Holubec Consulting Inc. (Holubec 2003b) suggests a saturated zone of 0.3 m, any depth of water over the tailings will provide an adequate oxygen barrier to prevent oxidation.

The saturated zone cover concept consists of two layers;

a) A surface layer that lowers the rate of evaporation of the saturated base esker material, and
b) A lower saturated layer that prevents oxidation of the tailings.

It is based on a *stagnant water cover* design concept investigated by Li et al (1997) and column testing by CANMET (MEND 5.4.2d) demonstrating that in absence of water movement, even a small depth of water greatly inhibits oxidation.

The proposed thin partially saturated granular cover has many positive attributes, such as:

- Provides a water oxygen barrier that is not dependent on having permafrost within the tailings.
- Is not sensitive to annual temperature changes or global warming.
- Will support vegetation because of the proximity of the water surface to the top of the cover.
- If esker material is used for cover material, it decreases the required volumes and thereby reduces the disturbance of the esker deposits. Eskers serve as a preferable animal habitat.

8.3 Past Cell 1a and 1 Monitoring

Cells 1a and 1 were covered with a sandy material in 1988 and 1995. This material was obtained from a large esker deposit, Fingers Lake Esker, which is located about 5 km south of the TCA. The cover thickness varies from about 0.6 to 1.5 m. In 1988 Lupin started a monitoring program to increase their understanding of: a) development of permafrost within the covered tailings; b) effect of cover thickness on the active layer, and c) water quality within the cover system and ponded water within the cell.

Since 1988, five monitoring programs have been instituted on the covered cells to confirm the final cover design. The instrumentation used to monitor the cells consisted of the following:

a) Three thermistors installed in Cell 1a in 1988.
b) In 1995, two thermistor strings were installed in Cell 1a (to replace the inactive 1988 strings), 3 were installed in Cell 1 and 1 was installed in Cell 2.
c) In 1998 two water-sampling pipes were installed within the esker material in Cell 1 to monitor the water quality within the pores.

d) In the summer of 2002 nine additional pipes were installed in the esker cover material in Cell 1 to monitor the water level and water quality within esker cover of Cell 1.

e) At the end of spring 2003, a test area was constructed in Cell 1 to monitor the water balance within the esker cover under more controlled conditions.

The first set of thermistors installed in 1988 in Cell 1a, adjacent to Boomerang Lake, showed the tailings to be frozen one year after cover placement. The tailings thickness was relatively thin, averaging about 3 m.

In October 1995 six thermistor strings were installed in Cells 1 and 2 to monitor the seasonal fluctuation of the active layer in areas where the tailings were covered with esker sand (Klohn-Crippen 1997). The location of these strings is shown on Figure 8-1. The operational life of these thermistors varied from 1 to 5 ½ years, with one still in operation after 9 years. Thermistor identification, location, and the last monthly reading, are given in Table 8-1. All these thermistor strings were installed to a depth of 13m.

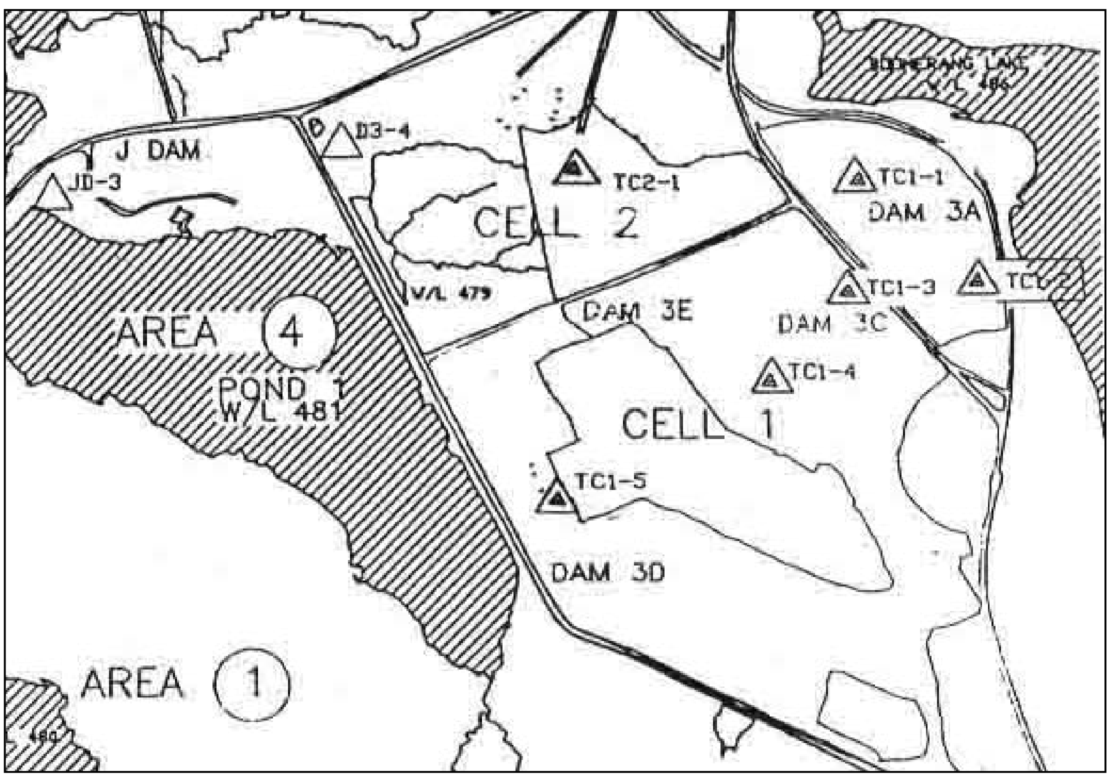

Figure 8-1. 1995 Thermistor installation in Cells 1a and 1

The maximum thickness of the active layer and the 'steady' ground temperature observed in 1996 are summarized in Table 8-2. It should be noted that the location of the groundwater surface at these locations is not known.

Table 8-1. 1995 Thermistor string installation summary

Thermistor	Location	Cover Thickness, m	Tailings Thickness, m	Stopped Operating
TC1-1	Cell 1a	0.9	+13	Oct 2000
TC1-2	Cell 1a	1.2	+13	Dec 1997
TC1-3	Cell 1	1.2	4.6	Operating
TC1-4	Cell 1	0.6	10.6	Dec 1999
TC1-5	Cell 1	1.6	11.7	Dec 1997
TC2-1	Cell 2	0.9	5.3	Dec 1999

Table 8-2. Permafrost performance at 6 locations observed in 1996

Thermistor	Cover Thickness, m	Active layer Thickness, m	Temperature at 13 m, ºC
TC1-1	0.9	1.5	-5
TC1-2	1.2	1.7	-6
TC1-3	0.6	1.2	-7
TC1-4	0.6	1.7	-3
TC1-5	1.6	1.8	-4.5
TC2-1	0.9	1.8	-6

Relating the active layer (thaw depth) to the thickness of esker cover in Figure 8-2 shows that by increasing the cover thickness, the active layer or depth thaw becomes greater.

In the absence of knowing the groundwater depth at each of these thermistors, water content of the saturated zone and the moisture content of the surface unsaturated zone, it is difficult to make definite comments on the Figure 8-2 relationship. Generalized conclusions that can be made are from the observations that: 1) the groundwater surface was at or is near the bottom of the esker cover and 2) tailings beneath the cover are completely or nearly fully saturated. Based on these assumptions, the relationship in Figure 8-2 indicates the following for the Lupin site:

a) Saturated tailings without a cover would experience a thaw depth of 1.3m.
b) To encapsulate the tailings completely with sand and gravel would require a minimum 2m cover plus additional thickness for warm years and other uncertainties.

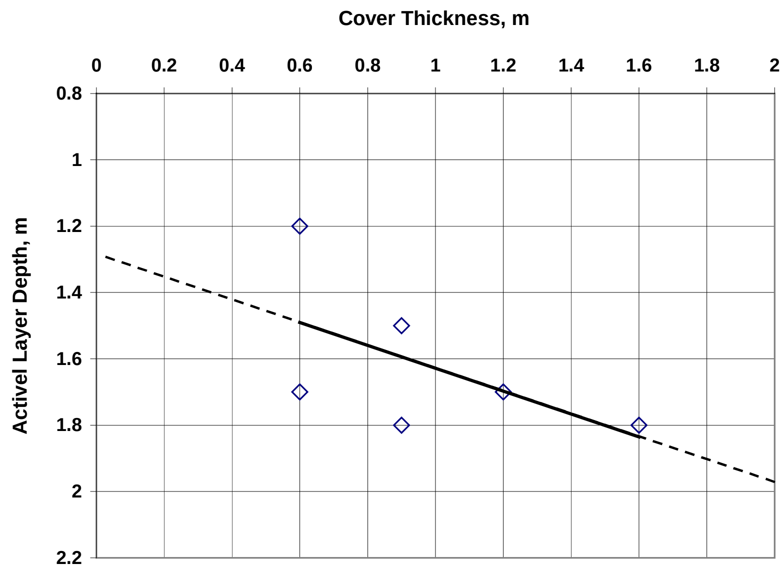

Figure 8-2. Thaw depth related to Lupin esker cover thickness

The progression of the active layer in and out of the cover and its changes over the years can be seen in the data of thermistor string TC1-3, which has been providing data since November 1995. The thaw depth progression for the 7 years between 1996 and 2002 is shown on Figure 8-3. At this location the thaw depth varied from 1.15 to 1.35 m during this period of monitoring. The cover at this location is 1.2m.

Figure 8-3 also illustrates that: a) thaw depth penetrated into the tailings by about 0.4m, b) unfrozen conditions lasted for less than 3 months and c) during this period the temperature within the thawed tailings reached a maximum of 5ºC. This temperature was interpreted from individual thermistor bead locations and likely due to the variation of snow cover.

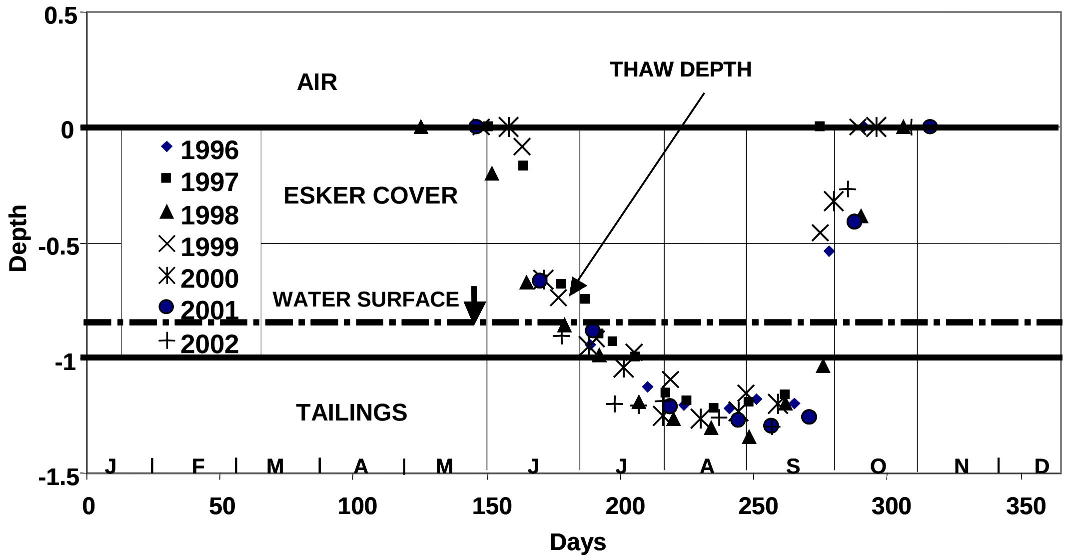

Figure 8-3. Thaw depth changes in esker covered tailings over a 7 year period, TC1-3

The thaw depth for the seven years (1996 to 2002) was plotted against the thawing index at Lupin for the same years respectively (Figure 8-4). This shows a good relationship between thaw depth and thawing index. The fluctuation of the data near the trend line can likely be attributed to the changes observed for the saturation of the esker material.

Monitoring of the esker covered tailings in Cell 1a and Cell 1 shows the following:

- Thickness of the esker varied from 0.6 to 1.6m.
- Active layer (thaw) depth varied from 1.2 to 1.8 m.
- Thaw depth was greatly influenced by the thickness of the saturated zone within the esker material.
- Good correlation between thaw depth and the thawing index.
- Thaw depth will fluctuate because of the variation of summer temperatures (thawing index) from year to year.
- Below the active layer, the tailings were completely frozen with ground temperatures ranging from- 3ºC to - 7ºC at a depth of about 13m.

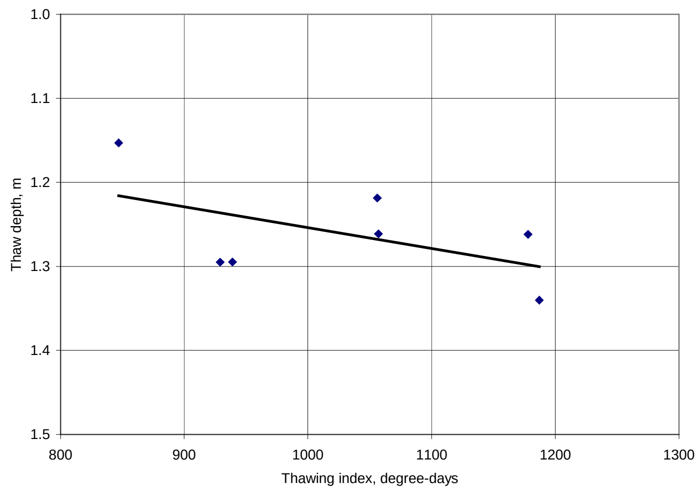

Figure 8-4. Thaw depth as a function of thawing index

8.4 2002 Esker cover groundwater monitoring

Lupin decided to pursue the saturated zone cover concept in 2002 and oriented its field testing and monitoring to confirm the validity of this concept. Nine 1.5-metre long pipes were installed within Cell 1 (Figure 8-5) in the summer of 2002 to:

- Determine accurately the thickness of the esker cover at Cell 1.
- Monitor the saturation level within the esker.
- Obtain water samples from the saturated esker zone.

To ensure that water samples were collected from within the esker pores, the pipes bases were installed about 150mm above the tailings surface. Thickness of the esker cover at the nine pipe locations is given in Table 8-3. Measurements of the esker cover during the installation of the pipes showed that the esker cover thickness varied between 1.0 to 1.3m with an average of 1.1m.

Water levels were measured in these pipes during the summer when the thaw depth reached the saturated zone. The results of this monitoring that extends over three summers, from August 2002 to September 2004, are given in Table 8-4 and are shown in Figure 8-6.

Figure 8-5. Location of pipes installed in 2002

Table 8-3. Esker thickness and saturation level in Cell 1 pipes (Measured in August 2002)

Pipe	Esker Thickness, m
1	1.2
2	1.1
3	1.0
4	1.3
5	1.2
6	1.0
7	1.2
8	1.1
9	1.0
Average	1.1

The saturation zone thickness monitoring in the esker cover of Cell 1 varied from an average of about 0.2 m around the discharge perimeter of Cell 1 (P-1, P-2, P-4 and P-5) to an average of about 0.8 m in the central portion of the Cell (P-5 and P-6). The least saturation was measured in P-2 in August 2004. The variation of the saturation is illustrated in Figure 8-6.

Table 8-4. Thickness of saturated zone in field pipes

Base Data	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9
Cover Thickness	1.17	1.07	0.98	1.30	1.17	1.02	1.23	1.07	1.00
Water saturation depth, m									
03-Aug-02			0.16	0.30	0.89	0.53		0.36	0.16
27-Aug-02		0.25	0.23	0.51	1.12	0.79		0.56	0.18
28-Jul-03	0.20	0.25	0.17	0.32	0.79	0.48	0.17	0.33	0.18
04-Jul-04	0.25	0.32	0.33	0.64	0.80	0.66	0.49	0.38	0.28
08-Aug-04	0.16	0.29	0.16	0.42	0.84	0.50	0.08	0.32	0.16
09-Sep-04	0.18	0.48	0.27	0.74	1.17	0.75		0.56	0.25
10-Sep-04							0.11		
Average thickness of saturated zone	0.20	0.32	0.22	0.49	0.94	0.62	0.21	0.42	0.20

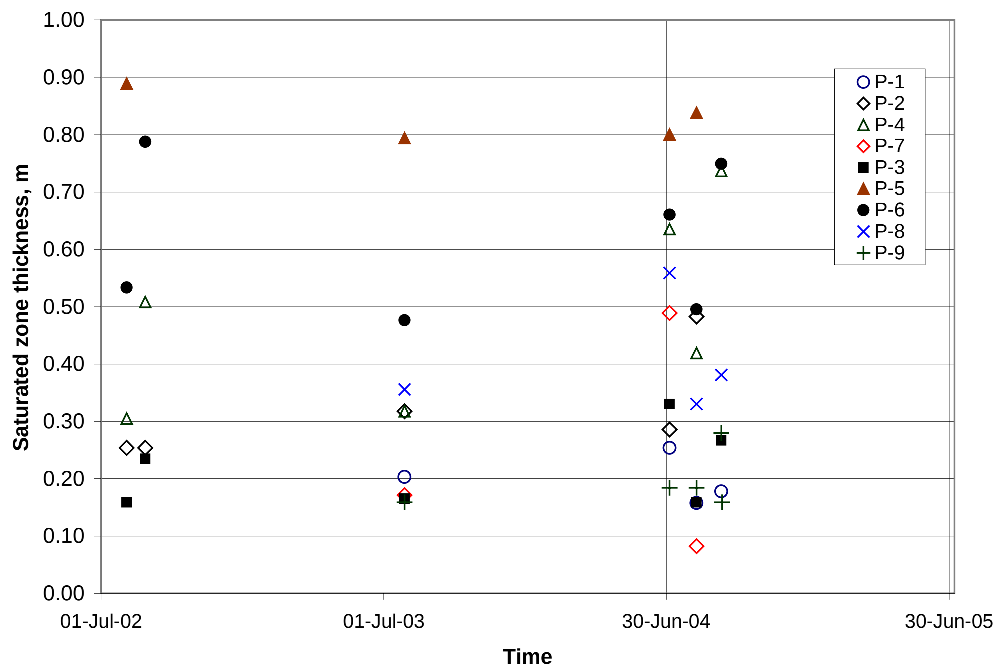

Figure 8-6. Changes of saturation zone thickness in 9 installed pipes

The groundwater profile within the esker cover in Cell 1 is illustrated on four figures (B21, B22, B23 and B24) in Appendix B and in Figure 8-7 that is a repeat of Figure B22. These figures illustrate the groundwater levels within the esker cover on the August 8, 2004.

Figure 8-7 illustrates that groundwater levels drop from a high at the northern edge of Cell 1 to a low near 3D Dam. The greatest depth of saturation is located at the center of Cell 1 at pipes P5 and P6. The reason for the greatest thickness of saturation is that this area presents both the middle of Cell 1 where the finer tailings would settle and also an area that is underlain by a former lake resulting in the greatest thickness of tailings. These two factors would have caused past consolidation of the tailings and depression of the tailings surface that can be seen by the lower base of the esker cover at pipes P5 and P6. The three north-south profiles in Figures B21 to B23 illustrate that the groundwater within the esker cover, when it is thawed during the summer, slopes towards Pond-1.

The four profiles show how the saturated zone within the esker cover varies and demonstrates that the esker cover has a saturated zone at its base.

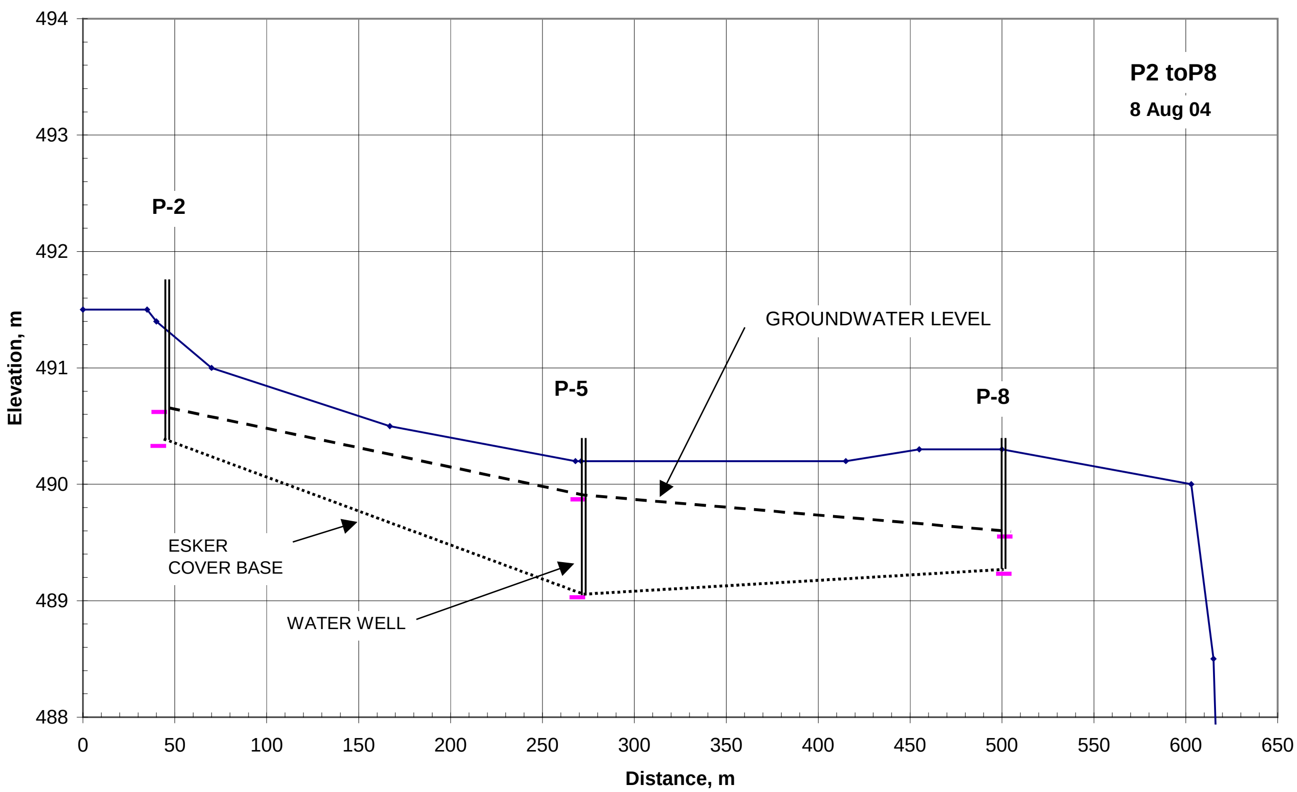

Figure 8-7. Groundwater profile along pipe section P2 to P8

8.5 2003 Test Pad Installation

In May 2003, an isolated test area was developed in the northwest corner of Cell 1. The purpose of the test pad was to determine groundwater level fluctuations due to water recharge and evaporation within the esker zone (saturated zone). The reason for a controlled test pad was that it is difficult to establish this value within the nine installed pipes. This difficulty arises because along the Cell 1 perimeter, where the tailings slurry was discharged, the tailings surface slopes towards the center of the cell and the esker groundwater would flow towards the center. Therefore, the perimeter pipes likely experience a low groundwater level and the central pipes would have high groundwater level. The location of the test pad is shown in Figure 8-8.

The test pad is a 10 m by 50 m enclosure that contains all climatic water within a HDPE wall that is anchored into permafrost. A schematic of the test pad along the long dimension is shown in Figure 8-9. A photo of the test pad installation is shown in Figure 8-10.

At the test pad location the stratigraphy is not completely representative of Cell 1 but it is suitable to provide the water balance within the esker information. At the test pad location, waste rock was placed on top of the tailings prior to being covered with about 0.75 m of esker gravelly sand in 1995. The presence of waste rock was determined during the construction of the test pad after blasting of the trench for the HDPE wall. It is estimated that the waste rock thickness is likely about 1.3 m thick and covers about 5 m of tailings.

The test pad is instrumented with two 1.5m long pipes to be used for measuring groundwater level and obtain water samples for water quality testing, and a 20 m deep thermistor string with 16 temperature sensors.

The two water pipes showed the groundwater level to be about 0.65 m below the ground surface. The groundwater levels in 2003 fluctuate near the base of the pipe because the pipes were not installed sufficiently deep, due to the presence of the waste rock overlying the tailings. In September 2004, the pipes were reinstalled with their base being nearly 1 m deep that gave better results.

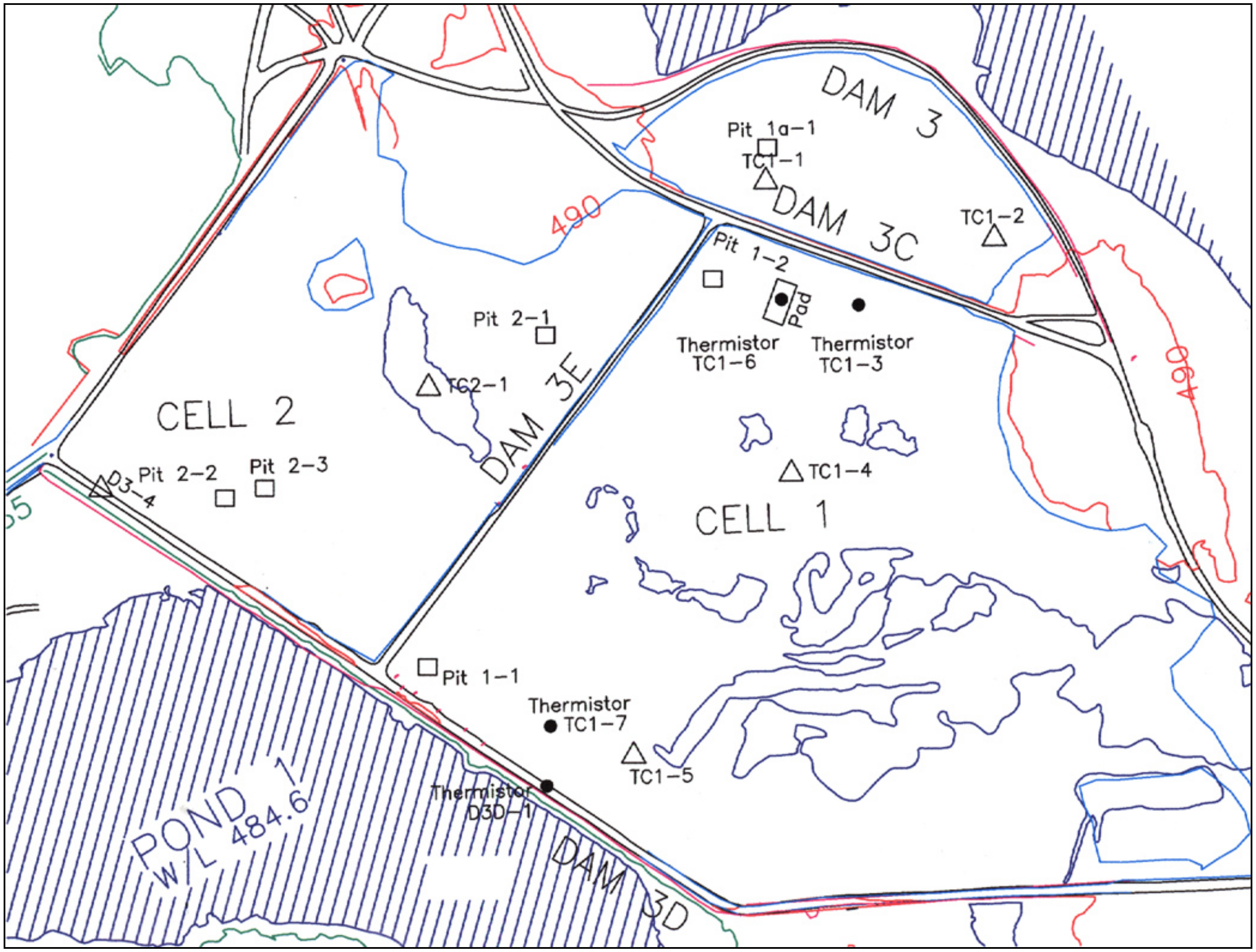

Figure 8-8. Test Pad and monitoring locations

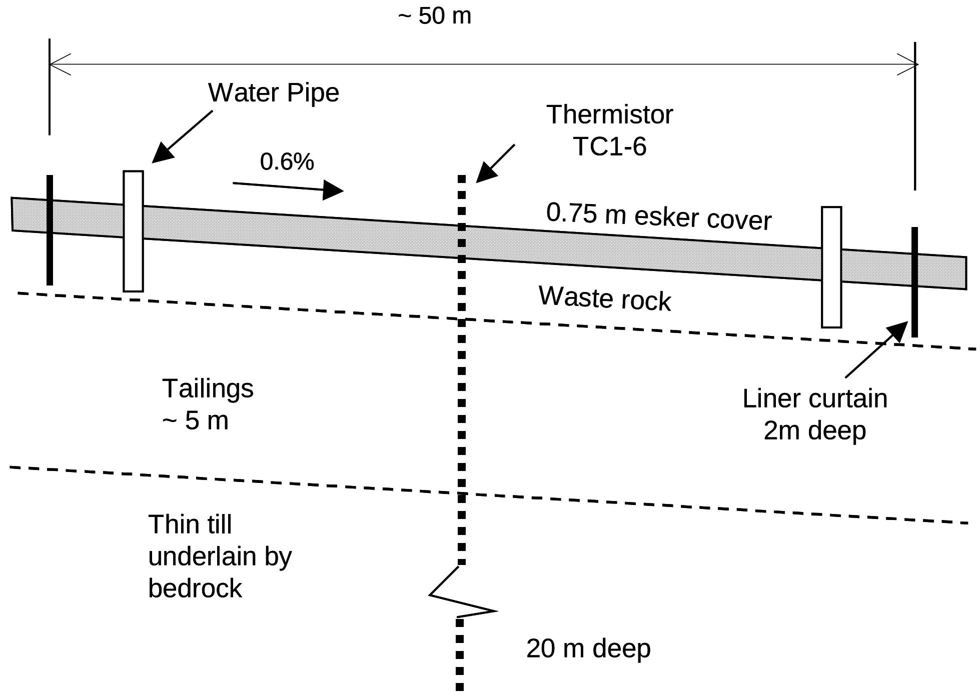

Figure 8-9. Schematic test pad section

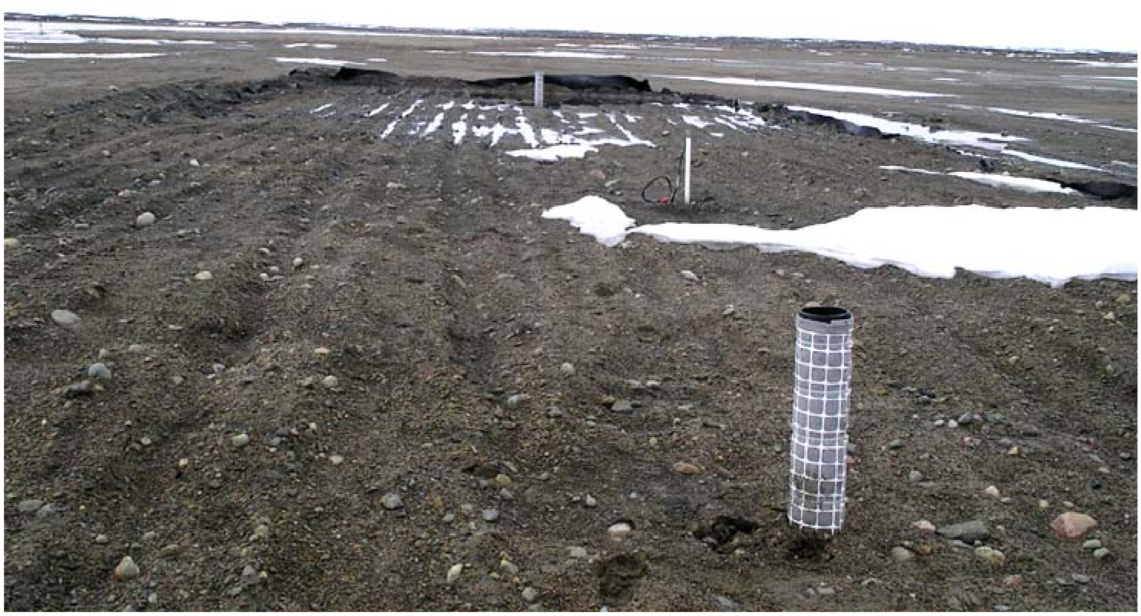

Figure 8-10. Photo of test pad instrumentation

Assuming an average measured esker cover thickness of 1.1 m at Cell 1, the height of the esker saturation zone at the perimeter, test pad and central part of the cell would be:

At cell perimeter	0.20 m
At test pad	0.45 m
At central pond area	0.56 m

Ground temperature measurements at the test pad showed the tailings to be completely frozen, with the active zone reaching a depth of 1.30 m. The ground temperature at the maximum thermistor depth of 20 m, where close to zero ground temperature fluctuation is exhibited, was measured to be -5.1ºC. Ground temperature profile fluctuations measured in 2004, and the thaw depth estimated from the ground temperature profiles, are shown in Figure C 15 and Figure 8-11.

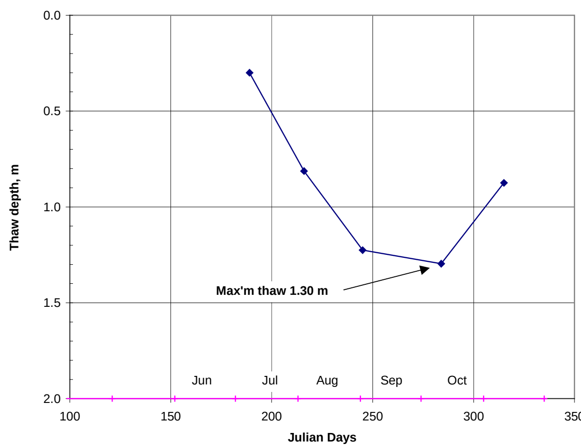

Figure 8-11. Thaw depth changes at test pad (TC1-6)

8.6 Test Pits

8.6.1 General

Nine test pits were dug with an excavator at several locations in Cell 1a, 1, 2 and 3 in September 2004 to gain information on several technical issues. The technical issues were:

- Determine the esker cover thickness and presence of a saturated zone within the cover.
- Penetration of tailings into the esker material as evidence of cryoturbation.
- Presence and degree of oxidation of tailings.

During this program the test pits were logged, photographed and selected samples were taken for moisture content and gradation determination. List of the test pits, their locations, thickness of esker material and brief notes are given in Table 8-5.

Table 8-5. List of test pits

Test Pit	Cell	Esker Thickness (m)	Notes
1-1	1	1.30	Test pit dug to install Pipe 7 to a greater depth. Esker saturated for 0.20 m.
1-2	1	0.76	Reached waste rock layer of unknown thickness at 0.76 m. Encountered water at waste rock interface. Relocated Pipe 1 to Cell 3.
1-3	1	0.69	Dug out pipe at south end of test pad. Encountered waste rock. Re-installed pipe to 0.81 m depth. Encountered high water.
1a-1	1a	1.30	Test pit in Cell 1A (covered in 1988). Base of esker wet; unknown saturation thickness. Esker consists of coarser material.
2-1	2 north	0.90	Base of esker wet; unknown saturation thickness. Minor oxidation at tailings surface. Cell covered in 1995.
2-2	2 south	0.86	Esker saturation zone at least 0.2 m. Base of esker collapsing due to wetness. Fine esker material.
2-3	2 south	1.00	Pit located close to ponded surface water. Fine grained saturated esker material at base of cover; collapsing.
3-1	3	1.30	Test pit located at recently placed (2 weeks previous) cover. Minor oxidation of tailings at surface.
3b-1	3b	0.97	Coarser esker material. Base of test pit collapsing due to material wetness.

The test pit locations are shown on Figure B25 for Cells 1a, 1 and 2 and Figure B26 for Cell 3 and 3b.

8.6.2 Test Pit Description

Test Pit 1-1 was dug in Cell 1 in order to reposition water Pipe 7 that periodically had insufficient water to obtain water samples. At this location the esker thickness was 1.30 m and there was no evidence of tailings penetrating the esker material. Photo 14 shows the test pit excavation with a solid smooth un-oxidized tailings surface at the base. Pipe 7 was installed 0.30 m deeper to a burial depth of 1.30 m.

Test Pit 1-2 was dug in Cell 1 in order to reposition water Pipe 1 that periodically had insufficient water to obtain water samples. The test pit showed that the esker was underlain by waste rock of unknown thickness and water was observed within the waste rock (Photo 15). This pipe location was discontinued because of the presence of the waste rock zone. Better information was available from the nearby Test Pad that had two water pipes.

Test Pit 1-3 was dug in the Test Pad to install the two water pipes at greater depths. Test Pit 1-3 was dug at the south water pipe. Waste rock was encountered at a depth of about 0.69 m below the esker surface. Water was encountered above the waste rock. Thickness of waste rock could not be determined with the limited capacity of the small backhoe. Photos 16 and 17 illustrate the high water table at this location.

Test Pit 1a-1 was dug to investigate the cover thickness and saturation level of the esker in Cell 1a. The thickness of the esker in this location was 1.30 m and its base was wet. The test pit was not open long enough to determine the groundwater level. The top of the tailings and the wet condition at the base of the excavation is shown in Photo 18.

Test Pit 2-1 was dug in the northern area of Cell 2 that received tailings in early 1990 and was covered in 1995. Minor oxidation of tailings at the surface of the tailings was observed, as shown in Photo 19. Esker cover at the base was moist to wet. The presence and thickness of the saturation level could not be determined during the short period of test pit excavation. Esker cover was 0.90 m thick at this location.

Test Pits 2-2 and 2-3 were excavated in the southern area of Cell 2 that was more recently filled with tailings. These test pits were south of a depression that contained pooled water. Test Pit 2-3 was nearly adjacent to the pooled water. The significance of the pooled water is that this area was located near the center of the cell where the smallest tailings particles would have settled and therefore represented the likeliest areas where tailings penetration into the esker could occur. Photos 20 and 23 show that there was no evidence of tailings penetrating the esker material and a high level of saturation portrayed by the collapse of the test pit. The esker cover thickness was 0.86 m and 1.00 m thick respectively.

Test Pit 3-1 was located in an area that was covered by esker material only several weeks earlier. This means that there was not enough time to create a saturated zone by rainfall water infiltration. The dryness at the esker-tailings contact indicates that water was not squeezed out of the tailings by the weight of the esker cover. A water pipe was installed adjacent to this test pit for future water level monitoring.

Test Pit 3b-1 was excavated in Cell 3b that was covered a year earlier in 2003. The esker material was observed to be saturated in the lower third of the cover, with the cover thickness being 0.97 m. Oxidation of the tailings was not observed, as can be seen in Photo 23.

8.6.3 Summary of Test Pit Observations

a) Esker Cover thickness and presence of saturated zone within the esker.
Esker cover thickness was observed to vary from about 0.9 to 1.3 m in areas where the tailings were not covered with a waste rock layer. In the two test pits in the northwest corner of Cell 1, the esker cover was measured to be about 0.7 m. However, in this area the esker material was underlain by a layer of waste rock; approximately 0.5m thick.

b) In all test pits, with the exception of Test Pit 2-1, saturated zone with free water was observed at the base of the esker material. In Test Pit 2-1, free water was not observed during the short exposure of the esker cover base.

c) Penetration of tailings into the esker material and evidence of cryoturbation.
Tailings penetrating into the esker material or evidence of cryoturbation were not observed in any of the test pits. In all test pits, there was a clear linear boundary between these two materials.

d) Presence and degree of oxidation of tailings.
In two of the seven test pits where esker material covers the tailings surface, minor oxidation of the tailings was observed: Test Pits 2-1 and 3-1. In both cases the tailings surface had been exposed for several years before a cover was placed and the depth of oxidation was judged less than 5 mm.

8.7 Laboratory Test Results

8.7.1 Tailings

The most extensive sampling of tailings was done in 1994 (Klohn-Crippen, 1995). During this program 42 tailings samples were taken at various locations from the tailings slurry discharge as shown on Figure B 27. Particle analyses of these samples showed the tailings to have predominantly silt sized particles, representing 73 % of the material. The range of particle sizes are illustrated on Figures B28 and B29. The numbers behind the sample identifications are the depths from which the samples were taken.

A summary of the silt content of these samples is provided in Figure 8-12.

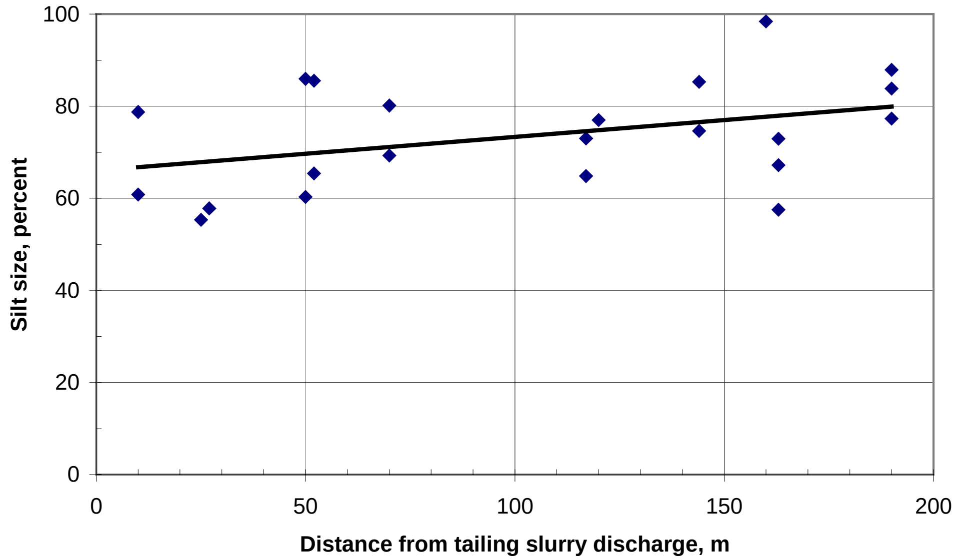

Figure 8-12. Summary of percent silt size particles in tailings (Klohn-Crippen 1995)

Three tailings samples were taken during the 2005-year test pit program and sieve analyses conducted. The results shown on Figure 30B provide similar results.

8.7.2 Esker material

Six samples were taken during the 2004 test pit program and sieve analyses were conducted. The particle size distribution curves of the total samples are shown on Figure B31 and particle distribution curves for sand and smaller material are shown on Figures B32 and B33. It should be noted that the samples were taken from a long vertical section of the test pit faces in order to obtain representative samples.

The results of these total samples given in percentage of gravel, sand and silt sizes are given in Table 8-6.

Table 8-6. Particle size distribution of esker material

Location	Particle sizes in %			Material Description
	Gravel	Sand	Silt	
Cell 1 - Top	40	58	2	Gravelly sand
Cell 1 - Base	48	50	2	Gravelly sand
Cell 3	30	68	2	Gravelly sand
Cell 3b	38	60	2	Gravelly sand
Cell 1a	50	47	3	Sandy gravel
Cell 2	25	69	6	Gravelly sand, silty
Average	39	59	3	

The particle size distribution tests show that the esker material in Cells 1a, 1, 2 and 3 is a well graded gravely sand with minor amount of silt sizes that represent about 2 % of the total. Only one sample from Cell 2 was somewhat coarser, being a gravelly sand with little silt (silt content 6%). Its Unified Soil Classification Symbol is GW.

Moisture contents were determined from four samples and they varied from 7.2% to 9.8%. These moisture contents represent the unsaturated esker material since the samples were taken above the saturated zone. Location and the individual water contents are given in Table 8-7

Table 8-7. Esker material water contents measured in 2004

Location	Water content %
Cell 1a-1	8.1
Cell 1a-2	7.2
Cell 2-1	9.8
Cell 2-2	8.5

8.7.3 Summary of tailings and esker properties

A summary of the index properties is given in Table 8-8.

Table 8-8. Summary of tailings and esker properties

Property	Esker	Tailings
Particle size		
Gravel	38 %	0
Sand	59 %	34 %0
Silt	3 %	66 %
Description	Gravelly sand well graded	Sandy silt poorly graded
Unified Soil Classification	GW	ML

8.8 Ground Temperatures in Tailings

Lupin has one of the most extensive and longest running ground temperature monitoring databases in the Canadian north. The first thermistors were installed in 1988, although they are no longer operating Additional thermistors were installed in 1995 (Cells 1, 1a, 2, and Dam 4), 2000 (esker, Dams 1a, 2), 2003 (Dam 6, Cell 1 test pad), and in 2004 (Dams 3D and K, Cells 1 and 3). Ground temperatures within the dams and tailings were presented and discussed in Chapter 5.0.

All of the thermistors have shown the tailings to be frozen. In this section the ground temperatures presentation is given in relation to the tailings. Ground temperature profiles measured in 2004 for the thermistors presented in this section are given in Appendix C.

Key information on the maximum depth of thermistor and mean annual ground temperatures at this depth; depth to the base of tailings; thaw depth observed in 2004, and the year the thermistor installed are summarized in Table 8-9.

Table 8-9. Summary of ground temperatures in tailings

Thermistor	Max'm Depth	MAGT @ Max depth	Base of Tailings, m	Thaw Depth, m	Install Year
Cell 1					
Interior					
TC1-3	13	-5.2	4.6	1.2	1995
TC1-6	20	-5.1	6	1.3	2003
At 3D Dam					
TC1-7	20	-4.3	10.9	1.6	Jun-04
D3D	20	-2.1		2.0	Jun-04
Cell 3b					
TC3-1	20	-3.9	16.4	1.4	Jun-04
DK-3	19.6	-2.9		3.1	Jun-04
Reference thermistor at esker					
Esker	17	-6.5		1.3	2000

Ground temperature profiles in Appendix C and the mean annual ground temperature (MAGT) at maximum depth show the ground temperatures being between - 3.9º C and -5.2ºC. The warmer ground temperatures at TC3-1 and TC1-7 (-3.9ºC and - 4.3ºC) were measured near dams where the adjacent water and the downstream embankment have a warming influence. At these two locations the tailings were frozen for the total tailings thickness that varied from 10.9m at TC1-7 to 16.4m at TC3-1.

At more distant location, northern part of Cell 1, MAGT at maximum depth were measured to be -5.1ºC and -5.2ºC at TC1-6 and TC1-3 respectively.

The maximum thaw depth in TC1-3, TC1-6 and TC3-1 varied between 1.2 m to 1.4 m. The small thaw depth is explained by relatively high groundwater level at these locations. The thaw depth at TC1-7 is deeper (1.6 m) because of slightly lower groundwater at this location. This thermistor is located near Dam 3D, which has no liner to maintain a high groundwater level at the periphery of the cell.

The thaw depths below the crests of Dams 3D and K are greater, at 2.0m and 3.1m, again because of lower groundwater levels. The reason for greater thaw depth at Dam K is that this dam has a liner that keeps the core of the dam dry.

A comparison of the thaw depth development during 2004 at Dams 3D and K are shown Figure 8-13.

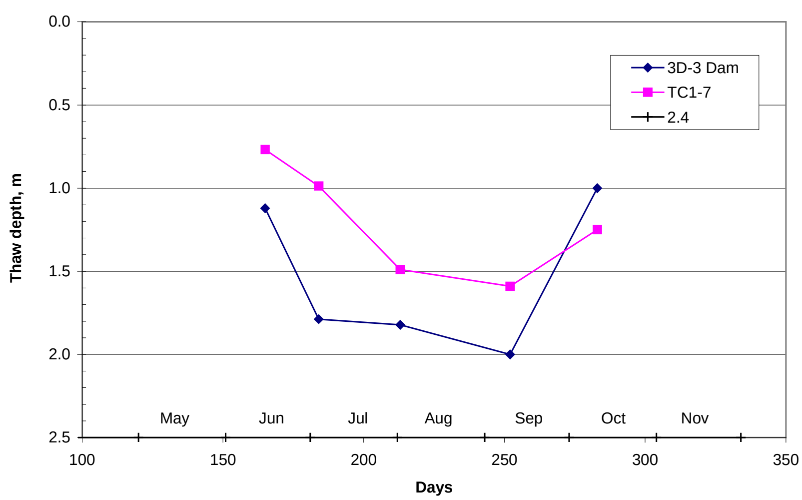

Figure 8-13. Thaw depth changes at Dam 3D, in 2004

The different thaw depths Dam 3D can be explained by the fact that the groundwater level below the dam crest (3D-3 Dam thermistor is lower, being closer to the downstream dam slope.

9.0 WATER QUALITY

9.1 General

Water quality within the saturated zone of the esker cover and the discharge water as it progresses from the saturated zone to ponded water on top of Cell 1, then to Pond 1 and Pond 2 respectively has been monitored to determine the likely water quality of water after closure.

9.2 Pipes installed in 1998

Water samples were taken in pipes TC1-1 and TC1-5 since 1998. Results given in Table 9-1 show that water quality data exceed the Water License limits in nickel, zinc and pH. It is likely that water quality improvement of the esker pore water is very slow because of the very slow migration of water through the esker-saturated zone. The slow migration is due to a small gradient of the tailings surface and the low permeability of the esker material.

Table 9-1. Pore Water Quality (ppm) in Esker Cover Pores Measured in 1998 Pipes.

Water License Parameter	Max'm Avg ppm	Average Values for TC1-1 & TC1-5				
		1998	1999	2000	2001[a]	2002[a]
Total Arsenic	0.5	0.41	0.01	0.01	0.02	0.012
Total Copper	0.15	0.80	0.77	0.04	0.05	0.21
Total Cyanide	0.8	<.002	<.002	<.002	<.002	<.002
Total Lead	0.1	NA	NA	NA	0.01	0.01
Total Nickel	0.2	3.99	3.15	1.14	2.20	3.06
Total Zinc	0.4	1.06	0.96	0.23	0.60	0.69
TSS	15					
pH	6 to 9.5	5.1	4.8	4.7	4.7	5.1

Note a): For Year 2001 only TC1-1 and for Year 2002 only TC1-5 are available.

9.3 Pipes installed in 2002

More extensive sampling and testing of the esker pore water was started in August 2002 to obtain a better understanding of water quality within the esker cover saturated zone and how this pore water affects the water as it emerges from the ground. For this purpose 9 pipes were installed in Cell 1 as shown in Figure 8-5.

The results from five water samples from the pipes installed in 2002 show that the total nickel exceedence is much smaller than measured in the 1998 test pipe TC1-5 and the total zinc met the discharge limits. It is likely that the lower metal concentrations were obtained because the newer pipes were installed about 0.15 m above the tailings surface. The values measured in the 5 pipes are shown in Table 9-2. Water samples could not be obtained in the remaining 4 pipes because of insufficient water within the pipes.

Table 9-2. Pore Water Quality (ppm) in Esker Cover Pores Measured in 2002 Pipes

Water License Parameter	Max'm Avg	Max’m Grab	P-2	P-4	P-5	P-6	P-8	Avg.
Total Arsenic	0.50	1.00	0.005	0.004	0.02	0.004	0.019	0.009
Total Copper	0.15	0.30	0.31	0.19	0.25	0.006	0.042	0.160
Total Cyanide	0.80	1.60	0.002	0.06	0.004	0.002	0.002	0.014
Total Lead	0.10	0.20	0.025	0.01	0.02	0.002	0.003	0.010
Total Nickel	0.20	0.40	1.32	0.85	3.51	0.015	1.11	1.361[a]
Total Zinc	0.40	0.80	0.62	0.32	0.91	0.035	0.300	0.437
TSS	15	30						
pH	6 to 9.5		3.96	5.7	5.0	5.9	4.9	5.09

Note a) Marginally above limits, L5x

The newer more extensive test results show the water quality of the esker pore is above the license limit for nickel and pH.

9.4 Water Quality Monitored in 2003 and 2004

Water quality within the pipes and in adjacent ponded water continued to be monitored in 2003 and 2004. Sampling in some pipes could not be obtained because of either no water or an insufficient water depth at the bottom of the pipes. Pipe P-1 was removed in 2004 because a waste rock layer was found below the esker that prevented the pipe from reaching the saturation zone and Pipe P-7 was installed to greater depth during the 2004 test pit excavation. The average water quality measurements from 7 of the 9 pipes installed are given in Table 9-3.

Table 9-3. Average water quality from pipe wells, 2003 & 2004

NWB License			Measurements	
Parameter	Unit	Max Avg:	28-Jul-03	08-Aug-04
Arsenic	mg/L	0.500	2.84	2.73
Cadmium	mg/L	n/a	0.00	0.00
Copper	mg/L	0.150	0.13	0.20
Cyanide	mg/L	0.800	0.03	0.02
Lead	mg/L	0.100	0.08	0.09
Nickel	mg/L	0.200	0.93	1.48
Zinc	mg/L	0.400	0.28	0.55
pH		6.0 to 9.5	4.6	4.5

The measurements of water quality in the esker saturated zone showed no significant change in metal concentrations but an increase arsenic was observed to have occurred from the 2002 measurements. This information indicates that the flushing of the saturated pore water is slow.

To study what happens to the saturated zone pore water as it emerges at the surface, a test pit was excavated beside pipe P-2 and sampled for water quality. Photo of the excavation beside P-2 is shown in Figure 9-1 and the monitored water quality results are given in Table 9-4.

Figure 9-1. Test Pit 2a used for water sampling beside P-2

Table 9-4. Water quality measurement in Test Pit 2a

NWB License			Measurements		
Parameter	Units	Max Avg:	28-Jul-03	04-Jul-04	08-Aug-04
Arsenic	mg/L	0.5000	0.073	0.041	0.099
Cadmium	mg/L	n/a		0.002	0.002
Copper	mg/L	0.150	0.302	0.292	0.255
Cyanide	mg/L	0.800	0.004	0.002	0.008
Lead	mg/L	0.1000	0.012	0.004	0.003
Nickel	mg/L	0.2000	0.544	1.170	0.912
Zinc	mg/L	0.400	0.498	0.463	0.350
pH		6.0 to 9.5	3.4	3.8	4.0

The Table 9-4 show much smaller concentration of arsenic but the remaining parameters are similar to the ones measured in the pipes.

The main impact of esker pore water on the receiving water can be determined from following the water quality from the pipes to areas where it emerges at Cell 1 ponded water surfaces and than progresses to the larger water bodies in Pond 1 and Pond 2. The ponded water in Cell 1 is shown in Figure 9-2. Water quality measured in Cell 1 ponded water area (2004) and Ponds 1 and 2 in 2003 and 2004 are given in Table 9-5 and Table 9-6 respectively.

Figure 9-2. Ponded water in Cell 1, location of water sampling

Table 9-5. Water quality in Cell 1 ponded water (2004)

NWB License			Measurements		
Parameter	Units	Max Avg:	**13-Jun-04**	**13-Jul-04**	**8-Aug-04**
Arsenic	mg/L	0.500	0.116	0.026	0.020
Cadmium	mg/L	n/a	0.001	0.000	0.001
Copper	mg/L	0.150	0.006	0.030	0.044
Cyanide	mg/L	0.800			0.002
Lead	mg/L	0.1000	0.002	0.002	0.002
Nickel	mg/L	0.2000	0.063	0.134	0.172
Zinc	mg/L	0.400	0.063	0.134	0.172
pH			4.08	3.51	3.68

Table 9-6. Water quality in Ponds 1 and 2 (2003 & 2004)

Parameter	Units	NWB	Pond 1		Pond 2	
		Max Avg:	12-Oct-03	8-Aug-04	12-Oct-03	8-Aug-04
Arsenic	mg/L	0.5	0.058	0.067	0.062	0.013
Cadmium	mg/L	n/a	0.000	0.000	0.000	0.000
Copper	mg/L	0.15	0.027	0.070	0.007	0.018
Cyanide	mg/L	0.8	0.026	0.110	0.018	0.180
Lead	mg/L	0.1	0.001	0.001	0.001	
Nickel	mg/L	0.2	0.098	0.091	0.091	0.083
Zinc	mg/L	0.4	0.262	0.262	0.178	0.207
pH		6.0 to 9.5	7.6	7.8	6.6	7.3

The progression of water quality from pores in the saturated zone within the esker, to its emergence within Cell 1 ponded water, passing through Pond 1 and reaching Pond 2 from where it has been periodically siphoned out, is shown in Table 9-7.

Table 9-7. Water quality of esker pore water as it emerges, average values

Parameter	Units	NWB		Wells	Pit 2a	Cell 1 ponded W	Pond 1	Pond 2
		Max Avg:	Max Grab:					
Arsenic	mg/L	0.5	1	1.864	0.071	0.054	0.062	0.038
Cadmium	mg/L	n/a	n/a	0.003	0.002			
Copper	mg/L	0.15	0.3	0.171	0.283	0.027	0.049	0.013
Cyanide	mg/L	0.8	1.6	0.021	0.005	0.002	0.068	0.099
Lead	mg/L	0.1	0.2	0.062	0.006	0.002	0.001	0.001
Nickel	mg/L	0.2	0.4	1.212	0.875	0.123	0.094	0.087
Zinc	mg/L	0.4	0.8	0.425	0.437	0.123	0.262	0.193
pH		6.0 to 9.5	6.0 to 9.5	4.7	3.7	3.8	7.7	6.9

The summarized results in Table 9-7 illustrate the following:

- Water quality of the saturate esker zone is marginally above the Nunavut Water Board (NWB) License. The volume of water within this zone is small and will take considerable time to be flushed out.
- As the saturated zone water emerges at the Cell 1 pond, it water quality meets the NWB metal limits.
- Additional improvement in water quality is found in Ponds 1 and 2. Water quality parameter values of the License listed parameters in Ponds 1 and 2 vary from a half to about one fiftieth of the values in the esker-saturated zone.
- Presently about 58% of the exposed tailings have been covered.

10.0 SUMMARY

10.1 Tailings Area Background

The Lupin tailings containment area (TCA) was first constructed in 1981 and tailings discharge began in 1982. Tailings deposition will be terminated in early 2005. The TCA was created by the construction of 8 earth dams around the TCA watershed perimeter. The basic design consists of a frozen homogeneous dam, with an internal liner as back-up, supported on frozen foundations. The highest two dams have a height of 7.9 and 5.9 m. Two intermediate dams are 3.3 and 3.9 m high and the remaining dams are small, with their heights varying between 1.0 and 2.5 m.

Starting in 1985, tailings were discharged into four cells, counting Cell 1a and 1 as the same cell, and Cell N being a part of Cell 5. The statistics of these cells are given in Table 10-1.

Table 10-1. Summary of tailings cell statistics

Cell	Watershed, ha	Tailings surface area, ha	Mean tailings depth, m	Tailings volume stored, m3
Cell 1a	6	6.3	1.7	107,000
Cell 1	41	36.1	3.5	1,263,000
Cell 2	21	15.0	3.0	450,000
Cell 3	67	50.0	4.0	1,724,000
Cell 5	56	34.3	4.5	1,544,000
Cell N	3	3	1.0	32,000
Totals	194	144.7		5,120,000

The cells were formed by the construction of internal dams that were generally located along higher ground. As a result, the greatest tailings depths are located in former lakes within the cells and the mean depths of the tailings are relative small, varying between 1 to 4.5 m.

The total of the tailings surface area of about 145 ha represents about 24% of the total TCA watershed of 616 ha.

10.2 Permafrost

The mean annual air temperature at Lupin was about -12.5ºC when the TCA was constructed in 1981. This would have created a mean annual ground temperature of about -8ºC. This provided an ideal location for the construction of frozen dams on permafrost foundations and the use of permafrost to encapsulate the tailings. Since the start of the TCA operation, the mean annual air temperature has warmed to about -10.5ºC and a reference thermistor located at a nearby esker shows a mean annual ground temperature of -6.5ºC. Ground temperature monitoring at Lupin, and scientific acceptance that global warming may destroy permafrost, shows that permafrost may not exist at Lupin some 100 years from now. This has to be considered in the closure design of the TCA.

10.3 Dams

All existing dams at the Lupin site, both perimeter and internal, have very high factors of safety against instability because they are frozen. Since the main body of the dam and the foundations consist of cohesionless soil, gravelly sands, and silty sands with some gravel and low ice content, their frozen strengths are very high. In addition, the dams and their foundations are, from a practical point of view, impermeable.

The stability and the seepage condition of these dams will diminish if the permafrost thaws over time. For this reason, and for the fact that dams would require inspection and maintenance in perpetuity, Lupin has selected not to have any dams after closure of the site.

The highest dam, situated at the historical discharge point of the TCA watershed, will be breached. As a result, no perimeter dams will remain after closure since they are located along the historical watershed divide and the upstream water will have dropped below the dam toes. The only dam that will have water on the present downstream side, is Dam 4, which is located along the present watershed divide. It will continue to form a watershed divide after closure, with natural water discharge courses on each side.

The internal dams that were constructed to contain tailings, will become rock-fill reinforced, esker-material earth structures that contain tailings on one or both sides. Since they will not contain any water, they will cease to be dams. Surface water from the cells will be allowed to runoff into the internal lakes through channels in bedrock.

10.4 Tailings Cover

Tailings at Lupin were observed to have a potential for acid drainage, if the tailings were exposed to prolonged weathering (Klohn-Crippen 1995). Many mines in continuous permafrost have been adopting the concept of encapsulating tailings in permafrost. This concept may not be viable in the future if permafrost keeps warming, as global warming is predicting.

Lupin has adopted a saturated granular zone cover design for the tailings. This design is based on the studies in southern climate areas that show only very small depth of water over the surface of tailings is necessary to practically stop any oxidation of tailings. Reasons for larger depths of water of 1.0 to 1.4 m over acid potential tailings in southern climates are to prevent disturbance of the tailings surface by waves and ice floes during ice break-up.

Lupin has selected to cover the tailings with 1.0 m of esker sand that will maintain a small depth of saturated water zone at the base of the esker. The overlying cover layer will minimize evaporation of water from this zone and the low permeability of the fine tailings, being more than 60 percent silt size, will prevent dropping of the groundwater level within the tailings due to future thawing

10.5 Cover Monitoring

Lupin started to cover exposed tailings in completed cells in 1988, and to monitor the covered tailings to assess the effectiveness of the covers. As a result, Lupin has collected the most extensive and longest observed performance records of covered cells in permafrost areas.

Data collected includes ground temperatures, water levels within the cover, water quality within the cover, slope of tailings surface, thickness of tailings deposition, moisture content of the cover, and particle size analyses of tailings and cover materials. Various studies have determined the durability (physical and chemical) of the cover material, water balance within the cover during drought conditions, and pore water expulsion potential from the compacted tailings during thaw conditions (Golder 2004a). Test pits excavated through the cover to the tailings surface were examined for evidence of cryoturbation, oxidation at the tailings interface, presence of ice lenses, and condition of the tailings/cover interface.

Some of the key findings from these studies and monitoring are:

- Thickness of the esker cover in Cells 1a, 1, 2 and 3 was observed to average 1.0m, ranging from 0.9 to 1.3 m. One smaller thickness of 0,7 m was found in an area where the tailings were covered with waste rock before the esker was placed.
- Depth of the saturated zone varied from 0.2 m at the perimeter of the cell to 0.6 to 1.0 at the central area.
- None of test pits excavated through the esker cover to the tailings interface showed any evidence of tailings having penetrated into the cover, either during construction or as a result of cryoturbation.
- The esker cover consists of a gravely sand with little silt. Esker above the saturated zone had a high moisture content, average being 8.4%. This high moisture content in the esker material above the saturated zone adds to the oxygen barrier.
- Extensive ground temperature monitoring in the tailings has shown that, in all locations, the tailings are completely frozen. The depth of the active layer averages about 1.2 m. and the thaw condition lasts for less than 3 months.
- Visual inspection of the esker cover has not found any signs of erosion caused by surface water.

10.6 Water Quality

Some findings from water quality monitoring are:

1) Water quality monitoring within the saturated esker zone showed the pore water in this zone being marginally above NWB License limits.
2) Water quality from ponded water on Cell 1 and at downstream locations in Pond 1 and Pond 2 are well below NWB License limits. At these locations the metal levels vary from 2% to 50% of the NWB License limits.
3) The existing water quality in Ponds 1 and 2 is for a tailings surface area that has, until the summer of 2004, been predominantly exposed. The present tailings surface area is now 58% covered by a layer of esker sand. Completing the cover for the whole area by 2006 will show considerable further water quality improvement in Ponds 1 and 2.

10.7 Surface Water Balance

Upon closure of the TCA, the surface water balance will be close to the pre-TCA conditions. Surface water input from the individual tailings cells will be small because of their small areas and it will flow out through bedrock-controlled channels. All perimeter dams will have been breached, so that all tailings buttress berms will be above water.

11.0 ACKNOWLEDGEMENT

The Lupin mine has been a Canadian pioneer in the design of dams in permafrost and the development of a cover for potentially acid generating tailings for remote permafrost areas that is affected by global warming. It has collected the most extensive and longest performance records of frozen dams and covered tailings cells in permafrost areas.

The writer has been privileged to be part in the design and analyzing of the performance data since 1980. He would like to thank all the Lupin management from 1980 to the present time for allowing the writer to participate in their project. He would like to thank especially Mr. Michael Tansey, Lupin's Reclamation Project Manager, for being most helpful in obtaining all requested information for the design and monitoring data of tailings cover.

Respectfully submitted,

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