HYDROLOGIC AND HYDROGEOLOGIC EVALUATION OF THE THICKENED TAILINGS DISPOSAL SYSTEM AT KIDD CREEK DIVISION, FALCONBRIDGE LIMITED

MEND Project 2.23.2 ab

October 1993

EXECUTIVE SUMMARY

The Kidd Creek Division of Falconbridge Ltd. has been using the Thickened Tailings Disposal (TTD) method at its metallurgical site near Timmins, Ontario. In 1991, Noranda Technology Centre was requested to examine the environmental situation at the site. The objective of the two-year study was to measure the hydraulic properties of the tailings site to analyze their effects on the long-term impacts to the environment.

The use of the TTD method for tailings disposal was originally proposed by Robinski (1975), for specific advantages such as low initial capital investment, low operational costs, good storage capacity per unit surface, and the elimination of high perimeter dams, slime ponds and decant systems. The method consists in the thickening of the tailings slurry which is discharged in an elevated central spigot line producing a large cone-shaped deposit. Currently, the tailings deposit at Kidd covers a surface of 1215 ha and resembles a broad, gently sloping (± 1%) cone. The tailings contain approximately 5% sulphur, and have been determined to be a strong net acid producer using B.C. Research Initial Test and Confirmation Tests.

Recent reports and publications by Robinski (1990) and Robinski et al. (1991) suggested that the TTD scheme has the potential to reduce acid generation and seepage by creating a homogeneous tailings mass of low hydraulic conductivity and high moisture retention characteristics in which oxygen entry and the resulting tailings oxidation are very limited.

NTC concentrated on the field evaluation of the principal components of the site hydrology to obtain a verification of the high moisture retention of the TTD deposit. The field program included measurements of moisture content, hydraulic head, water table elevation and hydraulic conductivity. Precipitation, pan evaporation and evaporation from tailings were monitored during 1991-1992 and a monthly water balance was prepared. Porewater was sampled and analyzed for major metal and ion concentrations.

The magnitude of the water balance components during average conditions -- runoff 42% of precipitation, evaporation 51% and infiltration 7% -- were similar to those predicted by the

HELP model. The water balance for extreme dry conditions predicted an infiltration deficit that results in surface de-watering at the end of the year that is similar to the de-watered condition observed during the summer of 1992 (a year with average rainfall and evaporation). A year of above normal precipitation will likely replenish the deficit. Normally, the tailings are saturated to the surface after spring snowmelt, and summer de-watering is replenished during the fall and with the following spring snowmelt.

Hydraulic gradients suggest that pore water in the saturated zone tends to move downward near the centre of the cone, and upward (and exfiltrate) along the slope of the tailings. Near-surface hydraulic gradients on the upper part of the cone indicate that upward flow dominates during the period of summer water table drawdown, and that downward flow dominates during the subsequent recharge period. Average linear pore water velocities in the tailings are very low (12 cm/y).

The thickness of the capillary fringe (the saturated tailings above the water table) was observed to be 4 m at the top of the tailings cone. A maximum thickness to 5 m to 6 m is predicted from published drainage curves of the tailings. The 5 m contour on the depth to water table contour map, therefore, delineates the area of enhanced surface tailings oxidation.

Over most of the tailings, the surface is observed to dry during the summer. Sulphide oxidation is observed at the surface and at depth along shrinkage cracks. The analysis of porewater indicates that sulphide oxidation is occurring in the tailings mass. De-watering during a draught year is expected to have little impact on long-term saturation of the tailings. However during these periods, oxidation is promoted deeper in the tailings. Considering the tailings cone at present, then following closure, tailings saturation and water table position are expected to resemble that presently observed in areas of the cone where deposition is not active. Release of contaminants from the tailings general mass to the environment should remain at present rates because porewater velocities are slow, and because of the sustained near-surface saturated conditions.

SOMMAIRE

La Division Kidd Creek de Falconbridge Limitée utilise la méthode de l'élimination des résidus miniers épaissis à son site métallurgique situé près de Timmins, en Ontario. En 1991, on a demandé au Centre de technologie Noranda (CTN) d'examiner la situation environnementale à cet endroit. La présente étude a pour objectif de mesurer les propriétés hydrauliques du parc à résidus et d'analyser leurs effets environnementaux à long terme.

Robinsky (1975) a été le premier à proposer cette méthode d'élimination des résidus en soulignant des avantages particuliers, comme une faible mise de fonds initiale, des coûts d'exploitation bas, une bonne capacité de stockage par unité de surface, et l'élimination de hauts barrages périphériques, de bassins de boues traitées à la chaux et de systèmes de décantation. La méthode consiste à épaissir les résidus miniers, puis à les déverser dans une conduite centrale surélevée, produisant un grand dépôt conique. Les résidus à Kidd couvrent actuellement une superficie de 1 215 Ha et possèdent la forme d'un large cône à pente faiblement accentuée (1%) qui atteint 13 m de hauteur en son centre. Les résidus ont une teneur en soufre d'environ 5% et sont fortement acidogènes, d'après le test initial et les essai de confirmation "BC Research".

Selon Robinsky (1990) et Robinsky et coll. (1991), la méthode de l'épaississement des résidus miniers permet de réduire la production et le suintement d'acide en créant une masse de résidus relativement homogène à faible coefficient de perméabilité et à forte capacité de rétention de l'humidité, qui limite considérablement la pénétration d'oxygène et l'oxydation des résidus qui en résulte.

Le CTN a concentré ses efforts sur les composantes hydrologiques principales pour vérifier la rétention de l'humidité des résidus. Dans le cadre du programme de travaux sur le terrain, on a mesuré le contenu en eau, la pression hydraulique, l'élévation de la nappe phréatique et le coefficient de perméabilité. En 1991-1992, on a mesuré la précipitation, l'évaporation en bassin et l'évaporation à partir des résidus. Un bilan hydrique mensuel a également été effectué, de même que l'analyse d'échantillons d'eau interstitielle afin de déterminer les

principales concentrations de métaux et d'ions.

L'importance des composantes du bilan hydrique dans des conditions moyennes (ruissellement : 42 % des eaux de précipitations, évaporation : 51 % et infiltration : 7 %) correspondait aux prévisions obtenues à l'aide du modèle HELP. Dans des conditions d'extrême sécheresse, le bilan hydrique montre un déficit d'infiltration qui cause, à la fin de l'année, un assèchement de la surface s'apparentant à l'assèchement observé pendant l'été 1992 (année au cours de laquelle les taux de précipitations et d'évaporation étaient moyens). Il est probable que le déficit sera comblé si l'on connaît, pendant une année, des précipitations au-dessus de la moyenne. Habituellement, le dégel du printemps entraîne une saturation des résidus à la surface et l'assèchement de l'été est compensé par les pluies automnales et la fonte des neiges au printemps suivant.

Les gradients hydrauliques indiquent que l'eau interstitielle dans la zone saturée a tendance à s'écouler vers le bas près du centre du cône et vers le haut le long de la pente des résidus, produisant du suintement. Les gradients hydrauliques situés près de la surface dans la partie supérieure du cône indiquent que l'écoulement vers le haut domine lorsque la nappe phréatique baisse et que l'écoulement vers le bas est à son maximum pendant la période d'alimentation qui s'ensuit. La vitesse moyenne linéaire de l'eau interstitielle dans les résidus est très faible (12 cm/a).

On a constaté que l'épaisseur de la frange capillaire (les résidus saturés au-dessus de la nappe phréatique) était de 4 m au sommet du cône de résidus. En se basant sur les courbes de drainage des résidus déjà établies, on prévoit une épaisseur maximale de 5 à 6 m. La courbe de niveau de 5 m sur la carte topographique, qui indique la profondeur de la nappe phréatique, délimite donc la zone d'oxydation accentuée des résidus de surface.

La surface de la plupart des résidus sèche pendant l'été. On observe alors une oxydation des sulfures à la surface et dans le sol, le long des fissures de rétrécissement. Une analyse de l'eau interstitielle indique une oxydation des sulfures dans les résidus. On prévoit que s'il y a des années de sécheresse importante, cette dernière n'aura que peu d'effet sur la saturation à long terme des résidus. Pendant ces périodes, toutefois, l'oxydation s'étend plus profondément dans les résidus. Si l'on prend le cône de résidus en ce moment et qu'on le compare à ce qu'il sera au moment de la fermeture du site, la saturation des résidus et la position de la nappe phréatique devraient ressembler à ce que l'on peut actuellement observer dans les parties du cône où la déposition ne se fait pas activement. Le rejet dans l'environnement de substances contaminantes provenant de la masse des résidus ne devrait pas augmenter, puisque la vitesse de l'eau de porosité n'est pas élevée et que les conditions de saturation près de la surface sont stables.

V2-1-T01

HYDROLOGIC AND HYDROGEOLOGIC EVALUATION OF THE THICKENED TAILINGS DISPOSAL SYSTEM AT KIDD CREEK DIVISION, FALCONBRIDGE LIMITED

YEAR II AND FINAL REPORT

by

Noranda Technology Centre
Mineral Sciences Laboratory
Environmental Group

July 1993

Table of Contents

List of Figures

List of Tables

Project Team

Luc St-Arnaud, P.Eng., M.Sc, Project Manager
Mark R. Woyshner, M.Sc., Consulting Hydrologist/Hydrogeologist

Acknowledgements

The authors would like to thank the staff of Environment Control and Services at the Kidd Creek Division, in particular B. Swarbrick and M. Casper, for their invaluable assistance. The work described in this report could not have been realized without the technical contributions of the staff of the Noranda Technology Centre (NTC). Technical discussions with E. Yanful (NTC), L. Barbour and W. Wilson (University of Saskatchewan), D. Blowes (University of Waterloo) and E. Robinsky and R. Salvas (E. Robinsky and Associates) were appreciated. K. Wheeland (NTC) and D. Bordin (Kidd Creek) provided project management.

Distribution

Falconbridge Kidd Creek Division: 10 copies
Noranda Technology Centre: 10 copies

Key Words

Acid Mine Drainage
Thickened Tailings Disposal
Tailings Decommissioning

1.0 Objectives and background.

In 1991, Noranda Technology Centre (NTC) was requested to assess the environmental situation at the Kidd Creek thickened tailings disposal (KCTTD) site. The tailings are deposited using the Thickened Tailings Disposal (TTD) method. The general objectives of the assessment were (1) to verify the hydrology of the tailings site, and (2) to recommend a final decommissioning scheme for the site.

The use of the TTD method for tailings disposal was originally proposed by Robinsky (1975), for specific advantages such as low initial capital investment, low operational costs, good storage capacity per unit surface, and the elimination of high perimeter dams, slimes ponds and decant systems. The method involves the thickening of the tailings slurry which is discharged in an elevated central spigot line which produces a large cone-shaped deposit. The TTD method is described in Shields (1975), Robinsky (1975, 1978, 1982, 1986, 1987), and Salvas (1989).

Recently, Robinsky (1990) and Robinsky *et al.* (1991) argued that the TTD method has the potential to reduce acid generation and seepage compared, to conventional deposition methods. This would be achieved by the creation of a homogeneous tailings mass of low hydraulic conductivity and high moisture retention characteristics in which oxygen entry and the resulting tailings oxidation are very limited.

The present study was aimed at providing an independent verification of some of the hydraulic and geotechnical characteristics of the TTD. The field program prepared and implemented in the late summer of 1991 included direct measurements of moisture at the tailings surface and a derivation of a water balance for the site. A description of the first-year program and the results obtained were given in a report (Noranda Technology Centre, 1992). The results are summarized as follows:

(1) the presence of a thick (3-m) capillary fringe, or tension-saturated zone above the water table, was inferred from measured physical characteristics such as tailings grain size and porosity.

(2) with the total inflows to the tailings being precipitation and tailings slurry disposal, runoff represented 33% of inflows, evaporation 41% of inflows, and infiltration 27% of inflows.

(3) water discharging with tailings and flowing in channels down the tailings cone to the ponds was estimated to contribute to 28% of total infiltration. It was suggested that if tailings slurry disposal were to cease, runoff to the ponds would decrease most significantly and infiltration would decrease to a lesser degree, with a limited effect on the water table elevation.

(4) Analysis of pore water in the unsaturated and saturated zones indicated that sulphide oxidation had occurred within the tailings mass.

The study supported that the TTD method seems to be advantageous because of lower dissolved metal fluxes to the environment, compared to a conventional deposit where segregation of particle sizes would have occurred.

The first-year (draft) report recommended additional hydrologic budget component measurement and modelling, water quality sampling and analysis, and hydrologic experiments under controlled laboratory conditions. These tasks were performed in year-two of the study (1992), and the present (final) report presents the results. Several sections of the 1991 report were revised and included in the present report. The available results of other complementary studies on the Kidd site are referenced, to help in the global evaluation of all aspects of the TTD method and for the preparation of a decommission plan.

1.1 Site description

The TTD site is located on the north side of the Kidd Creek metallurgical site, 26 km east of Timmins, Ontario (Fig. 1). The area is generally flat, and is part of the Porcupine river watershed. The Porcupine river flows from the east to the north of the site, then shifts to the south to pass the west side of the site, almost circling the site entirely before reaching Night Hawk Lake to the southwest.

Since 1975, approximately 50 million tonnes of tailings have been deposited, roughly covering a circular surface of 1,215 ha. During this period, the thickener underflow density was gradually increased from 50% in 1976 to 61.5% at present. An account of the TTD system operation at Kidd was presented by Yeomans (1985).

At present, the tailings cone extends, at its centre, 23 meters above the perimeter diking, and has a slight concave slope of $\pm$ 1%. Field and laboratory testing show the average value of hydraulic conductivity to be approximately 1 x 10^{-7} m/s (Yang *et al.*, 1992; NTC, 1992; Robinski, 1990). Porosity was shown to be about 46%, though varying by $\pm$ 7% with depth due to alternating summer and winter deposition. During the summer evaporation allows deposition to consolidate and be more dense with a lower porosity. The dry density is about 1.7 g/cm^3 and the specific gravity, 3.1. The tailings surface is non-vegetated and shows polygonal shrinkage cracks (Fig. 2). The shrinkage limit was shown to be approximately equal to the liquid limit (23%).

Beneath the tailings cone, the dominant overburden material is a thick varved clay, constituting part of a sequence deposited some 8,000 to 10,000 years ago during the last phase of glacial Lake Ojibway (Quigley, 1980). The clay is overlain by a thin layer of organic soil (peat), and underlain by uneven till and bedrock. Observations by previous researchers (A. Salvas, personal communication) indicated that a bedrock ridge exists underneath the location of the present main embankment. During a previous drilling campaign (O'Connors, 1991) a sand unit was also found at one location beneath the centre of the tailings.

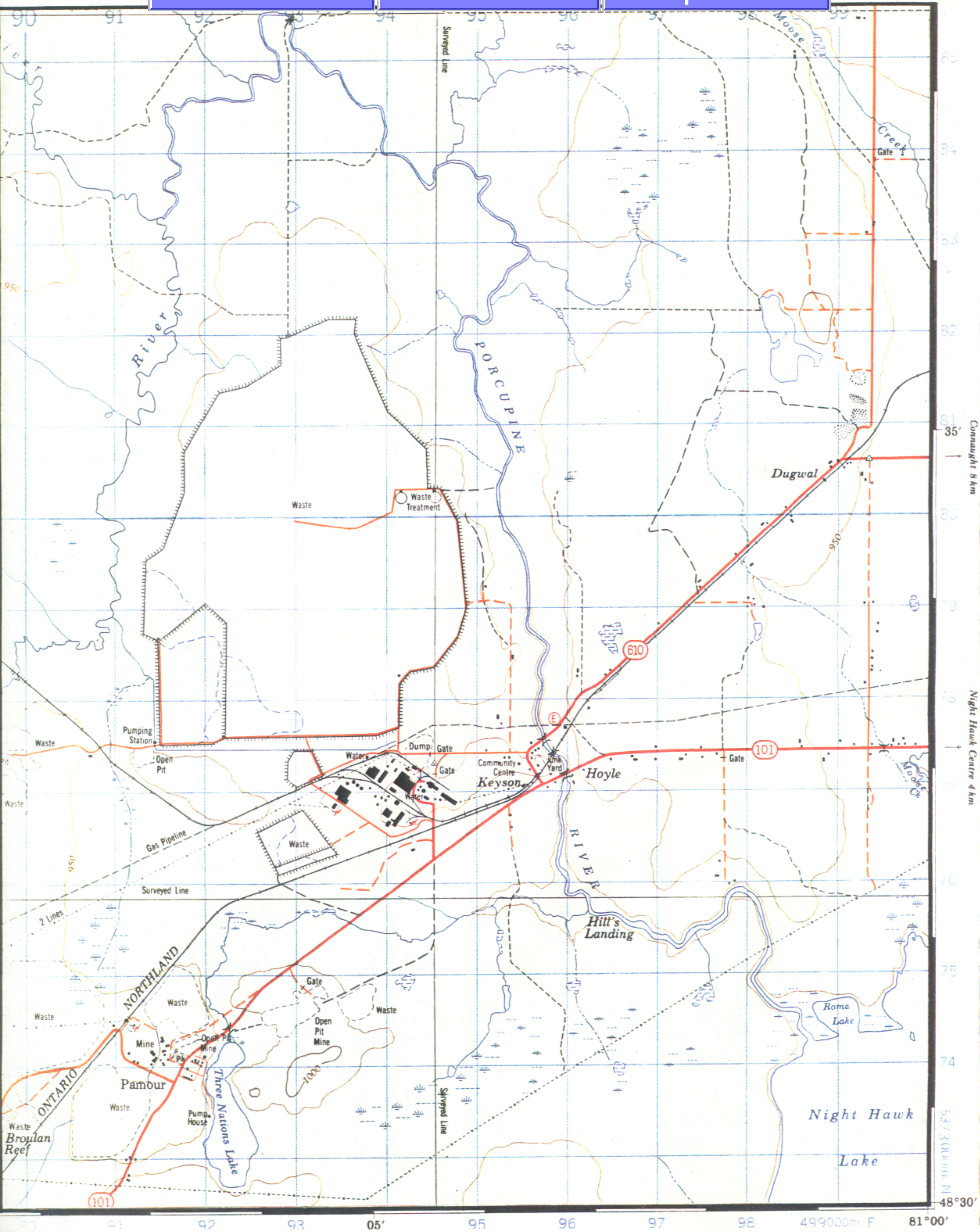
Drilling logs from Falconbridge Exploration Division were compiled and plotted as five stratigraphic sections (Appendix D). The sections indicate that the bedrock elevation can vary up to 5 m. The clay also varies substantially, both in thickness and continuity; about 5 m to 23 m of clay were found off site, on the north end, and less than 1 m to 10 m of clay with sand seems were found below the eastern edge of the tailings. Underlying the clay, glacial till can range from 5 m to 40 m in thickness.

1.2 Regional climate

The climate of Northern Ontario may be generally classified as modified continental, the modification being mainly due to the presence of the Great Lakes on the south and, to a minor extent, to Hudson Bay on the north. The climate of the Kidd Creek region is particularly modified by Lake Superior; air masses generally track across the lake which results in higher precipitation and a seasonal lag, retarding the onset of spring.

A pattern of relatively low winter and high summer precipitation prevails in Northern Ontario, although not to the degree that this occurs in the Prairie Provinces, and this seasonal contrast decreases from northwest to southeast. Cold polar air masses producing dry, clear weather generally persist a high proportion of the time during the winter. In the summer, a continuing succession of cyclonic storms sweeps over the area and warm, humid air masses from the south alternate with cooler and drier air from the north; this produces a typical pattern of two or three days of clear weather followed by warmer more humid weather, often with changeable winds and rain for a day or two. The average annual precipitation is approximately 860 mm.

Figure 2. Photograph of tailings surface.

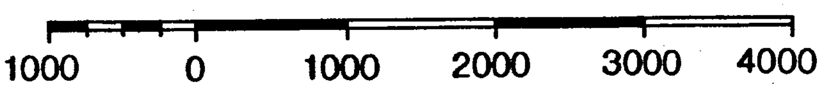


PORCUPINE
River
RIVER
Moose Creek
Gate
Surveyed Line
Waste
Waste Treatment
Pumping Station
Open Pit
Gas Pipeline
Surveyed Line
2 Lines
Dump
Gate
Water
Community Centre
Junk Yard
Keyson
Hoyle
Dugwal
610
101
Hill's Landing
NORTHLAND
ONTARIO
Mine
Open Pit Mine
Pamour
Pump House
Broulan Reef
Three Nations Lake
Roma Lake
Night Hawk Lake
Moose Cr
950
1000
Connaught 8 km
Night Hawk Centre 4 km
35′
48°30′
05′
81°00′
499000m. E

Roads:	Routes:		
hard surface	revêtement dur	dual highway / double chaussée / 2 lanes	more than 2 lanes / plus de 2 voies
hard surface	revêtement dur	2 voies / 2 lanes or more	less than 2 lanes / moins de 2 voies
loose or stabilized surface, all weather	gravier, aggloméré, toute saison	2 voies ou plus	less than 2 lanes / moins de 2 voies
loose surface, dry weather	de gravier, temps sec		
unclassified road or street	route non classée ou rue		
cart track	de terre		
trail, cut line or portage	sentier, percée ou portage		

FOR COMPLETE REFERENCE SEE REVERSE SIDE POUR UNE LISTE COMPLÈTE DES SIGNES, VOIR AU VERSO

SCALE 1:50 000



SOURCE:

Ministry of energy mines and resources Canada, drawn from 1983 air photos; ref. 42A/11 Pamour, Cochrane district, edition 3.

Noranda Technology Centre

HYDROGEOTECHNICAL GROUP

Figure No. 1

KIDD CREEK

METALLURGICAL SITE MAP

2.0 Hydrologic processes and the water balance

A hydrologic budget to verify the present and long-term hydrological balance of the tailings was developed. The position of the line of saturation in the tailings is controlled by the quantity of water stored in the tailings mass, which is defined as "storage water", or S. Storage changes with time due to man-induced and meteorological hydrologic parameters, as described by the water balance equations:

$$S = P - E - R - I - D \tag{1}$$

where,
- P = Precipitation,
- E = Evaporation,
- R = Runoff,
- I = Infiltration,
- D = Drainage.

Infiltration (I) is controlled by the water balance at the tailing surface (the tailings-atmosphere boundary):

$$I = P - E - R \tag{2}$$

The water balance components were evaluated based on field measurements and available records, and are described in the following sections. A monthly water balance was developed for the tailings site during 1992. For comparison, a water balance was also developed with mean monthly data. Tailings hydrology was also predicted during extreme dry conditions by incorporating into the water balance the year of lowest recorded precipitation (1958) and highest evaporation (1979).

2.1 Precipitation

Excluding the water deposited with TTD, precipitation is the sole influx of water to the tailings cone. In the Timmins area, it generally falls as rain from May through October and as snow from November through March. The snow cover, which accumulates during winter, melts mostly during April.

Two regional meteorological stations in the proximity of KCTTD site record precipitation: Timmins Airport (48° 34' N, 81° 22' W, 295 m elevation) and Connaught, Ontario (48° 37' N, 80° 55' W, 281 m). Operated by the Ontario Climatic Centre, Timmins Airport has a 38 year period of record (installed April, 1955). Connaught, which has a 20 year period of record (1962-81), is now discontinued . Closer to the tailings, the Kidd Creek metallurgical site (metsite) has been measuring precipitation since 1984 and is located near the entrance gate. Finally, at the onset of this study

(August 1991), a tipping bucket rain gauge was also installed on the tailings. In all, there are three stations currently measuring precipitation. The record of monthly totals for these station appear in Appendix B.

Since precipitation is measured at the metsite and on the tailings, a comparison is instructive. Using monthly totals (Aug-Oct, 1991 and Jun-Oct, 1992), a linear regression analysis (Appendix B) indicates that the metsite predicts precipitation on the tailings with a 93% reliability (R^2=0.93). Though similar amounts were measured at each station at low rainfall levels, more rain fell on the tailings at high rainfall levels. Therefore, more rain was measured at the tailings station than at the metsite station -- a total of 798 mm verses 581 mm, respectively. The metsite gauge likely needs to be recalibrated.

The Timmins airport record was used to estimate the historical normal (or average) amount of precipitation at the tailings meteorological station. A correlation to Timmins airport (Appendix B) was developed using measured monthly totals at the KCTTD site from Aug-Oct, 1991 and Jun-Oct, 1992; it has an 82% reliability (R^2=0.82). Using this correlation, an extended (38 year) record of precipitation was developed for the KCTTD site and is located in Appendix B. The mean monthly precipitation is shown in Table 1. Rainfall and snowfall were partitioned from precipitation using monthly factors from the Timmins airport record.

Table 1. Normal precipitation on the Kidd Creek tailings cone.

Month	Precipitation (mm)	Rainfall (mm)	Snowfall (cm)
January	46.3	2.3	44.0
February	35.6	1.1	34.5
March	50.7	11.2	39.5
April	42.2	21.9	20.3
May	61.0	54.9	6.1
June	80.9	80.9	0
July	85.0	85.0	0
August	84.4	84.4	0
September	83.7	82.0	1.7
October	87.4	72.5	14.9
November	70.5	26.8	43.7
December	57.3	5.7	51.6
Annual Total	765	505	260

Note: Snowfall is expressed as depth in cm. A factor of 0.1 is commonly used to convert to water content.

Snowfall is measurable during all months of the year except July and August (Timmins airport record). During the months November through March snowfall generally accumulates and forms a snow cover which melts mostly in April.

At the end of March 1992, a snow density survey was conducted on the Kidd Creek tailings. Details of the survey appear in Appendix B. It was determined that approximately 170 mm of water was on the tailings as a 60 cm snow cover. This finding compares reasonably well with a similar survey which was conducted by PWA/W-E-R (1993) and with the snow depth measurement which was conducted at Timmins airport meteorological station (Table 2).

Table 2. Snow depth at Timmins airport (1991-92).

Month	Snowfall (cm)	Cumulative snowfall (cm)	End of month snow cover (cm)
November	56.5	56.5	19
December	47.1	103.6	22
January	61.0	164.6	56
February	32.5	197.1	59
March	16.9	214.0	56

In 1992 the measured water content at the end of March (170 mm) is 79% of the cumulative snowfall (214 mm). This implies 44 mm was lost from the snow cover (predominately melted) before the end of March, likely during November and March. If weighted by snow cover depth, 11 mm and 33 mm would have melted during November and March, respectively. Therefore, 79%, 16% and 5% of the snow cover melted during April, March, and November, respectively.

Table 3 shows the normal snow cover at Timmins airport. By using the 1992 factor of 0.79, the water content of the snow cover at the end of March was estimated at 166 mm, which is equivalent to the normal snowmelt during April.

Table 3. Normal snow depth at Timmins airport (1955-90).

Month	Snowfall (cm)	Cumulative snowfall (cm)	End of month snow cover (cm)
November	57.2	57.2	21
December	70.6	127.8	51
January	28.6	156.4	69
February	24.7	181.1	69
March	29.3	210.4	44

2.2 Runoff

A study of runoff and erosion from the KCTTD cone (Phase I final report, January 1993) was conducted by Paul Wisner and Associates (PWA) and the Environmental Applications Group (EAG) in conjunction with W-E-R Engineering Ltd. The report, which was prepared for Falconbridge Limited, Kidd Creek Division, describes the runoff processes on the cone and determined the runoff coefficient by month during 1992.

The ratio of runoff (R) to rainfall (P) is defined as the runoff coefficient (C = R/P). Table 4 shows the observed runoff coefficients by month at two stations located on the runoff channel which encircles the tailings deposit to the north. The observed runoff coefficients were used in the water balance to calculate the monthly runoff.

Table 4. Observed monthly runoff coefficients (after PWA/W-E-R, 1993).

Month in 1992	Runoff Coefficient, C	
	At the flume (upstream station)	Above the ponds (downstream station)
April (snowmelt event)	1.00	0.60
May	0.50	0.27
June	0.00	0.03
July	0.01	0.08
August	0.18	0.27
September	0.41	0.40
May-Sep (rainfall events)	0.22	0.24

2.3 Evaporation

Evaporation is the diffusion of water vapour into the atmosphere from water surfaces. In northern Ontario evaporation is driven primarily by solar radiation. To a lesser extent, though, evaporation is also caused from the "atmospheric demand for moisture" which can be thought of in terms of relative humidity; evaporation is high when humidity is low. Evaporation is also influenced by water quality; it is higher with fewer dissolved species.

The potential (unobstructed) rate of evaporation is limited by the availability of water. When water is abundant, for example following snowmelt, and the tailings are saturated, then evaporation is not limited and the actual evaporation is equal to the potential rate. As the tailings dry during summer, the availability of water at the tailings surface deceases, which increases the soil suction (the force with which soil holds water). Evaporation begins to be less than the potential rate as soil suction exceeds 3,000 kPa (Wilson, 1990). The soil is very dry at 3,000 kPa since plants generally wilt at 1,500 kPa.

Evaporation is commonly estimated by measuring "pan evaporation" and applying a coefficient (usually 0.7). Pan evaporation is the amount of water which evaporates from a small reservoir, typically a U.S. weather bureau "Class A" evaporation pan (1.2 m dia. by 25 cm). Pan evaporation is measured at Amos, Quebec (48° 34' N, 78° 08' W, 310 m). A U.S. "Class A" evaporation pan was also installed on the KCTTD near BH6. Observed monthly values at Amos were correlated to Kidd values and were used to extend the record of pan evaporation at Kidd. The record of pan evaporation at Amos and the KCTTD site appear in Appendix C. Linear regression analysis indicates the correlation has a reliability of 95% (R^2= 0.95).

In addition to pan evaporation, evaporation from the tailings surface (tailings evaporation) was calculated by an energy budget method utilizing the Bowen ratio partitioning method of surface energy (Bowen, 1926). The method included the measurement of net radiation, soil heat flux, and vertical gradients of air temperature and vapour pressure (i.e., dew point temperature). A rigorous account of the Bowen Ratio Energy Balance (BREB) method appears in Appendix C. Instrumentation was installed near BH6 during July 1991 and continued during 1992. Unfortunately, during 1992 problems were encountered with the measurement of dew point temperature. Without the vapour pressure gradient, tailings evaporation could not be calculated for 1992. Tailings evaporation was calculated for 1991.

The ratio tailings evaporation to pan evaporation is defined as the evaporation coefficient (C_E). At Kidd, the observed tailings evaporation during August, September and October of 1991 was 129 mm; during the same period, pan evaporation at Kidd was 282 mm. Therefore, an estimate for C_E is 0.46. Since 0.7 is the value of C_E which is commonly used to estimate potential evaporation, tailings evaporation shows limitations by water availability.

Table 5 shows normal evaporation at the KCTTD site for each month from May through October. Pan evaporation was calculated with correlation to Amos, PQ and tailings evaporation is 0.46 of pan evaporation.

Table 5. Normal evaporation at the Kidd Creek thickened tailings site.

Month	Pan Evaporation (mm)	Tailings Evaporation (mm)
May	159	73
June	175	81
July	188	86
August	145	67
September	81	37
October	51	23
Total	800	368

2.4 Infiltration and tailings recharge.

Water that does not run off the tailings surface either evaporates at the surface or infiltrates into the tailings. However, not all of this water reaches the water table to flow through the tailings. In fact, during the summer much of the water that does enter the tailings subsequently evaporates. Figure 3 illustrates this point during July. It is a plot of observed hydraulic heads near the surface of the tailings. T1, T2 and T3 are tensiometers placed 1, 2 and 3 m respectively below the tailings surface and B1-5 and B1-4 are piezometers placed 3.8 and 4.9 m respectively below the tailings surface. Figure 3 shows that before the recharge period during August (indicated by a rising water table), water flow was towards the surface (indicated by upward hydraulic gradients in July). Ostensibly, water at the tailings surface was evaporating which caused the upward flow. During July, most of the rainfall that did not run off would have evaporated. During August and September, as evaporation decreased and rainfall increased, infiltration reached the water table and recharge the tailings (indicated by downward gradients and a rising hydraulic head).

The region above the water table, which is known as the vadose zone, holds moisture by capillarity and resists flow through the tailings. Water readily exchanges with the atmosphere; infiltrating as a liquid and evaporating as a gas. In this sense, the vadose zone, particularly the region closest to the tailings surface, can be seen as a store for moisture -- a buffer or capacitor. The vadose zone is largest during the summer when the water table is low.

Infiltration is quantified by subtracting runoff and evaporation from precipitation (i.e., rainfall and snowmelt). Infiltration by month was calculated in the water balance (Section 2.8). The typical seasonal pattern is depicted. During the summer, shortly following snowmelt, infiltration is negative which depletes soil moisture, drys the tailings and lowers the water table. Then, as evaporation recedes following summer, infiltration is positive and soil moisture is replenished and the water table rises again. Annual (net) infiltration is generally positive which is balanced by drainage and a change in storage.

During the recharge period of 1991 (the first year of study), soil moisture content and water table elevation was monitored at the top of the cone (piezometer nest NTC-A1). The findings are shown in Figure 4. Since this station is located near the top of the cone, the water table is furthest from the surface and the vadose zone is most developed than other places on the cone. The water content profile shows the density layering from alternating summer and winter deposition, as described in Yang *et al.* (1992). Due to evaporation, tailings deposition during summer consolidates more than deposition during the winter, and therefore has a higher bulk density. Since water content is defined as the ratio of the weight of the water to the weight of the solids, a higher density layer would have a lower water content measurement for a given weight (amount) of water. Saturation is therefore depicted as a range from 22% to

27% (w/w). Figure 4 features a rising water table and capillary fringe, which is responding to positive infiltration. Most significantly, the thickness of the capillary fringe, the tension-saturated zone which extends above the water table, is delineated at approximately 4 m.

The capillary fringe is not always the same thickness. When the water table drops, the capillary fringe elongates, and when the water table rises (as in Fig. 4), it retracts. The capillary fringe is held by surface tension, which causes its top to fluctuate with less magnitude than that of the water table. A plot of suction versus water content (drainage curve) best illustrates this phenomenon. Figure 5 shows the drainage curve for the Kidd Creek thickened tailings (Yang *et al*, 1992). Matric suction, the force with which soil holds water by surface tension is the negative pressure head. Pressure head is zero at the water table, positive below and negative above. Figure 5 indicates that up to a suction of about 5 to 6 m of water, significant de-watering does not occur. Since this is the suction exerted at the top of the capillary fringe, 5 m to 6 m is the predicted maximum thickness of the capillary fringe. During recharge when infiltration is positive, the thickness is smaller, as in Figure 4.

2.5 Saturated pore water flow

Below the water table, water is free to flow through saturated pores, according to Darcy's law.

$$q = K\,i \tag{3}$$

where, q = specific discharge (m/s),
K = hydraulic conductivity of tailings (m/s),
i = hydraulic head gradient in the direction of flow.

The pore water velocity within the tailings (v) can be estimated by incorporating porosity (n).

$$v = \frac{K\,i}{n} \tag{4}$$

The porosity is 0.46 and hydraulic conductivity is 1 x 10^{-7} m/s (Yang *et al.*, 1993; NTC, 1992; Robinsky *et al.*, 1991). Vertical hydraulic head gradients were measured with piezometer nests, and horizontal gradients, with a piezometer nest cross-section. Figure 6 shows the locations of the piezometer nests which were installed during 1991 and 1992. A description of the methods are found in Appendix D.

The hydraulic heads are illustrated with precipitation for each piezometer nest along cross-section A-A' (Figs. 7 through 10) and at B1 (Fig. 11). In general, the hydrographs indicate the lowered water table of June rising during July and August, in response to precipitation, and remaining at a high level through the autumn and early winter. During this period, the hydraulic heads readily responded to individual rainfall events, rising as much as a meter, only to fall again during the dry period that follows the storm. These large fluctuations in water table levels typically occur in fine-grained soils, a process which has been described by Abdul and Gillham (1984). It is related to the fact that the water table can rapidly rise through the capillary fringe (i.e., the tension-saturated zone) after an infiltration event of minor intensity. This phenomenon is clearly evident in Figure 7 (A2) during June and July when submersible pressure transducers were installed in the piezometers to measure the water level every hour. At the end of July the transducers were relocated to B1 (Fig. 11), where the same phenomenon was observed but to a lesser extent because the water table had already risen.

The vertical hydraulic gradients at each piezometer nest are illustrated in Figures 12 through 15 by plotting the hydraulic head against the piezometer tip elevation. The water table is given at the h=z intersect, where the pressure head equals zero. As a result, the range of the water table elevation is indicated at each piezometer nest. At the top of the cone (at A1, A2 and B1) the range was about 4 m to 5 m, and further down the cone (at A3 and A4), the fluctuation was 3 m.

Figures 12 through 16 also indicate a changing vertical gradient, which is also depicted in the hydrographs (Figs. 7 through 11). In general, the gradient is consistently downward at top of the cone (at A1 and B1) but is progressively more upward as one descends the cone; at nests A2, A3 and A4 the gradients are both downward and upward. This data indicates that water would tend to move downwards at the top of the cone (where infiltration dominates), laterally and upwards further down the cone (where exfiltration dominates). At the lowest water table elevation, an upward gradient exists at the top of the cone (A1, A2 and B1), which is likely caused by consolidation of the tailings. At B1, the upward gradient in the vadose zone (0.125 measured with tensiometers) was caused from evaporation.

Figure 17 features hydraulic head contours along cross-section A-A' following the largest rainfall of the year. The downward flow from the top of the cone and lateral flow along the cone is clearly depicted. Upward flow dominates past A4, at the seepage face. The lateral hydraulic gradient is 0.017 which is similar to the slope of the tailing surface (1.5%). This is not surprising because horizontal hydraulic gradients in a homogeneous porous mass of tailings are influenced by the slope of the surface. Using this gradient in Darcy's law and applying the porosity and hydraulic conductivity, the flow velocity is 12 cm/y and the specific discharge is 54 mm/y. Assuming no significant leakage from the base of the tailings (because of the clay base), then the water that infiltrates, moves laterally. Therefore, for a normal year when storage does not change, an estimation of infiltration (precipitation less runoff and evaporation) is the horizontal specific discharge (54 mm/y). Since some basal percolation is expected, this is a minimum estimation of infiltration.

Table 6. Average hydraulic gradients and specific discharges.

Piezometer Nest	Hydraulic Gradient, i	Specific Discharge, q (mm/d)
A1	0.07	0.6
A2	0.02	0.2
A3	0.02	0.2
A4	0.001	0.01
B1	0.07	0.6
A1-A4 (horizontal)	0.017	0.15

Note: Hydraulic conductivity of 1×10^{-7} m/s was used to calculate specific discharge.

2.6 Depth to water table

Since March 1991, water level measurements in a borehole network have been measured on a monthly basis by Kidd Creek personnel. Each borehole was installed with a fully screened piezometer which extends the entire depth of the saturated zone; specifications are found in O'Connor (1991). Although fully screened piezometers do not accurately indicate the position of the water table, if vertical gradients are small (as they are at the KCTTD), then the piezometers can be used to estimate the position of the water table. Figure 18 shows the borehole data along a westwardly cross-section from BH1 to BH4. In general, the water table is high after snowmelt, low during the summer, high during the fall, and low during winter.

Figure 19 is a contour map that illustrates depth to water table from the tailings surface at the end of June 1992, a time when the water table was at its lowest elevation. The depth to water was between 6 m and 7 m at the top of the cone and between 1 m and 2 m at the base of the cone. To the south and west, the water table is controlled by the elevation of the ponds and perimeter stream; the depth to water is zero at the edge of the pond. Assuming the maximum depth of the capillary fringe is 5 m (Section 2.4), which is the depth of saturation above the water table, the 5 m contour approximates the edge of the saturated tailings. Above the 5 m contour an unsaturated zone certainly develops, but below the 5 m contour, the tailings are predominantly saturated. It is expected, though, that a thin unsaturated zone does develop below the 5 m contour from evaporation. Since oxidation and the production of acidity is promoted in the unsaturated zone, the 5 m contour delineates an area of higher oxidation.

2.7 Contribution of water to the tailings by slurry discharge.

The water that discharges out of a spigot as tailings slurry flows down the cone in a small braided channel. When the flow reaches the end of the channel it spreads out, about 500 m down the cone where the grade decreases. The increase in width is accompanied by a decrease in depth and velocity, causing deposition of tailings and the formation of a fan. The wetted areas of the channel and fan were determined by planimetry of infrared areal photographs (1:5000 scale), and consisted of 1% of the total tailings area (maximum). Piezometer nest C1 was located at the head of a fan, in the channel, and piezometer nest C2, further downstream, at the edge of a fan. The methods for installation are found in Appendix D.

Figures 20 and 21 show the hydraulic heads for C1 and C2, respectively, in association with precipitation. Similar to the other piezometer nests (Section 2.5), the water table fluctuates and responds to precipitation and dry spells. The water table fluctuation and hydraulic gradients are highlighted in Figure 22. Also similar to the other piezometer nests, both upward and downward gradients are noted at each station, with downward gradients dominating at C1 (0.01) and upward gradients dominating at C2 (-0.005). These data indicate a control of the tailings pore water flow beneath the channel and fan area by the pressure dynamics of the cone. The fluctuation of about 1.5 m is less than that at the other piezometer nests, though. In addition, the depth to water table is shallow (0.4 m to 1.8 m at C1, and 0 to 1.2 at C2) in comparison to the other piezometer nests. The depth to water table contour map (Figure 19) also indicates that at C1 and C2 water levels are controlled more by the topography than by the ponds. Therefore, these data suggest some contribution of water by tailings slurry discharge. However, considering the channel area constitutes 1% of the tailings, infiltration by thickened tailings discharge is negligible in the water balance (less than 1% of precipitation).

2.8 Water balance

A water balance for the tailings cone is essentially a deterministic model which calculates the change in tailings moisture storage (S). The monthly values of precipitation, evaporation and the runoff coefficient are given to calculate infiltration (I), and by subtracting drainage (D), S is found for each month. The change in storage is physically manifested by a change in water table elevation and tailings saturation. By setting S to zero at the end of snow melt, negative values for succeeding months indicate a loss of moisture and a lower water table, and positive values indicate a gain of moisture and a higher water table. The water balance was calibrated with the data collected in 1992. For comparison, it was also developed for average (normal) conditions by using the precipitation and evaporation normals (i.e., averages of the record). S was predicted for extreme dry conditions by using the year of lowest recorded precipitation (1958) and highest evaporation (1979). Precipitation during 1958 has a 39 year recurrence and evaporation during 1979, a 26 year recurrence

(Appendix B); the probability of both occurring is expected to be higher. All units are expressed as depth (mm) per tailings surface (1215 ha) and data sources are presented in Table 7.

Table 8 shows the monthly water balance for 1992, which was generally a year of normal precipitation and normal evaporation. Evaporation, though, was high during May and precipitation was high during August. Storage was found to decrease during May and June and increase through the rest of the year. The position of water table during 1992 confirms the predicted trend (Fig. 18). In December, at the end of the year a storage deficit of 35 mm is indicated. The water table position was observed to drop about 2 m by the end of 1992, which reflects the 35 mm deficit in the water balance. The specific yield[1] of the tailings is 0.02 (35 mm/2 m), which is similar to that calculated during the first year of study (0.023; NTC, 1992). These findings of the 1992 monthly water balance were incorporated in the KCTTD site annual water balance (Figure 23).

Table 9 shows the monthly water balance for normal conditions. The storage, as in 1992, was found to decrease following snowmelt and increase after summer. For normal conditions, though, S decreases less and for three months (from May through July), low during August and increases from September through November. By the end of November, S is at its original level (0). During winter (Dec-Mar), S decreases slightly, only to be replenished by spring snowmelt. No annual deficit of S was found. The meteorological normals are averages for a period of record and therefore do not reflect the monthly variations from the record that is typical for a year with a normal annual total.

Table 10 shows the monthly water balance for extreme dry conditions. The storage was found to decrease from May through August and basically stay low for the remainder of the year. Furthermore, from August through the end of the year, S is similar to that of June and July of 1992. Therefore, the moisture conditions observed during June and July of 1992 (Fig. 24) reflect those of an extreme dry year. Since moisture was nearly replenished by the end of 1992, the de-watering following an extreme dry year should be replenished with normal rainfall. However, since an additional year of evaporation would follow, normal conditions would sustain the de-watered condition; above normal rainfall would be necessary for replenishment.

---

[1]Specific Yield (S_y) is the volume of water released per unit area of porous media due to a water table decline. Like porosity, it is a dimensionless term but smaller because the voids are not evacuated. The usual range of S_y is 0.01 to 0.3.

Table 7. Sources of water balance information.

Site Measurements:	Precipitation (rain gauge and snow survey) Tailings Evaporation (energy balance and pan evaporation) Pond Evaporation (pan evaporation) Tailings Storage (water table) Infiltration (piezometers) Exfiltration/Seepage (piezometers) Throughflow (piezometers)
Mill measurements:	Final Effluent (Porcupine River) Recycle Tailings Disposal
Mill Estimates:	Frederickhouse River Mill Evaporation Other Sources to Ponds (sewer & waste water)

Notes (1) Mill measurements were provided by Kidd Creek metallurgical site.

(2) Mill estimates were based on metallurgical site water balance, provided by Kidd Creek (1990). These estimates were reviewed and although appear reasonable are considered preliminary and subject to further review.

Table 8. Hydrologic balance for the Kidd Creek tailings cone (1992).

Hydrologic component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation, P (mm)	55.4	25.2	13.1	61.5	37.4	48.0	91.7	142.5	135.4	35.6	71.9	68.3	786
Rainfall, Pr = P - Ps (mm)	2.0	0.0	3.4	59.7	24.5	46.8	91.7	142.5	133.6	23.6	26.9	8.7	563
Snowfall, Ps (cm)	53.4	25.2	9.7	1.8	12.9	1.2	0.0	0.0	1.8	12.0	45.0	59.6	223
Snowmelt, SM (mm)	0.0	0.0	33.0	171.8	12.9	1.2	0.0	0.0	1.8	12.0	0	0	233
Inflows, Q = Pr + SM (mm)	2.0	0.0	36.4	231.5	37.4	48.0	91.7	142.5	135.4	35.6	26.9	8.7	796
Runoff coefficient, C	1.00	1.00	1.00	0.88	0.27	0.03	0.08	0.27	0.40	0.40	0.50	0.80	-
Runoff, R (mm)	2.0	0.0	36.4	203.7	10.1	1.4	0.3	38.5	54.2	14.1	13.3	7.0	381
Pan evaporation, Ep (mm)				50	227	188	156	141	103	25			890
Tailings evaporation, Et (mm); 46% of Ep				23	104	86	72	65	47	12			409
Infiltration, I = Q - R - E (mm)	0	0	0	5	-77	-40	20	39	34	10	14	2	6
Drainage, D (mm)	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-54
Storage, S (mm)			0	0	-81	-126	-111	-76	-47	-41	-32	-35	-

Notes: Precipitation during Jun-Oct was measured at the KKTTD site, other months were correlated to Timmins airport.
Snowfall was correlated to Timmins airport.
Snow cover melt distribution (79%, 16% and 5% during Apr, Mar and Nov respectively) was deduced with a snow survey in March, 1993.
Runoff Coefficients were adapted after PWA/W-E-R, 1993.
Pan evaporation at the KCTTD was correlated to Amos, PQ.
Storage is the value from the previous month plus infiltration and drainage; it is assumed 0.0 after snowmelt.

Table 9. Hydrologic balance for the Kidd Creek tailings cone (normal conditions).

Hydrologic component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation, P (mm)	46.3	35.6	50.7	42.2	61	80.9	85	84.4	83.7	67.4	70.5	57.3	765
Rainfall, Pr = P - Ps (mm)	2.3	1.1	11.2	21.9	54.9	80.9	85.0	84.4	82.0	55.9	26.8	5.7	512
Snowfall, Ps (cm)	44.0	34.5	39.5	20.3	6.1	0.0	0.0	0.0	1.7	11.5	43.7	51.6	253
Cumulative snowfall (cm)	139.3	173.8	213.3							0.0	43.7	95.3	
Snowmelt, SM (mm)	0.0	0.0	33.6	188.8	6.1	0.0	0.0	0.0	1.7	11.5	11.2	0	253
Inflows, Q = Pr + SM (mm)	2.3	1.1	44.8	210.7	61.0	80.9	85.0	84.4	83.7	67.4	38.0	5.7	765
Runoff coefficient, C	1.00	1.00	1.00	0.80	0.25	0.10	0.10	0.10	0.20	0.40	0.45	0.80	-
Runoff, R (mm)	2.3	1.1	44.8	168.6	15.3	8.1	8.5	8.4	16.7	27.0	17.1	4.6	322
Pan evaporation, Ep (mm)				46	159	175	188	145	81	51			845
Tailings evaporation, Et (mm); 46% of Ep				21	73	81	86	67	37	23			389
Infiltration, I = Q - R - E (mm)	0	0	0	21	-27	-8	-10	9	30	17	21	1	54
Drainage, D (mm)	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-54
Storage, S (mm)	-7	-12	-16	0	-32	-44	-59	-54	-29	-16	0	-3	0

Notes: Precipitation and snowfall were correlated to Timmins airport.
Snow cover melt distribution (79%, 16% and 5% during Apr, Mar and Nov respectively) was deduced with a snow survey in March, 1993.
Runoff Coefficients were adapted after PWA/W-E-R, 1993.
Pan evaporation at the KCTTD was correlated to Amos, PQ.
Storage is the value from the previous month plus infiltration and drainage; it is assumed 0.0 after snowmelt.

Table 10. Hydrologic balance for the Kidd Creek tailings cone (extreme conditions).

Hydrologic component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Minimum precipitation, P (mm); 1958	32.5	23.2	18.5	43.3	86.6	84.9	93.2	31.5	86.8	15.4	76.5	63.5	656
Minimum rainfall, Pr = P - Ps (mm)	-2.0	-26.1	5.3	41.8	82.0	84.9	93.2	31.5	86.8	13.9	46.0	8.9	466
Minimum snowfall, Ps (cm); 1958	34.5	49.3	13.2	1.5	4.6	0.0	0.0	0.0	0.0	1.5	30.5	54.6	190
Cumulative snowfall (cm)	119.6	168.9	182.1							0.0	30.5	85.1	
Snowmelt, SM (mm)	0.0	0.0	28.7	145.4	4.6	0.0	0.0	0.0	0.0	1.5	9.6	0	190
Inflows, Q = Pr + SM (mm)	-2.0	-26.1	34.0	187.2	86.6	84.9	93.2	31.5	86.8	15.4	55.6	8.9	656
Runoff coefficient, C	1.00	1.00	1.00	0.88	0.25	0.10	0.10	0.10	0.20	0.40	0.45	0.80	-
Runoff, R = Q x C (mm)	-2.0	-26.1	34.0	163.8	21.7	8.5	0.3	3.2	17.4	6.2	25.0	7.1	259
Maximum pan evaporation, Ep (mm); 1979				41	165	199	313	128	109	51	20		1026
Tailings evaporation, Et (mm); 46% of Ep				19	76	92	144	59	50	23	9		472
Infiltration, I = Q - R - E (mm)	0	0	0	5	-11	-15	-51	-31	19	-14	21	2	-75
Drainage, D (mm)	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-54
Storage, S (mm)			0	0	-15	-35	-91	-126	-111	-130	-113	-115	-

Notes: Precipitation at the KKTTD site was correlated to Timmins airport and has a 29 year recurrence.
Snowfall was measured at Timmins airport, ON.
Snow cover melt distribution (79%, 16% and 5% during Apr, Mar and Nov respectively) was deduced with a snow survey in March, 19
Runoff Coefficients were adapted after PWA/W-E-R, 1993.
Pan evaporation at the KCTTD site was correlated to Amos, PQ and has a 26 year recurrence.
Storage is the value from the previous month plus infiltration and drainage; it is assumed 0.0 after snowmelt.

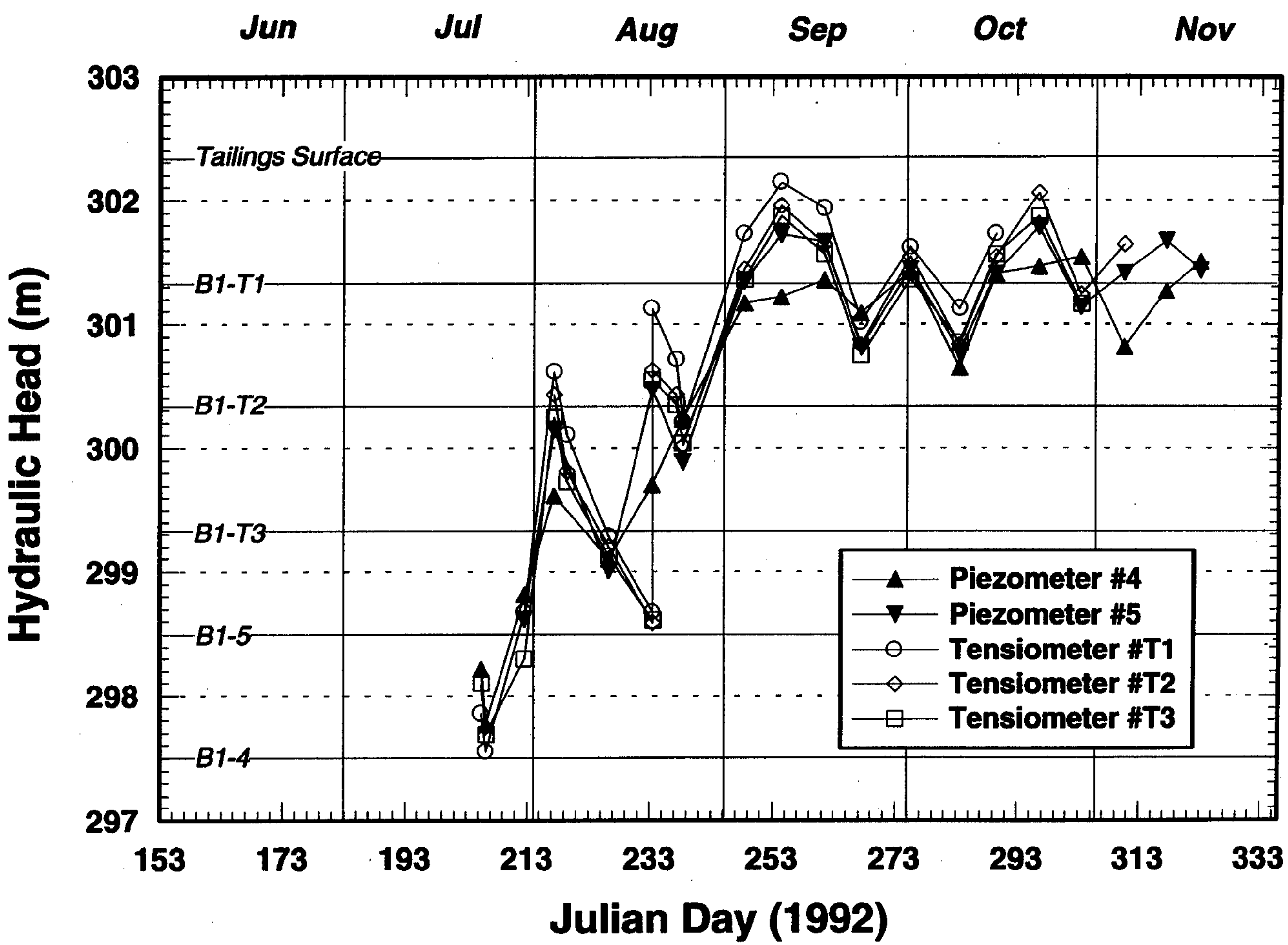


Figure 3. Hydrograph of Near-surface Hydraulic Heads at NTC B1

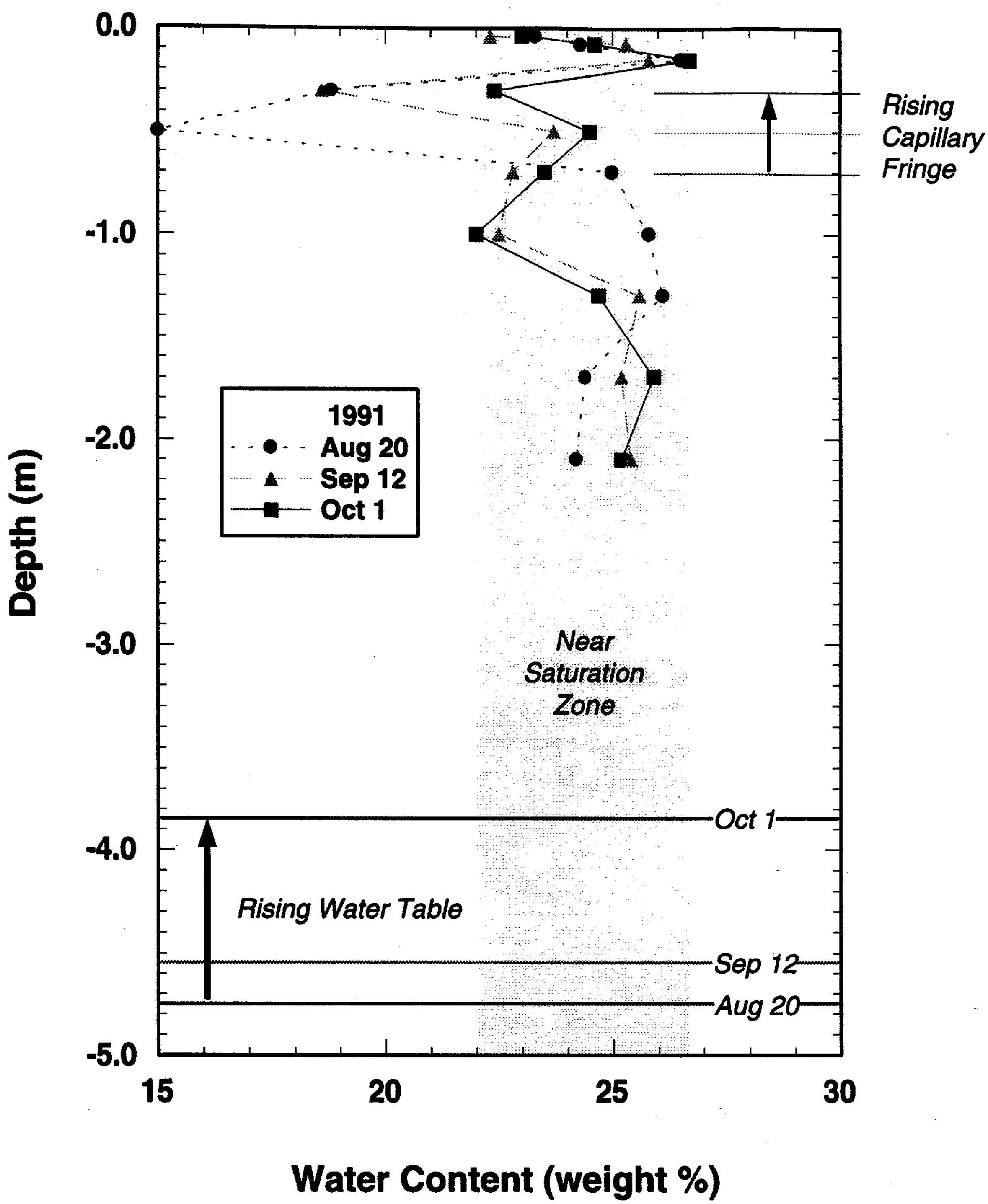


Figure 4. Recharge Conditions at Piezometer Nest A1

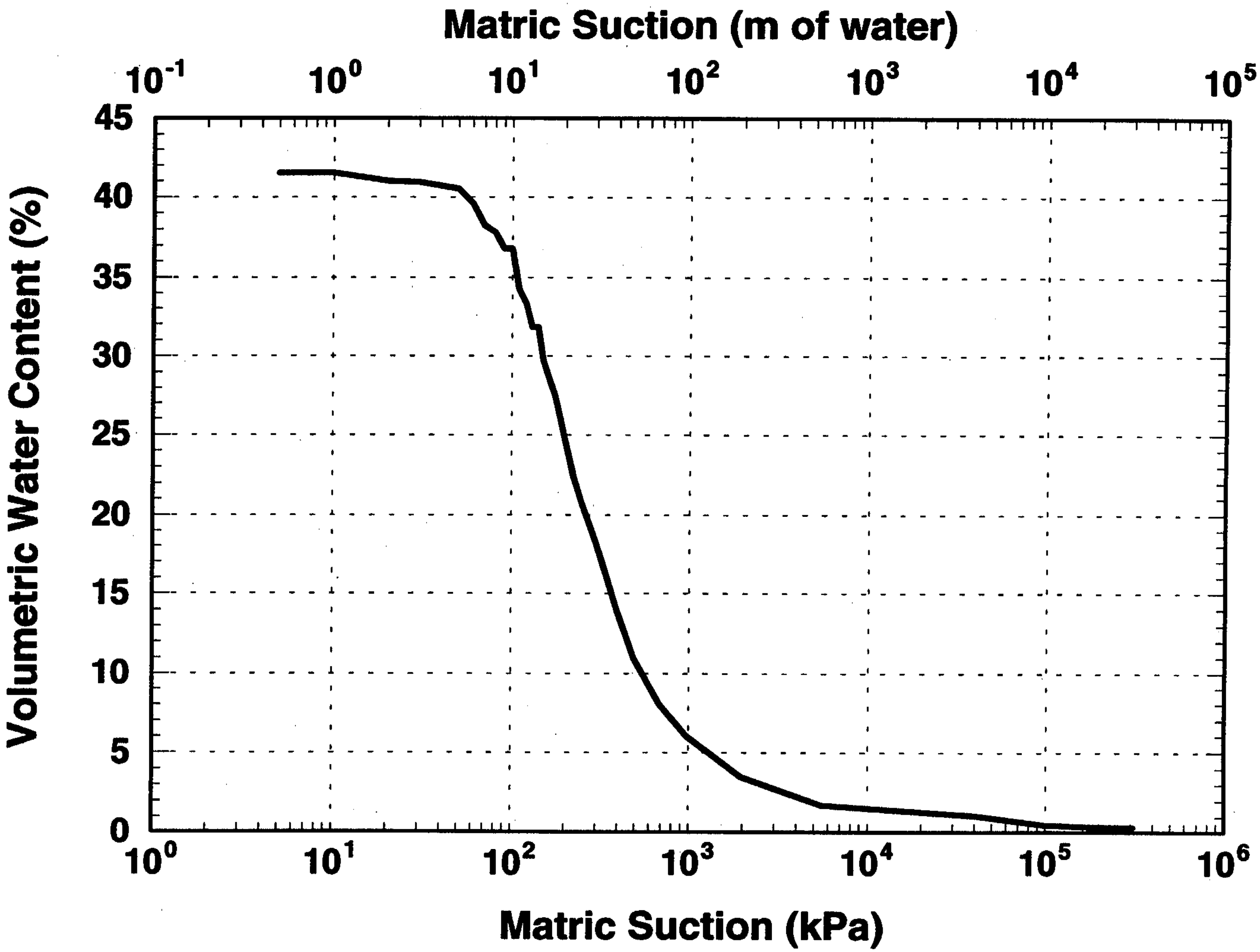
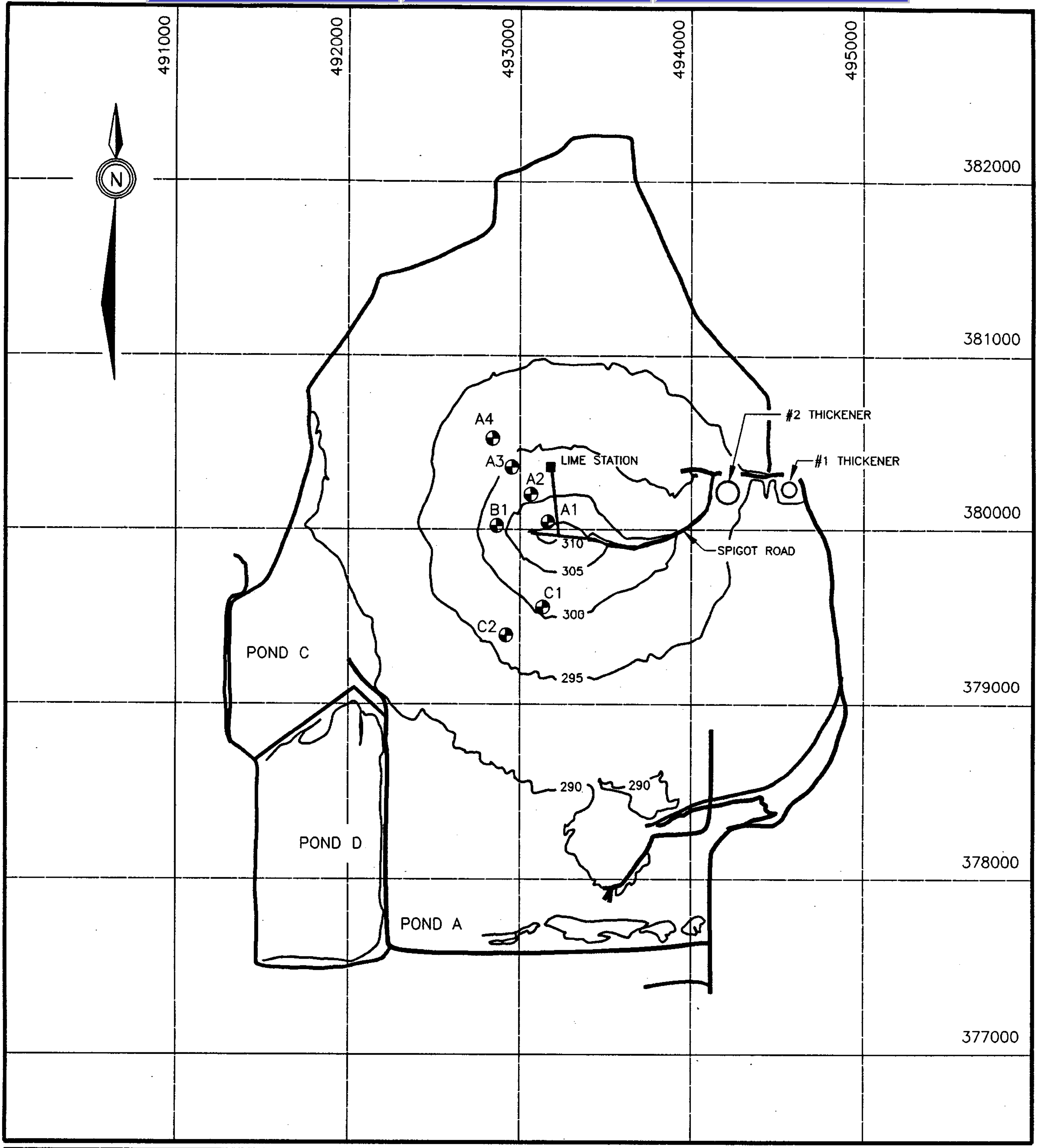


Figure 5. Drainage Curve of the Kidd Creek Tailings (after Yang *et al.*, 1992)



NORANDA TECHNOLOGY CENTER

HYDROGEOTECHNICAL GROUP

Figure 6. Piezometer Nest Location Map

TAILINGS DISPOSAL AREA
KIDD CREEK MINES LTD.

DRAWN BY: KSS	SCALE 0 0.5 1.0 km	DATE: MARCH 1993

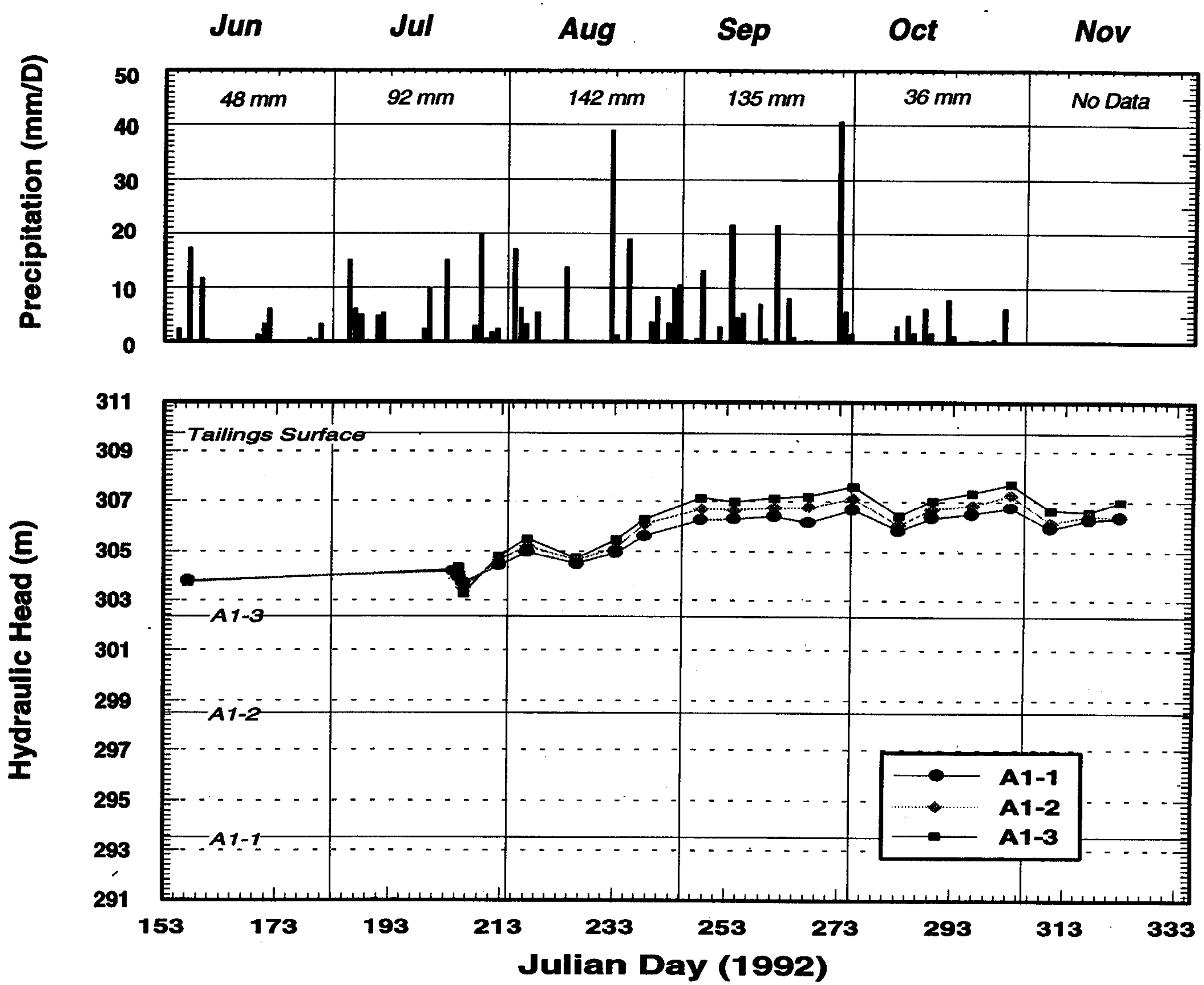


Figure 7. Hydrograph of Hydraulic Heads at NTC A1

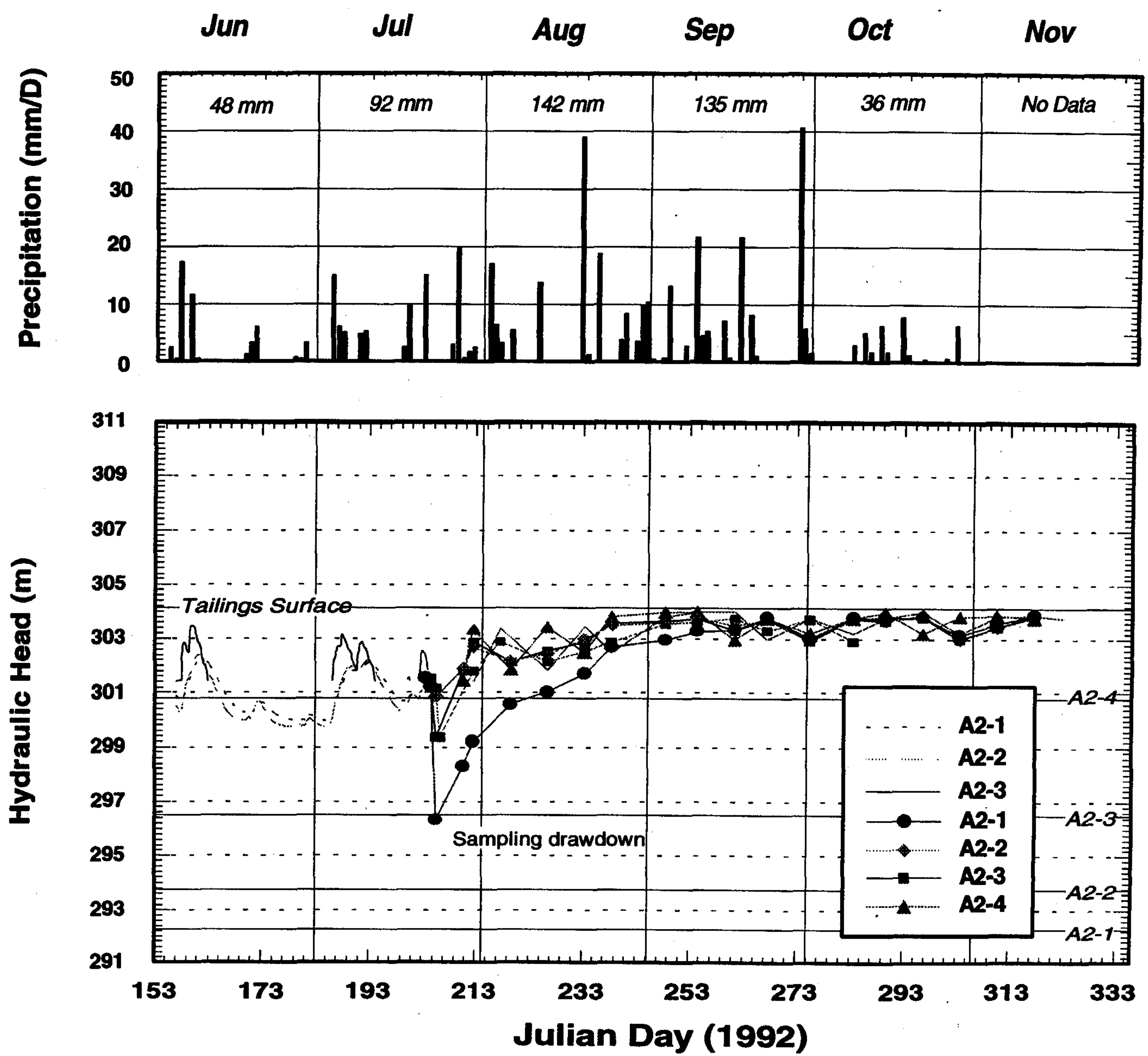


Figure 8. Hydrograph of Hydraulic Heads at NTC A2

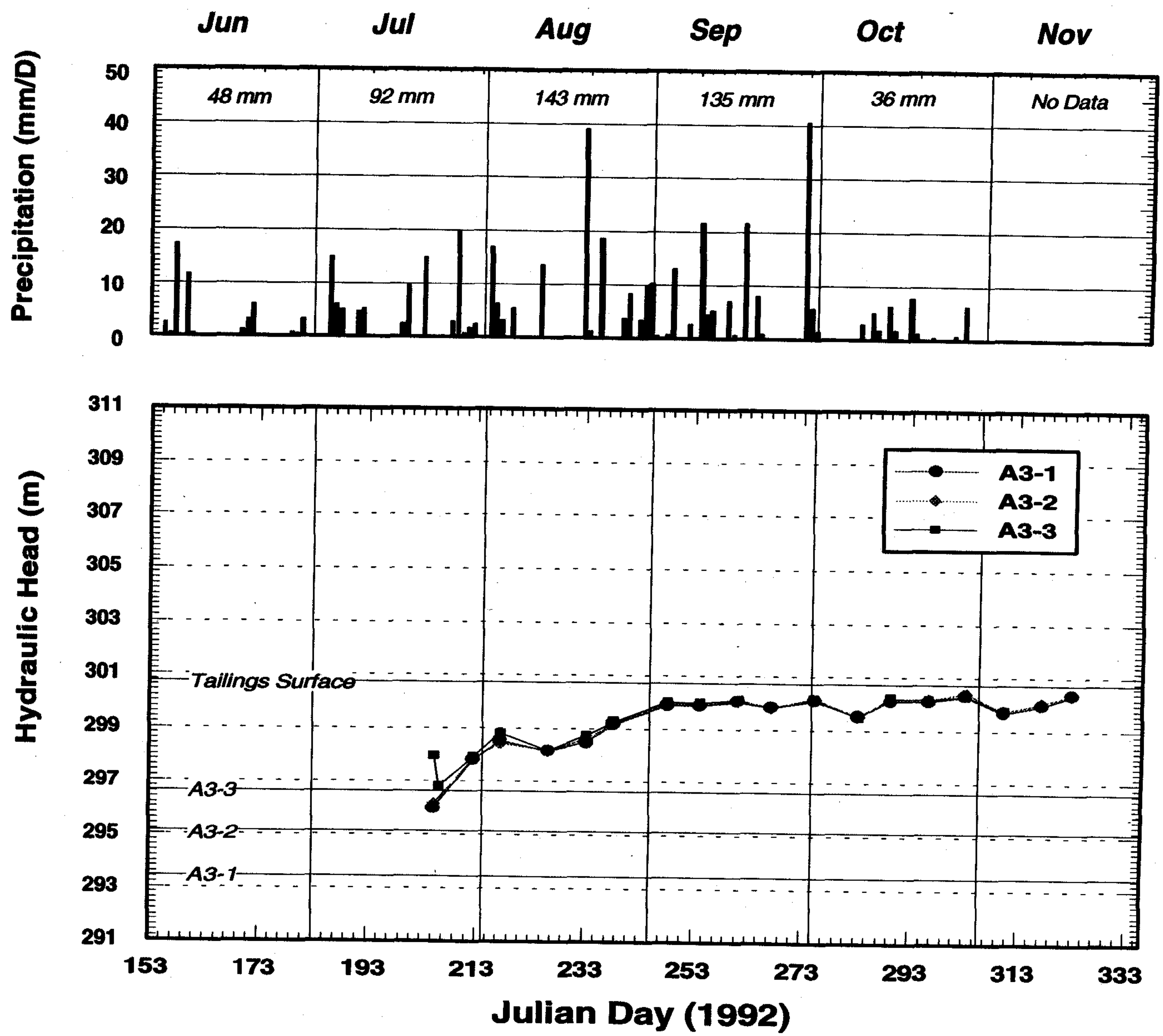


Figure 9. Hydrograph of Hydraulic Heads at NTC A3

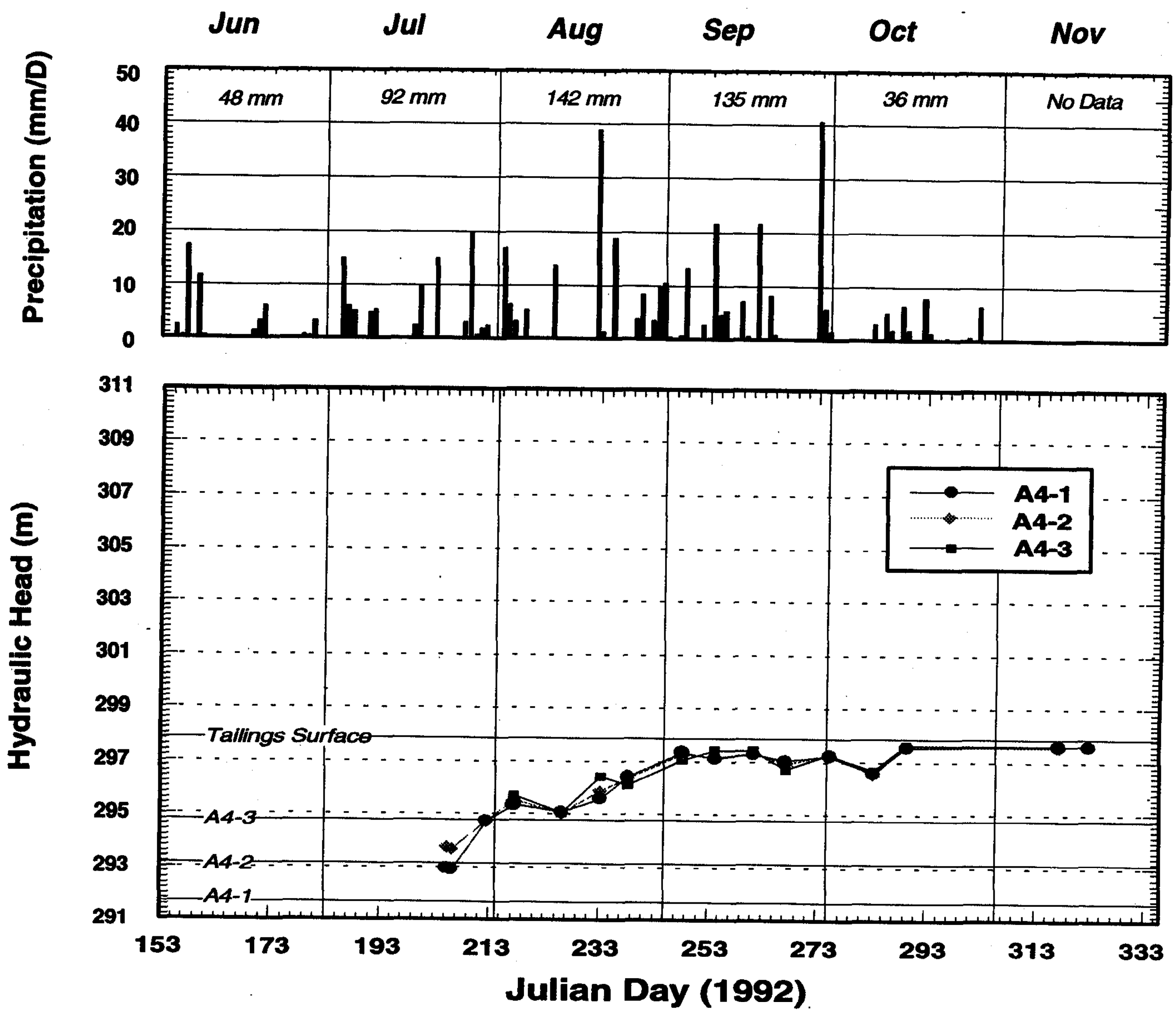


Figure 10. Hydrograph of Hydraulic Heads at NTC A4

Welcome Screen | Search | Report List

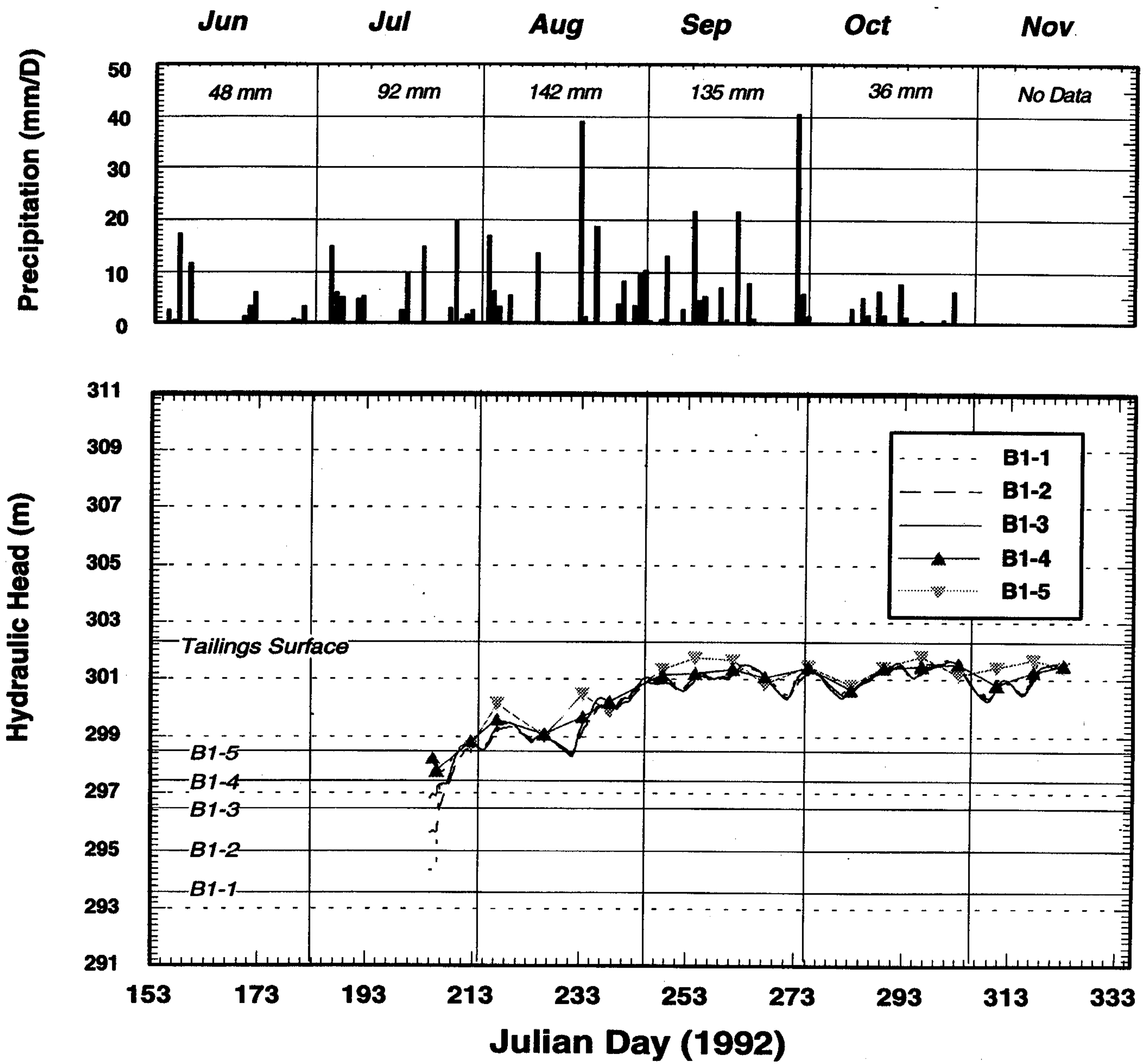


Figure 11. Hydrograph of Hydraulic Heads at NTC B1

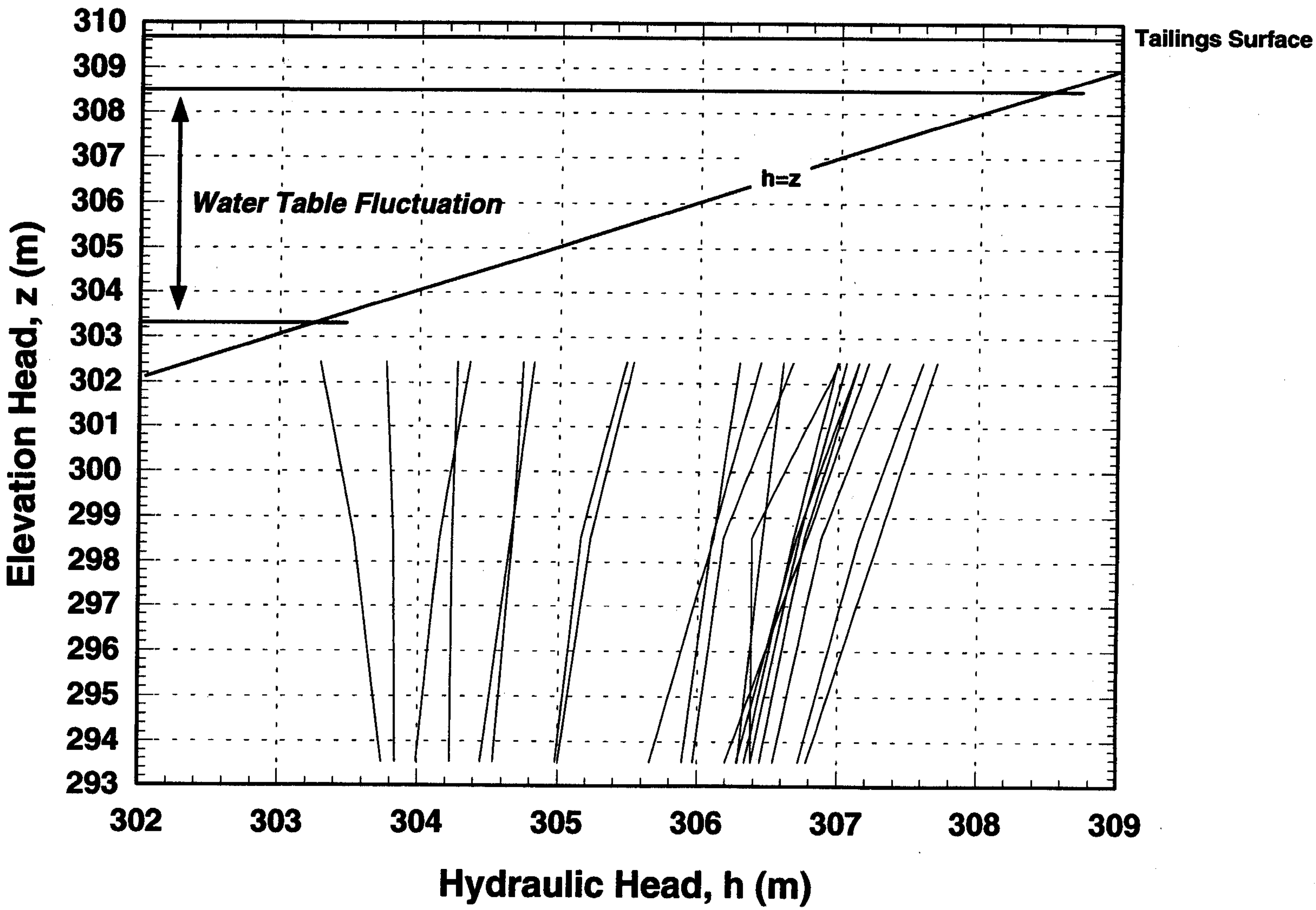


Figure 12. Hydraulic Heads at Piezometer Nest A1 August through November 1992

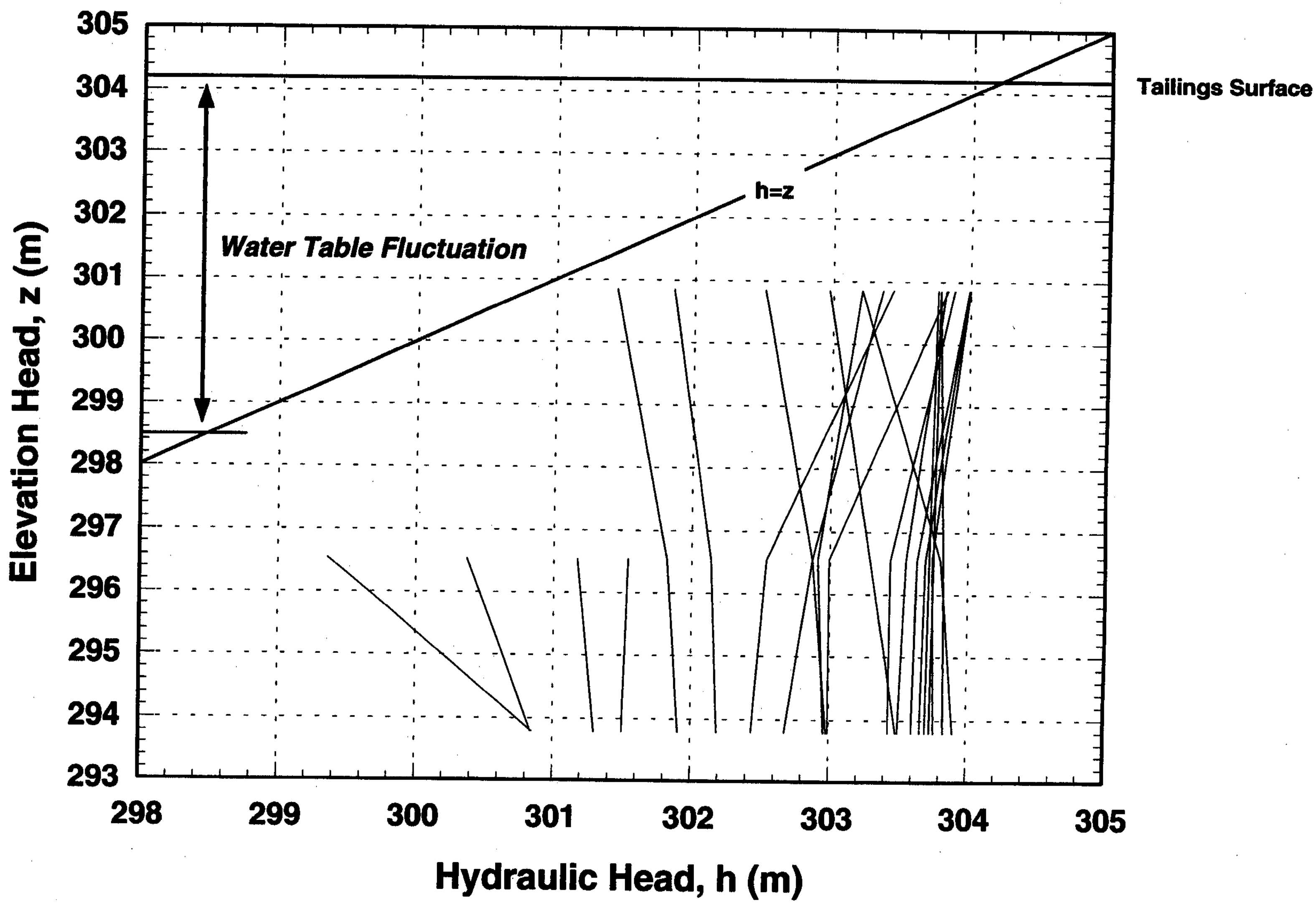


**Figure 13. Hydraulic Heads at Piezometer Nest A2
August through November 1992**

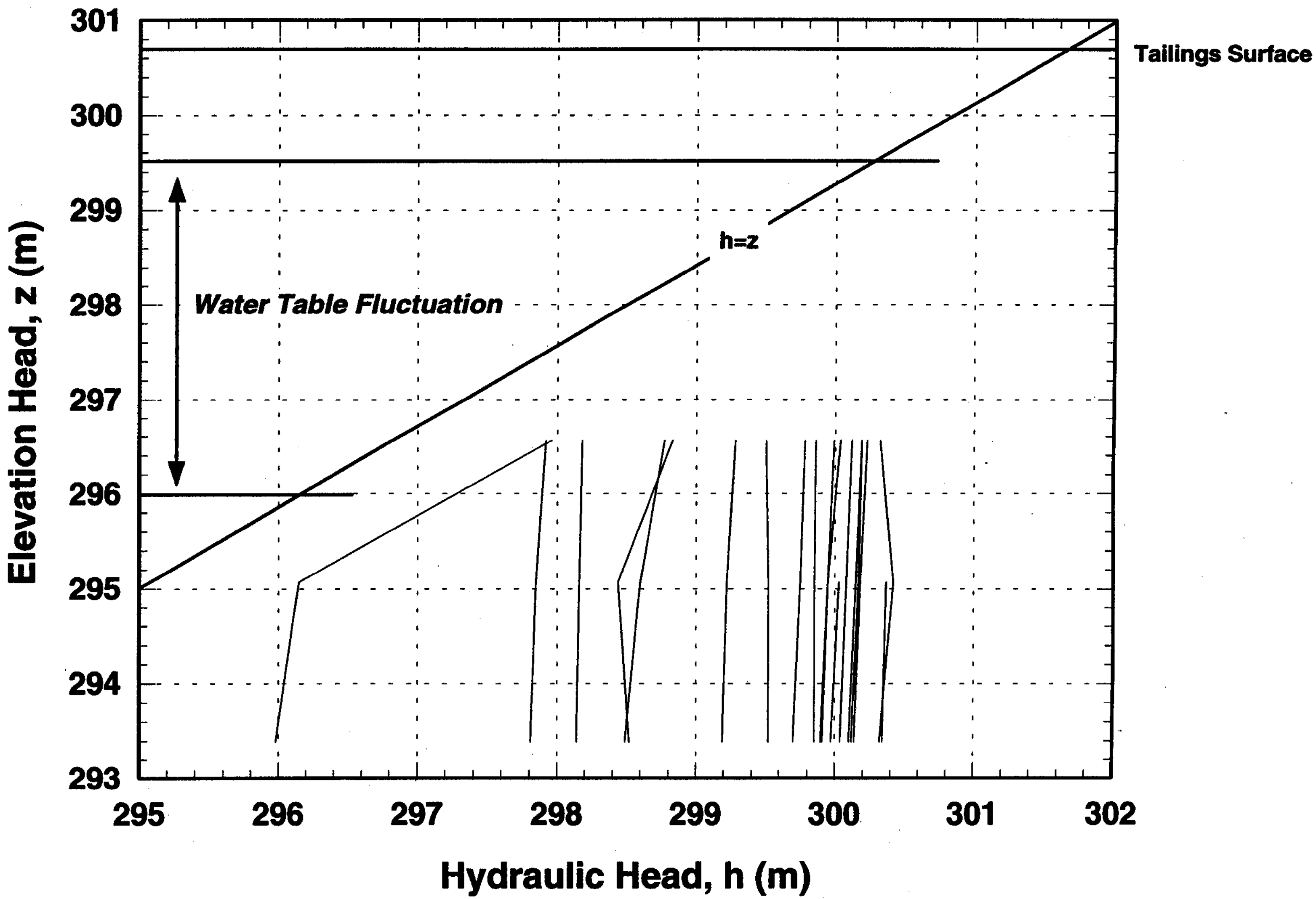


Figure 14. Hydraulic Heads at Piezometer Nest A3
August through November 1992

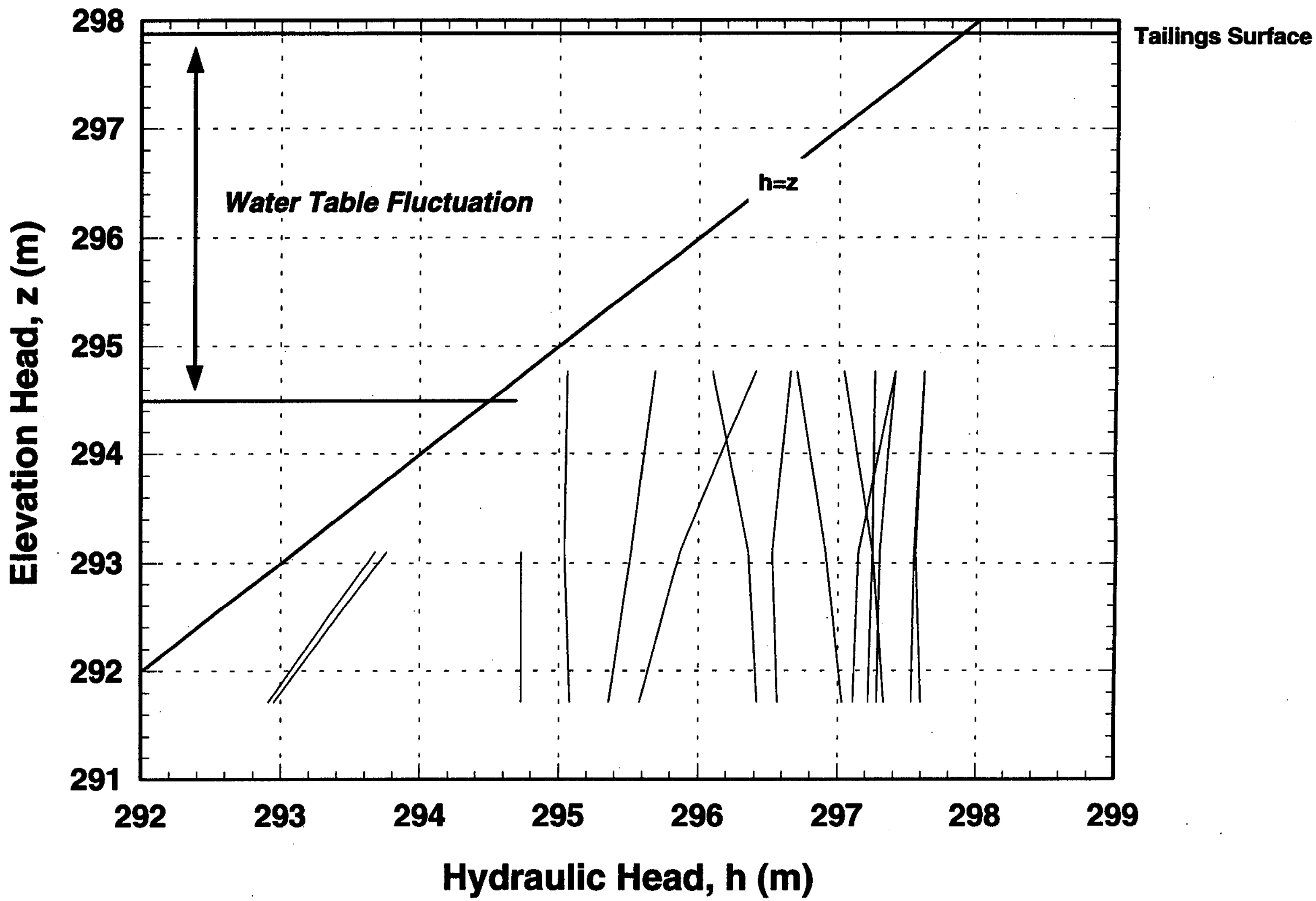


Figure 15. Hydraulic Heads at Piezometer Nest A4 August through November 1992

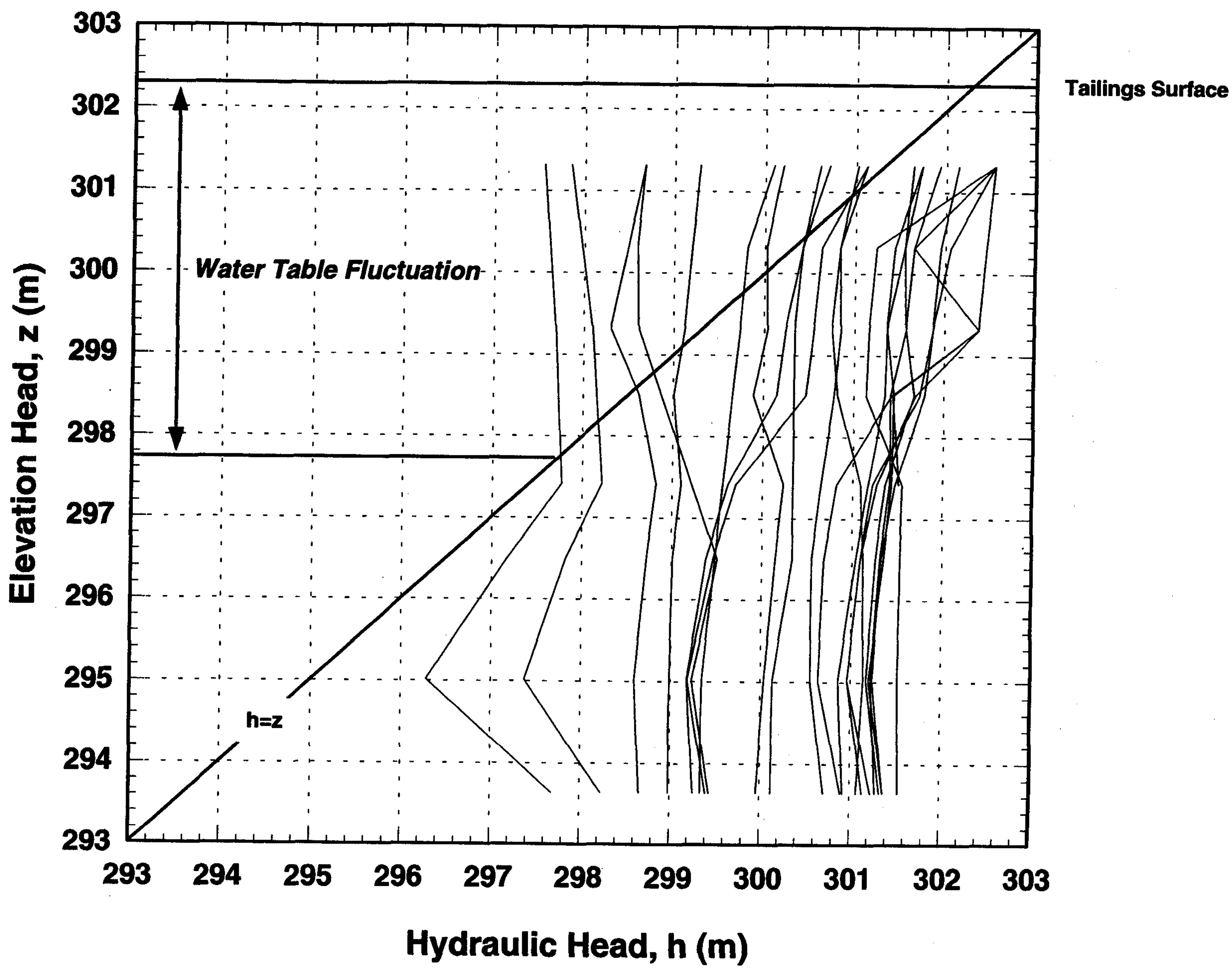
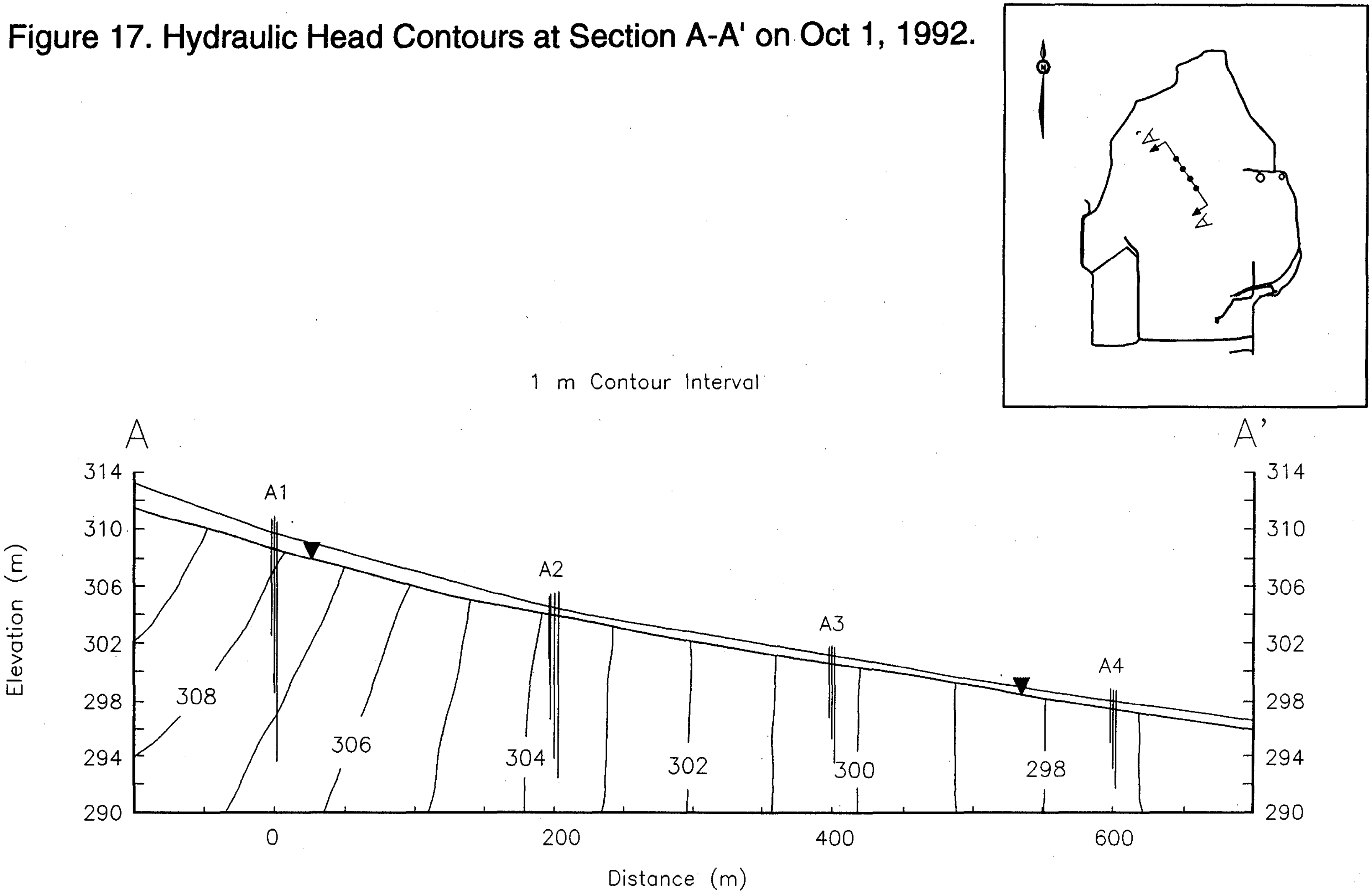


Figure 16. Hydraulic Heads at Piezometer/Tensiometer Nest B1, Tailings Meteorological Station, August through November 1992

Figure 17. Hydraulic Head Contours at Section A-A' on Oct 1, 1992.



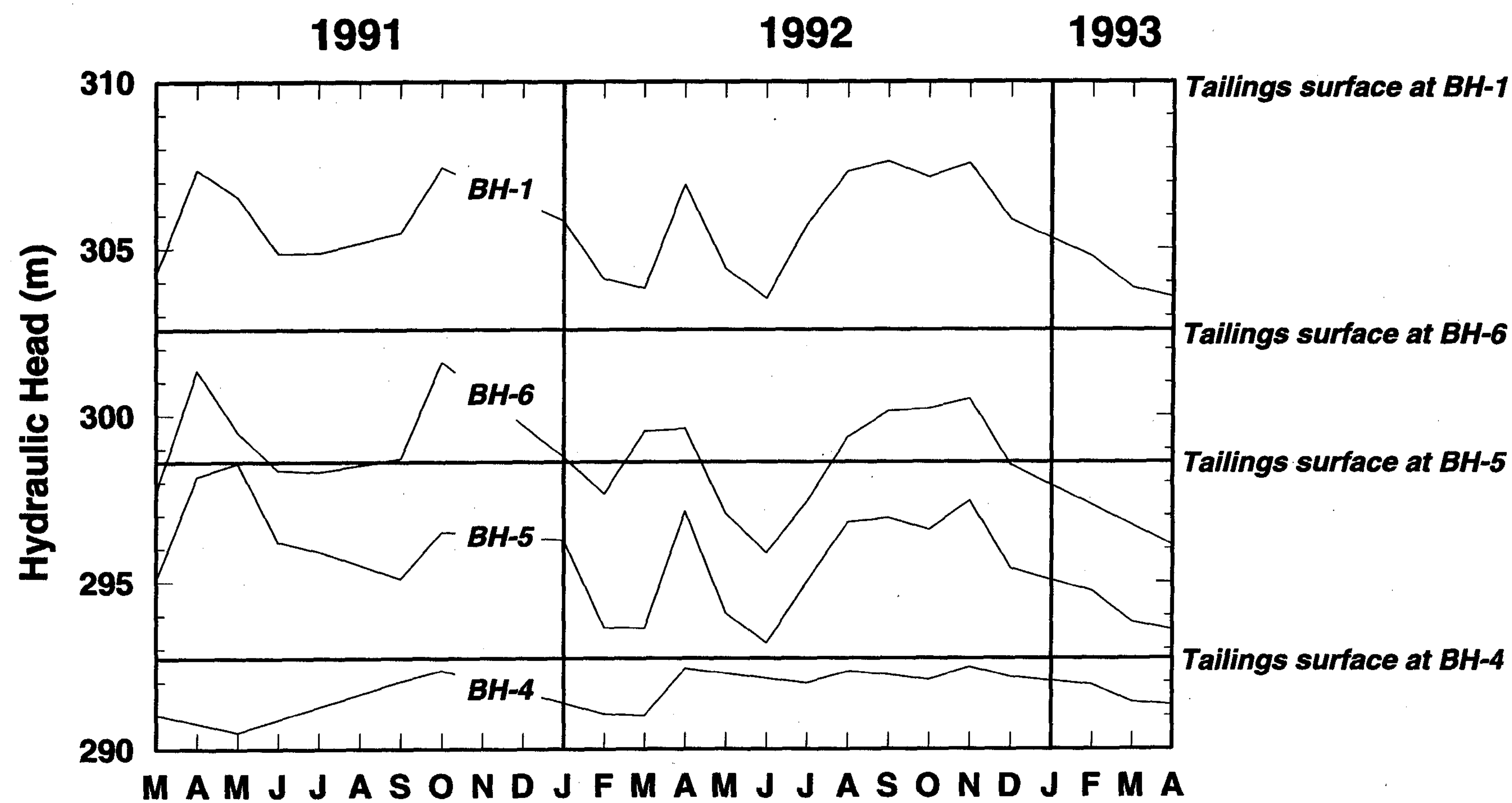
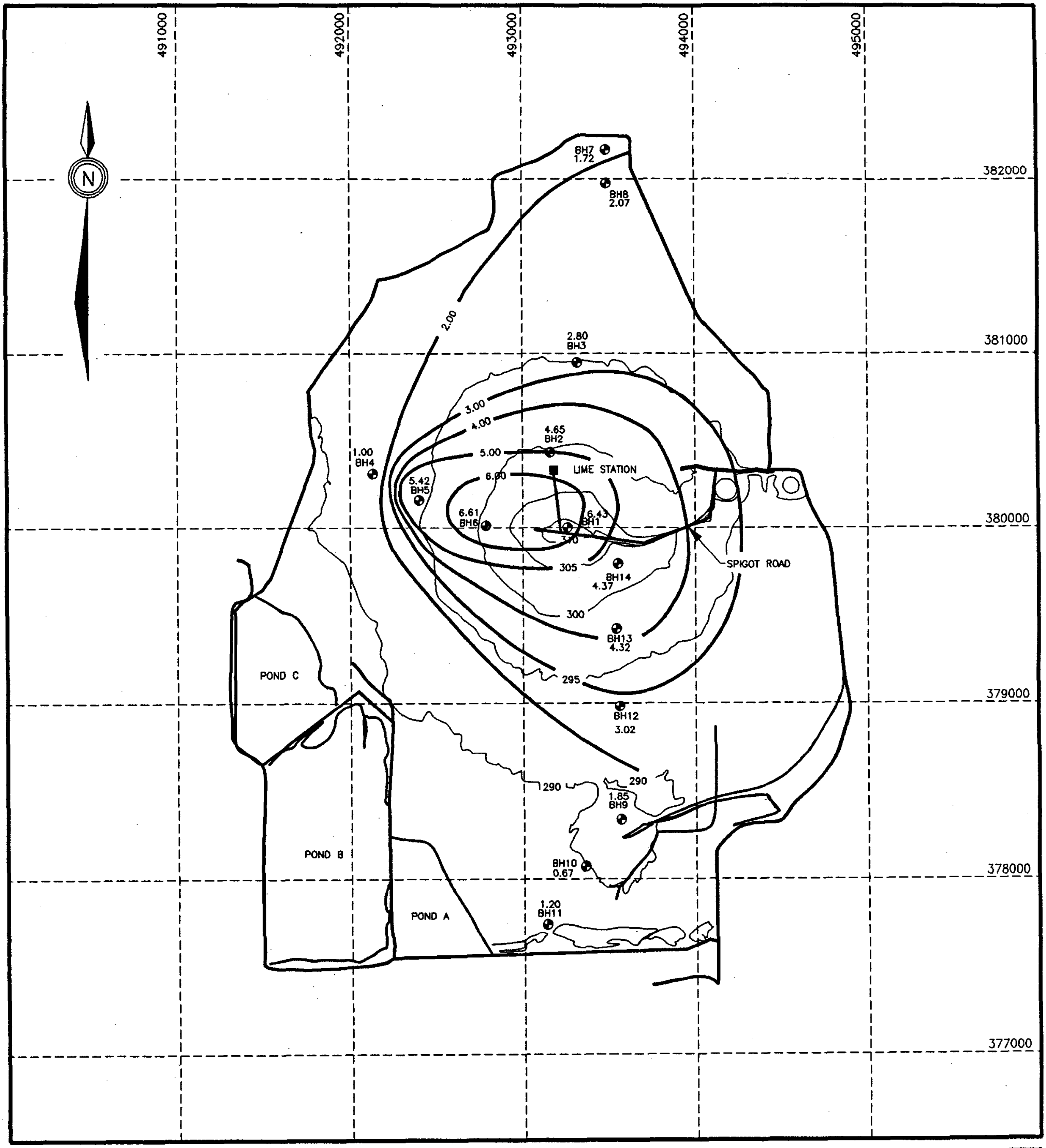


Figure 18. Hydrograph of Hydraulic Heads at BH1, BH4, BH5, and BH6



NORANDA TECHNOLOGY CENTER HYDROGEOTECHNICAL GROUP	Figure 19. Depth to Water Table Contour Map TAILINGS DISPOSAL AREA KIDD CREEK MINE LTD.	
DRAWN BY: KSS	DATE: MAY 1993	SCALE 0.0 – 1.0 Km

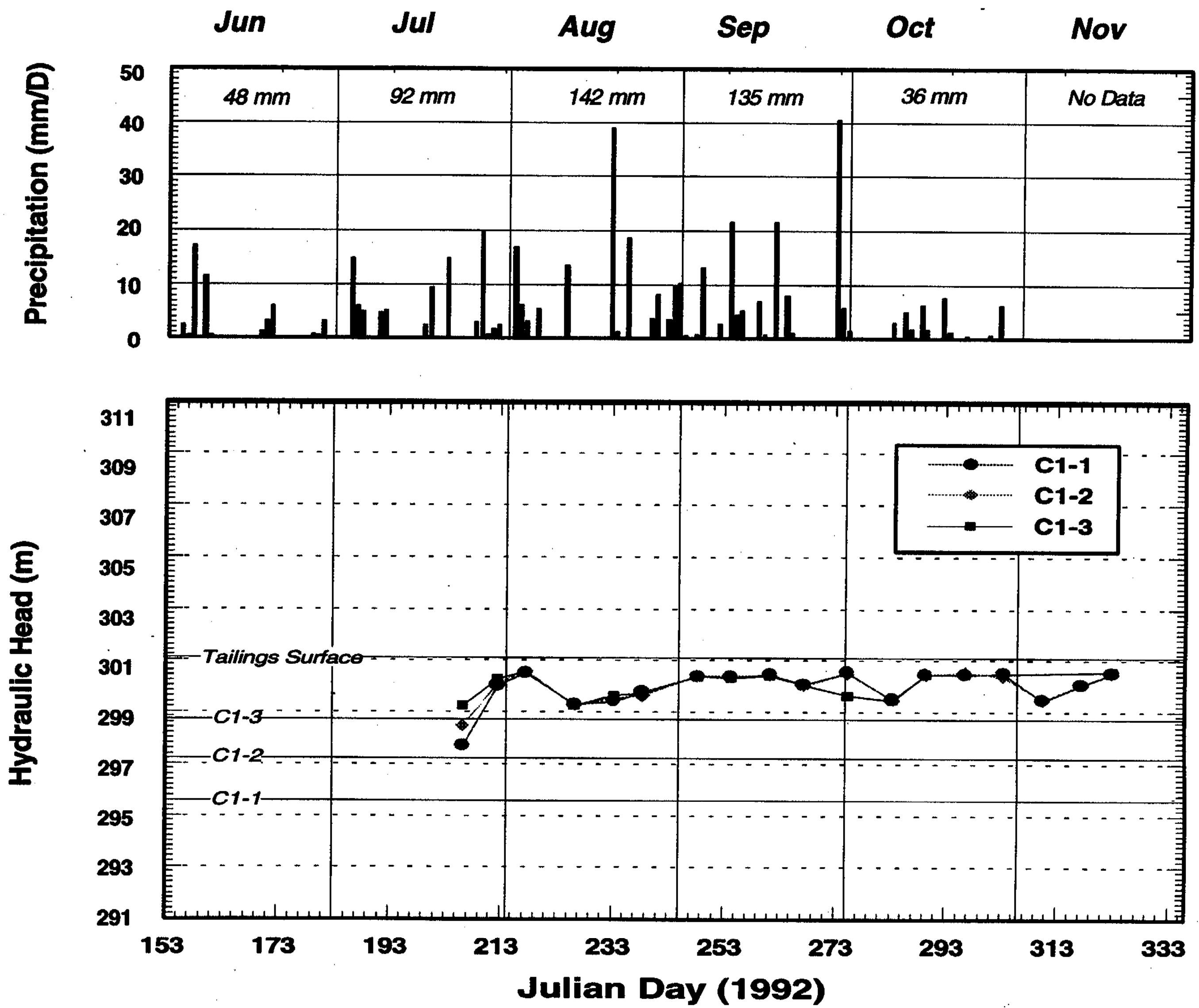


Figure 20. Hydrograph of Hydraulic Heads at NTC C1

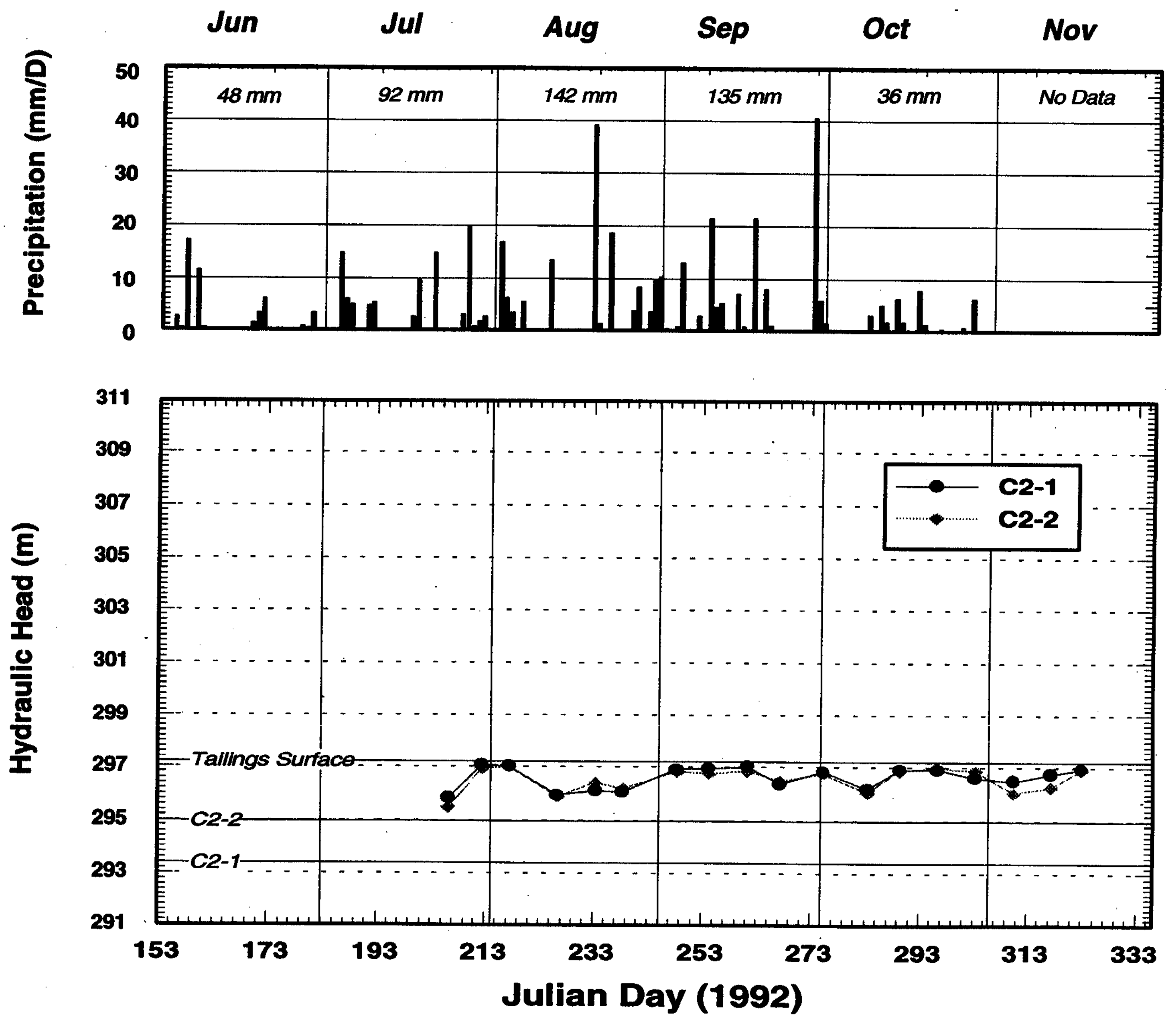


Figure 21. Hydrograph of Hydraulic Heads at NTC C2

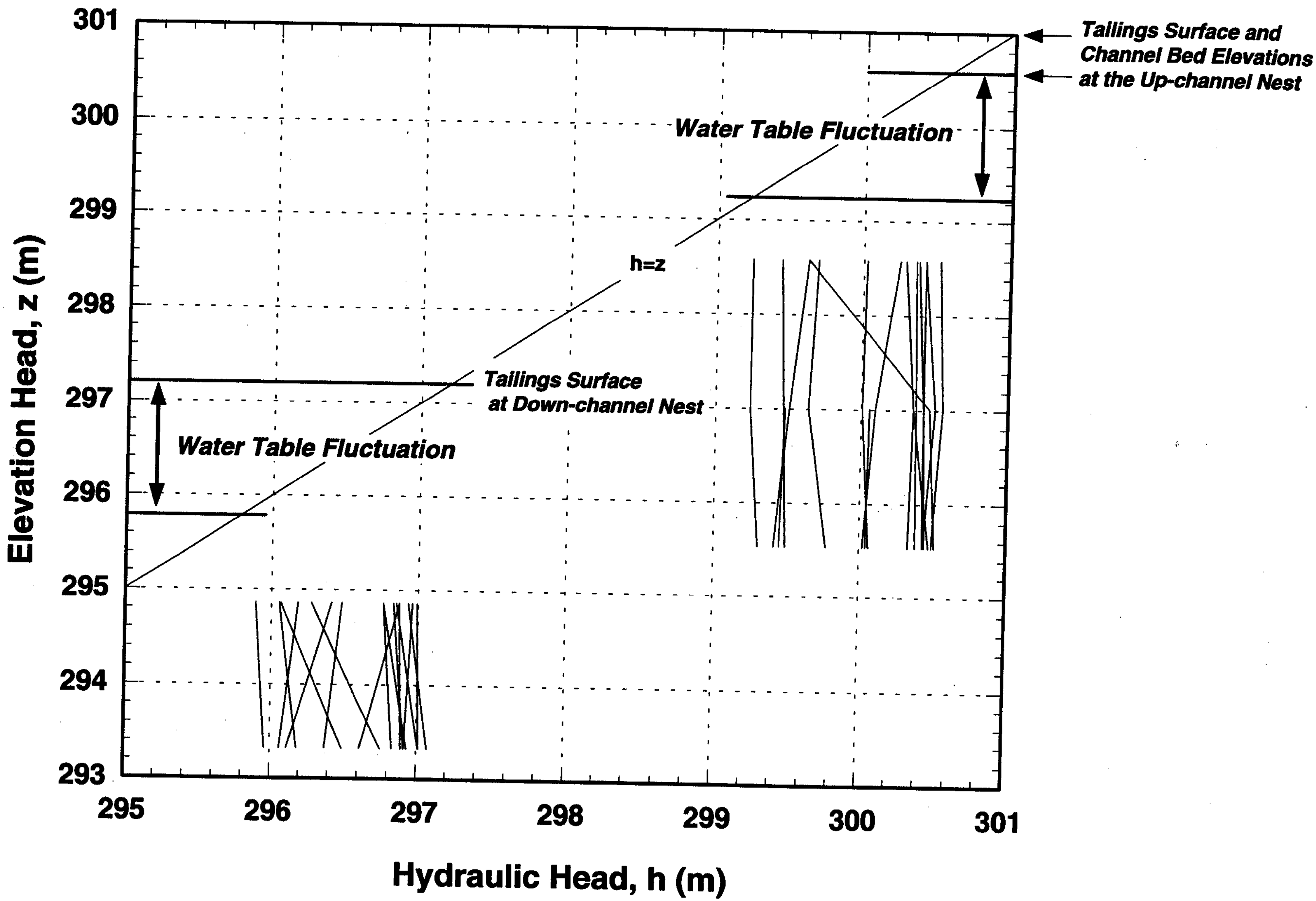


Figure 22. Hydraulic Heads at Piezometer Nests C1 and C2 below an On-cone TTD Channel, August through November, 1992

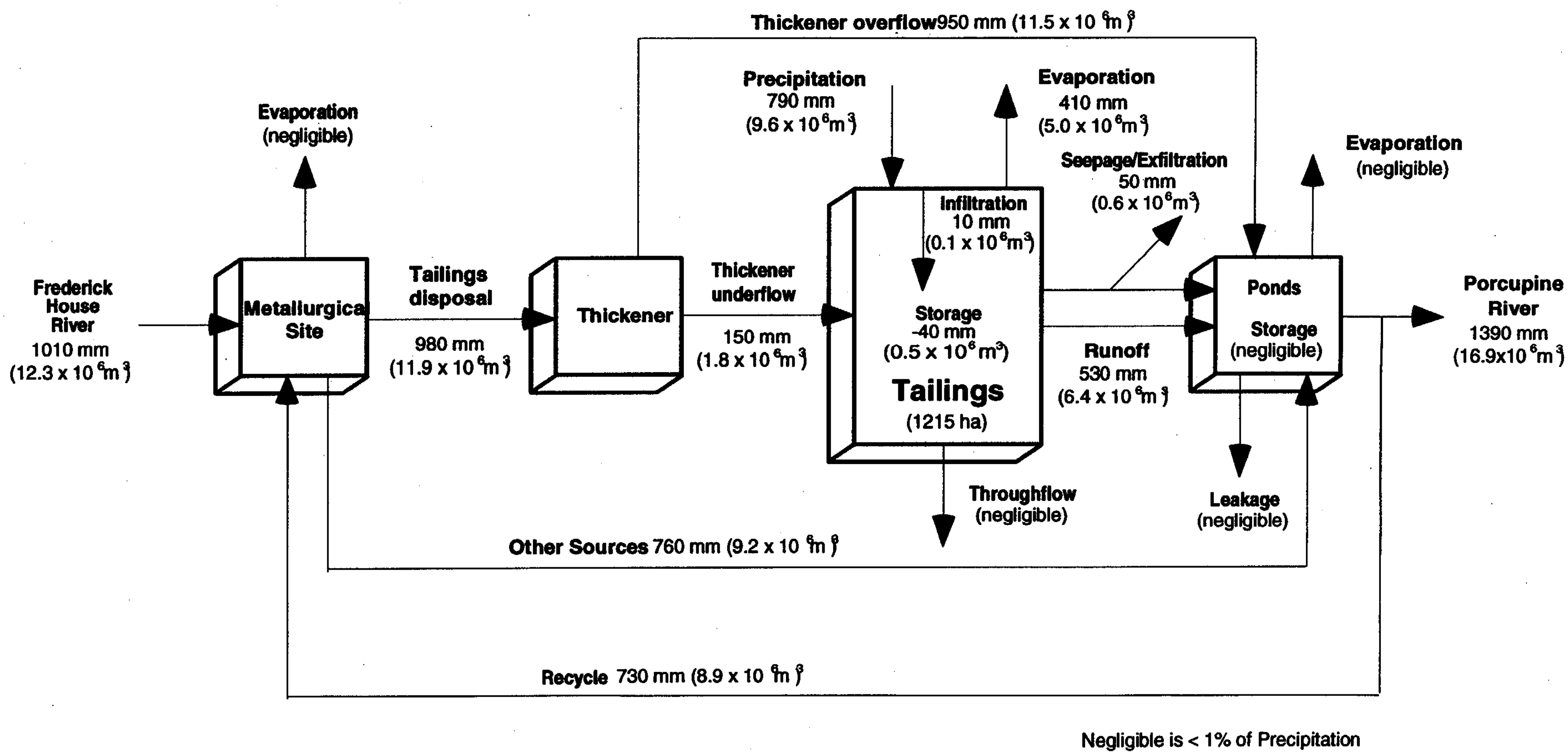


Figure 23. Water Balance of the Kidd Creek Thickened Tailings Site, 1992

3.0 Geochemistry

The present geochemical conditions of the thickened tailings cone was analyzed by characterization of the oxidation rate and pore water chemistry. Tailings oxidation rate was analyzed using observed oxygen profiles of the near surface tailings (top 1 m) and the mass-transport computer model POLLUTE. Saturated tailing pore water was sampled from the piezometers and analyzed for metals and general minerals. The laboratory analysis from both the 1991 and 1992 sampling appear in Appendix E.

3.1 Tailings Oxidation

Pore gas was measured for gaseous oxygen concentration at various depths in the tailings. The concentrations were measured in 6 mm stainless steel tubes which were permanently placed at depth and sealed from side tube leakage (Fig. 24). The buried end of the tube was rapped with geotextile, placed in sand at the bottom of an auger hole and sealed to the surface with bentonite. The exposed end of the tube, from which to extract a gas sample, was sealed with a rubber septum. A teledyne portable oxygen gas meter, equipped with a syringe needle which to sample a small volume of gas, was used to measured the gaseous oxygen concentration.

Gaseous oxygen monitoring nests were installed in July of 1992 and were located at the top of the cone, near piezometer nests A1 and B1, where oxidation is most likely occurring. Oxygen profiles measured two days after installation are presented in Fig. 25. The shape of the profiles at the two stations are similar, and indicate a linear depletion of oxygen concentrations down to a depth of 0.7 m. This would suggest that very little oxygen consumption due to pyrite oxidation reactions would be occurring along the profile. This concept is illustrated by the lines on Fig. 25 which were produced using the mass-transport computer model POLLUTE. A profile where oxygen consumption occurs is curvilinear, like the solid line on Fig. 25 which was produced using a reaction constant K of 0.06/day. In order to adequately represent the field data, the model was run with no reactions occurring above 0.7 m, and a K of 0.18/day from 0.7 m to 1.0 m.

Linear profiles may indicate sulphide depletion in the top 0.7 m of the tailings profile at nests A1 and B1, or an absence of oxygen consumption due to other factors. It is also possible that equilibration of the oxygen probes had not occurred before the sampling; more readings will be taken in the near future to verify this.

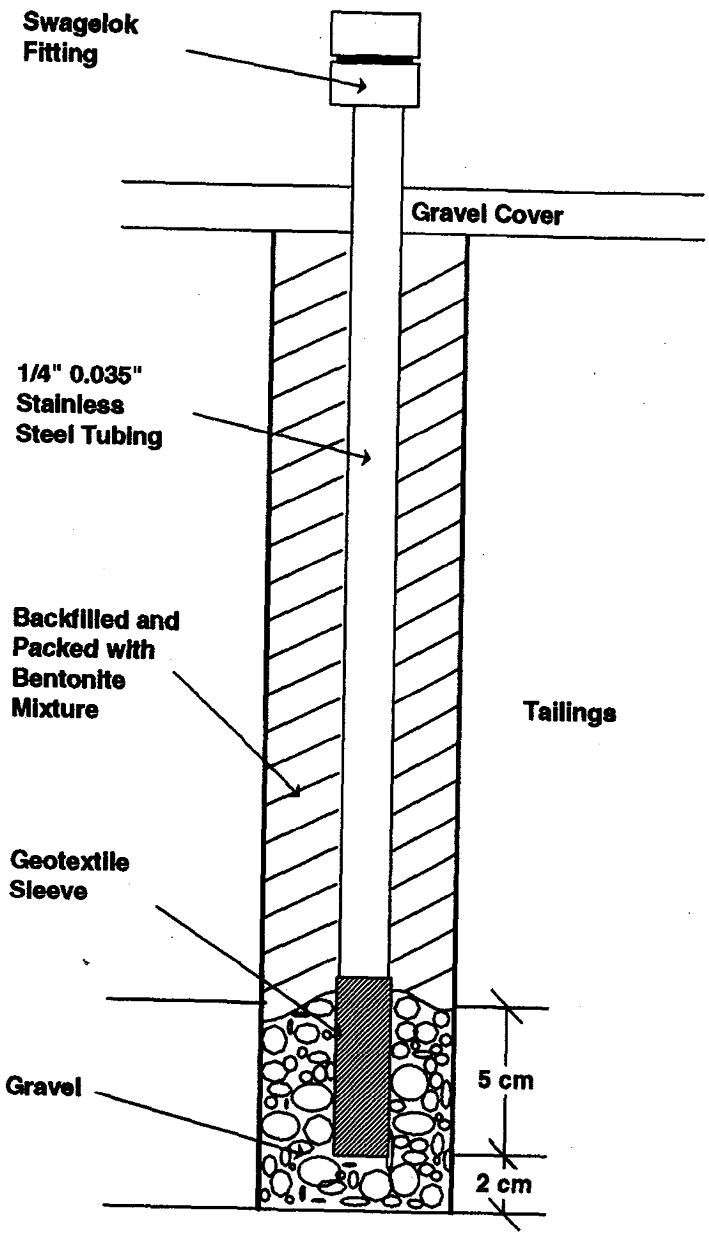


Figure 24: Pore Gas Sampling Probe

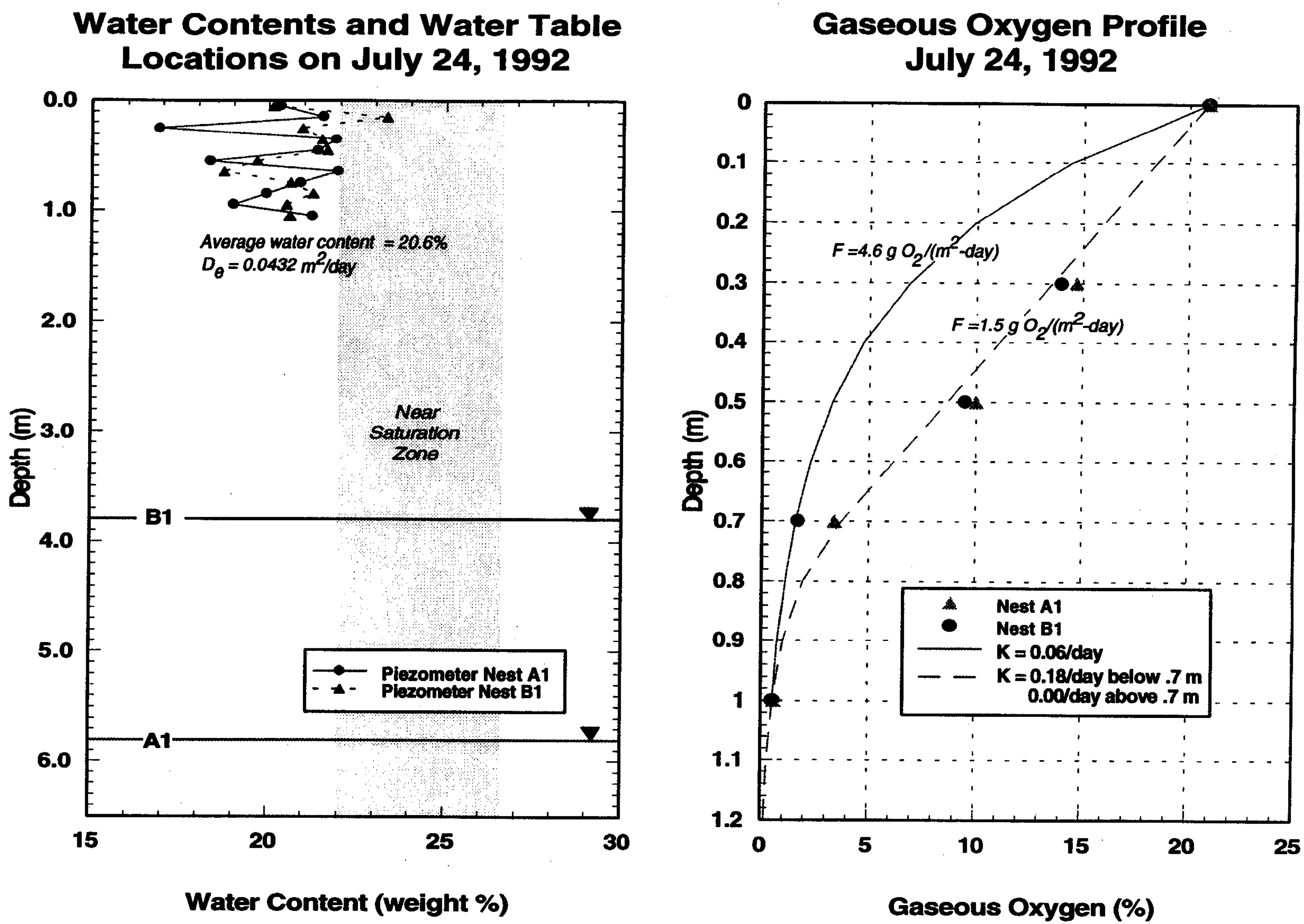


Figure 25. Vertical Profiles of Water Contents, Water Table Location and Gaseous oxygen concentrations at NTC A1 and A2 on July 24, 1992.

3.2 Tailings Pore Water Sampling and Analysis

Sampling of saturated zone pore water was conducted in each piezometer that was installed by NTC. The methods are found in Appendix E.

1991 sampling: Zn, Fe(T) (total iron), and SO_4 (sulphate) concentrations at different depths in the unsaturated zone reached respective values of 533 mg/L, 125 mg/L, and 2020 mg/L (Station A1). High Cu concentrations of 184 mg/L were also encountered. Complete results are listed in Appendix E.

In the saturated zone, Zn, Fe(T) , and SO_4 concentrations reached respectively 5.44 mg/L, 119.86 mg/L, and 1430 mg/L. The pH varied from 5.9 to 8.0, and specific conductance ranged from 2220 µS/cm to 6990 µS/cm. These measurements indicate that some degree of sulphide oxidation is occurring within the tailings mass.

Metal concentrations generally decreased with depth at stations A1 and A2, with the highest concentrations occurring immediately beneath the water table. For example, the Fe(T) concentration of 119.86 mg/L was recorded in A2.4, located at a depth of 3.83 m from the surface. Total iron concentration decreased to 4.17 mg/L at A 2.3, at a depth of 8.5 m. Corresponding Zn concentrations decreased from 5.44 mg/L to less than 0.02 mg/L, and SO_4 values, from 1390 mg/L to 705 mg/L. These trends are typical of oxidizing sulphide tailings, when dissolved metals enter the pore water in the shallow unsaturated zone prior to being transported downward in the saturated zone.

1992 sampling: Maximum measured concentrations were 2.7 mg/L for Zn (at A1.3), 178.6 mg/L for Fe(T) (B1.3), and 4970 mg/L for SO_4 (A4.2). These maximum concentrations are lower than those measured in 1991, mainly because some of the shallower piezometers dried under low water table conditions. The water samples were at a minimum of 2 m below the water table surface at most stations except A4 (A4.3 was less than 50 cm below the water table in August).

Discussion: It is generally agreed that the unsaturated zone in an oxidizing tailings mass can be separated into three zones (Blowes and Jambor, 1990): a shallow, sulphide-depleted zone where oxidation reactions have completely consumed sulphide minerals; an intermediate, active-oxidation zone where oxidation reactions occur; a deeper buffering zone, where dissolved metals are removed from solution by chemical reactions such as precipitation and co-precipitation. The 1991 and 1992 water sampling suggest that most of the metals dissolved in pore water are removed in the unsaturated zone. Metals seem to reach the shallow saturated zone only at relatively small concentrations (Zn < 6 mg/L).

Chemical removal mechanisms such as precipitation of Fe hydroxides and sulphates and co-precipitation of Zn with Fe are probably responsible for the decrease in dissolved metal concentrations with depth. More detailed assessments of the pore water and solids chemistry is being pursued as part of another study.

Local variations in the solids and pore water chemistry could be expected from visual traces of sulphide oxidation observed during the excavation of a 2 m deep test pit near A1. The reddish-brown colouring typical of Fe oxides and hydroxide formation did not form a distinct front such as seen in other tailings deposits (for example at Waite Amulet, NTC, 1990), but was rather randomly distributed along straight, sub-vertical planes, probably old desiccation cracks. Close observation of the hydroxide coating revealed that it is very thin (1 mm) and superficial, suggesting that these vertical oxidation zones were limited.

4.0 Summary

The general objectives of the investigation were to verify the hydrology of the thickened tailings disposal site and to assess the impact of tailings oxidation to the immediate hydrologic environment. The measurement and compilation of hydrologic and hydrogeologic data was conducted. Pore water quality sampling and analysis were conducted. Interpretation of these data were conducted and hydrologic budgets were developed for 1992, normal conditions and extreme dry conditions.

4.1 Findings

(1) During rising water table (recharge) conditions, following summer drawdown the thickness of saturated pores (capillary fringe) above the water table at the top of the tailing cone was observed to be 4 m. A maximum thickness of 5 m to 6 m, which is predicted from published drainage curves of the Kidd Creek tailings, is expected at the top of the tailings cone during summer drawdown.

(2) A depth to water table contour map was developed for the lowest observed water table position during 1991 and 1992. The 5 m contour delineates the area of enhanced surface tailings oxidation.

(3) The water balance predicted an infiltration deficit for extreme dry conditions (Table 11), which results in surface tailings de-watering at the end of the year that is similar to the de-watered conditions during the summer of 1992. Above normal precipitation will likely replenish the deficit. Infiltration during normal conditions is similar to the 9% that was predicted with the HELP model (Robinski *et al.*, 1991).

Table 11. Water balance summary expressed as percent of precipitation.

Hydrologic Component	1992	Normal Conditions	Extreme Dry Conditions
Runoff	48	42	39
Evaporation	51	51	72
Infiltration	1	7	-11

(4) The influx of water by tailings slurry discharge for recharge to the tailings cone was deduced to be negligible in the water balance.

(5) Hydraulic gradients indicate that pore water tends to move downward in the saturated zone near the centre of the tailings, and tends to move upward (and

exfiltrates) along the slope of the tailings. However, the average horizontal linear pore water velocities in the tailings are very low (12 cm/y).

(6) Analysis of pore water indicates that sulfide oxidation is occurring in the tailings mass.

4.2 Conclusions

(1) Considering the tailings cone as is, then following closure, tailings saturation and water table position is expected to resemble that presently observed in areas of the cone where deposition is not active.

(2) De-watering during a draught year is expected to have little impact on long-term saturation of the tailings. However during these periods, oxidation is promoted deeper in the surface tailings.

(3) Release of contaminants from the tailings site to the environment should remain at present rates because pore-water velocities are slow, and because of the sustained presence of near-surface saturated conditions.

4.3 Recommendations

(1) Measurements of the water balance components should be continued in 1993 to validate the 1992 findings.

(2) Pore gaseous oxygen and pore water quality sampling and interpretation should continue to obtain a better understanding of the geochemical processes undergoing in the tailings.

(3) The effect of decommissioning options on tailings saturation and oxidation should be addressed.

5.0 References

ABDUL, A.S., and R.W. GILLHAM (1984). Laboratory studies of the effects of the capillary fringe on streamflow generation, Water Resources Research 20 (6), p. 691-698.

BLOWES, D.W., and JAMBOR, J.L., (1990). The pore water geochemistry and the mineralogy of the vadose zone of sulphide tailings, Waite Amulet, Quebec. Applied Geochemistry, 5.

BOWEN, I.S., (1926). The ratio of heat losses by conduction and by evaporation from any water surface. Phys. Rev. 27: 779-787.

KIDD CREEK (1990). Preliminary metallurgical site water balance. Internal files, Kidd Creek Division, Falconbridge Limited.

NORANDA TECHNOLOGY CENTRE (1990). Generation and evolution of acidic pore waters at the Waite Amulet tailings. Final report to CANMET, DSS contract No. 09SQ.23440-8-9162.

NORANDA TECHNOLOGY CENTRE (1992). Hydrological evaluation of the thickened tailings disposal system at Kidd Creek Division, Falconbridge Limited. Presented to Falconbridge Ltd., Kidd Creek division, Environmental control and services.

O'CONNORS (1991). Geotechnical report presented to Kidd Creek Division, Falconbridge Limited.

PAUL WISNER AND ASSOCIATES INC., and W-E-R ENGINEERING LTD. (1993). Tailings area surface hydrological study Falconbridge Ltd Kidd Creek division. Phase I final report presented to Falconbridge Ltd., Kidd Creek division, Environmental control and services.

QUIGLEY, R.M., (1980). Geology, mineralogy and geochemistry of Canadian soft soils: a geotechnical perspective. Canadian Geotechnical Journal, 17: 261-285.

ROBINSKY, E.I. (1975). Thickened discharge -- A new approach to tailings disposal, Bulletin, The Canadian Institute of Mining and Metallurgy, pp. 47-59.

ROBINSKY, E.I., (1978). Tailings disposal by the thickened discharge method for improving economy and environmental control, in: Tailings Disposal Today, Volume 2: Proceedings of the Second International Tailings Symposium, Denver, Co.,pp 75-92.

ROBINSKY, E.I., (1982). Thickened tailings disposal in any topography. Light Metals, 239.

ROBINSKY, E.I., (1986). Solving some difficult geotechnical problems with the thickened tailing disposal system. 3rd Conference on Construction and Mining in Difficult Soils. Sudbury, Ontario.

ROBINSKY, E.I., (1987). Current status of the sloped thickened tailings disposal system. Proceedings of the international conference on Bauxite Tailings, Kingston, Jamaica, 1986, pp. 91-99.

ROBINSKY, E.I., (1990). Depositional behaviour of thickened tailings and their hydrology Kidd Creek Mines. Draft report presented to Falconbridge Limited, Project 89-566.

ROBINSKY, E., BARBOUR, S.L., WILSON, G.W., BORDIN, D., and FREDLUND, D.G., (1991). Thickened sloped tailings disposal: an evaluation of seepage and abatement of acidic drainage. Draft paper to be presented at the Second International Conference on the Abatement of Acidic Drainage, Montreal, September 1991.

SALVAS (1989). Beneficial characteristics of sloped tailings deposits.

SHIELDS, D. H., (1975). Innovations in tailings disposal. Can. Geotech. J., 12, pp. 320-325.

YANG, N., BARBOUR, S.L., and WILSON, G.W. (1992). A laboratory characterization of the properties of the Kidd Creek thickened tailings required for evaporative flux modelling.University of Saskatchewan, Dept. of Civil Eng, Geo-Environmental Engineering Group, 74 p.

YEOMANS, T.J., (1985). Tailings disposal at Kidd Creek Mines Ltd. Proc. Can. Mineral Processors, 17th Annual Meeting, Ottawa, 1986, pp. 184-223.

Appendix A

Meteorological data collected at Kidd Creek thickened tailings

Summary of the meterological data collected at Kidd Creek thickened talings.

Meterological Parameter		1991 Aug	1991 Sep	1991 Oct	1992 Jun	1992 Jul	1992 Aug	1992 Sep	1992 Oct	1992 Nov
Precipitation (mm)	Total	80.8	87.8	61.8	48.0	91.7	142.5	135.4	35.6	-
	Average	2.6	2.9	2.0	1.6	3.0	4.6	4.5	1.1	-
	Maximum	44.4	21.3	11.7	17.3	19.8	39.1	40.6	7.9	-
Pan Evaporation (mm)	Total	-	70	54	188	156	141	103	25	-
Soil Evaporation (mm)	Total	58	46	25	-	-	-	-	-	-
Soil Temperature (C)	Average	19.8	12.0	5.0	15.7	19.8	15.4	10.6	3.9	-0.5
	Maximum	35.7	25.1	15.4	30.4	33.6	34.0	22.5	18.1	-0.1
	Minimum	9.4	0.8	0.0	0.3	4.5	0.5	2.0	-0.6	-1.4
Air Temperature (C)	Average	17.6	10.1	4.0	13.9	15.4	13.2	9.5	2.3	-5.6
	Maximum	32.7	25.3	19.9	28.0	26.4	28.1	24.8	18.8	5.5
	Minimum	5.8	-2.6	-3.6	-1.2	2.7	3.6	-1.9	-6.6	-22.8
Dew Point Temperature (C)	Average	11.5	6.5	1.2	-	-	-	-	-	-
	Maximum	22.2	20.6	20.2	-	-	-	-	-	-
	Minimum	0.8	-3.9	-10.4	-	-	-	-	-	-
Relative Humidity (%)	Average	76.9	84.3	83.6	66.3	75.6	84.5	83.8	85.6	89.9
	Maximum	99.1	99.9	99.0	97.8	96.9	95.6	94.9	95.2	93.9
	Minimum	25.3	40.2	45.0	20.9	25.8	32.8	37.8	41.2	59.8
Wind Speed (m/s)	Average	3.7	4.7	4.7	4.4	3.9	3.4	4.7	4.0	4.0
	Maximum	9.5	13.0	11.8	12.6	8.6	9.4	11.0	10.3	9.1
	Minimum	0.4	0.4	0.8	0.5	0.5	0.5	0.5	0.6	0.4
Net All-Wave Radiation, Q (MJ/m2)	Total	289	200	130	280	281	239	169	78.2	-
Soil Sensible Heat, G (MJ/m2)	Total	13.3	-13.7	-2.68	18.1	15.2	-3.59	-11.1	-25	-
Air Sensible Heat, H (MJ/m2)	Total	123	73.0	39.8	-	-	-	-	-	-
Latent Heat, Le (MJ/m2)	Total	143	131	87.9	-	-	-	-	-	-
Bowen Ratio, B (H/Le)	-	0.86	0.56	0.45	-	-	-	-	-	-

Notes: (1) Soil temperature is an average of the top 10 cm, measured at 2 and 8 cm
(2) Air temperature and relative humidity were measured 2 m above the tailings surface
(3) Dew point was measured at approximately 1 and 2.5 m above the tailings surface and presented as a composite average
(4) Wind was measured at 3 m above the tailings surface
(5) Soil sensible heat flux was measured at 10 cm depth
(6) Air sensible heat flux was calculated by H=Q-G-Le
(7) Latent heat flux was calculated by Le=(Rn-G)/(1+B)
(8) Bowen ratio was calculated with air temperature and vapor pressure gradients

Meterological summary at Kidd Creek thickened tailings site, August 1991

Day	Soil Temperature			Air Temperature			Dew Point Temperature			Relative Humidity			Wind Speed		
	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (%)	Max (%)	Min (%)	Ave (m/s)	Max (m/s)	Min (m/s)
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	17.5	20.7	14.8	14.8	17.5	11.8	12.0	13.2	10.9	90.3	97.4	83.2	3.5	5.0	2.0
4	16.1	19.5	14.1	13.2	15.7	11.0	10.0	11.5	8.4	88.1	98.0	74.8	4.3	6.5	1.6
5	16.8	22.3	11.6	15.1	20.1	8.4	7.3	10.8	5.1	70.9	87.0	49.8	3.2	5.7	1.3
6	18.8	24.9	13.1	16.8	22.5	9.3	9.2	12.2	7.3	72.2	97.3	48.5	1.7	2.9	0.5
7	21.5	30.4	15.2	19.5	25.5	12.8	10.9	12.8	8.9	69.3	95.6	44.3	1.5	3.1	0.8
8	21.0	29.7	16.4	17.9	24.1	12.5	12.5	15.0	10.6	79.7	94.1	55.1	2.9	7.7	1.7
9	20.0	25.3	15.6	17.2	21.9	12.5	12.1	15.2	9.2	81.6	97.2	57.8	3.1	5.8	1.5
10	20.9	27.6	15.7	19.5	26.4	12.6	9.4	11.9	7.3	64.1	90.8	39.1	5.2	8.6	2.2
11	22.7	32.1	14.9	20.0	27.1	11.6	8.6	10.3	5.4	58.6	86.8	34.2	4.7	6.2	2.3
12	25.2	35.7	16.6	22.4	31.0	12.5	8.6	12.3	5.0	52.2	82.9	25.3	2.0	3.3	0.9
13	26.8	34.6	20.3	25.3	32.7	18.3	13.3	15.7	10.4	53.9	75.4	35.2	3.4	5.9	2.0
14	26.4	35.3	20.8	22.9	28.4	17.0	16.2	19.1	14.1	73.8	87.3	58.1	2.5	5.1	1.1
15	23.3	31.6	18.6	20.5	26.6	13.6	15.3	19.1	10.7	80.3	94.6	58.4	4.1	6.3	2.9
16	17.1	18.5	14.5	12.9	15.7	9.3	10.6	15.2	7.6	90.8	96.3	80.4	3.8	5.3	2.3
17	18.0	20.5	16.1	17.2	19.3	14.1	15.8	17.7	13.0	95.1	97.0	93.3	5.3	8.9	1.1
18	14.9	18.5	12.7	11.5	14.3	9.7	9.5	12.6	6.7	92.8	99.1	82.9	4.0	5.5	3.0
19	15.9	23.8	9.4	12.6	19.2	6.3	4.8	10.4	0.8	70.4	95.8	44.0	2.9	4.4	1.2
20	18.8	27.8	11.6	16.1	24.2	7.8	7.3	11.8	5.0	69.0	98.5	38.1	1.6	3.1	0.4
21	20.4	29.1	13.3	18.8	25.9	11.3	7.8	10.8	4.9	59.4	82.3	34.3	3.5	5.6	1.7
22	16.3	19.2	12.9	13.1	18.9	9.1	10.3	14.4	7.1	88.7	97.5	59.6	4.9	7.1	2.5
23	14.9	21.9	11.3	10.4	15.4	6.9	5.7	7.2	3.0	81.8	98.4	59.3	2.1	3.9	1.2
24	17.5	26.9	10.3	13.5	20.7	5.8	6.5	9.4	4.4	73.7	97.2	46.2	3.1	5.2	0.9
25	17.1	19.7	14.1	17.1	20.5	13.2	12.7	16.9	7.6	81.4	91.9	71.7	6.3	9.4	3.8
26	20.4	27.1	16.2	22.0	28.7	17.2	18.4	21.6	15.1	86.9	92.8	73.5	5.2	8.7	1.6
27	22.0	25.6	19.1	21.9	25.8	18.6	20.1	22.2	17.8	91.9	97.9	83.6	3.9	6.1	1.7
28	24.1	31.4	19.2	23.7	29.9	17.5	18.0	20.9	15.7	77.6	96.3	51.9	1.8	3.7	0.7
29	22.8	27.6	18.4	24.8	30.7	19.2	18.2	21.2	14.1	73.3	88.8	61.3	5.9	9.5	3.0
30	22.6	28.0	16.4	22.4	28.9	11.6	18.1	21.1	8.8	83.5	94.8	58.1	5.2	9.2	2.1
31	14.3	19.3	10.7	8.6	11.5	6.0	3.2	8.4	1.1	78.7	93.7	65.9	6.5	8.6	3.3
Ave	19.8	35.7	9.4	17.6	32.7	5.8	11.5	22.2	0.8	76.9	99.1	25.3	3.7	9.5	0.4

Notes: (1) Soil Temperature is an average of the top 10 cm, measured at 2 and 8 cm.
(2) Air Temperature and Relative Humidity was measured at 2 m above tailings surface.
(3) Dew point was measured at approximately 1 and 2.5 m above the tailings surface and presented as a composite average.
(4) Wind was measured at 3 m above the tailings surface.

Meterological summary at Kidd Creek thickened tailings site, September 1991

Day	Soil Temperature			Air Temperature			Dew Point Temperature			Relative Humidity			Wind Speed		
	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (%)	Max (%)	Min (%)	Ave (m/s)	Max (m/s)	Min (m/s)
1	15.9	23.9	9.9	11.2	17.7	5.8	4.5	7.9	2.5	72.7	94.0	48.1	2.7	4.6	1.6
2	17.1	24.5	10.9	15.8	23.7	8.7	7.2	10.6	5.5	65.2	88.2	40.2	5.2	8.6	2.3
3	16.0	18.8	13.5	16.9	19.3	13.1	12.9	18.4	7.3	83.2	95.6	65.0	6.1	8.8	4.7
4	15.4	19.3	13.0	15.8	19.5	11.0	10.9	12.6	9.4	88.5	95.4	64.6	4.6	7.9	1.9
5	14.6	20.9	10.3	11.5	16.7	7.0	7.8	10.1	5.4	84.2	96.8	57.5	2.3	5.2	0.5
6	16.1	21.5	12.0	12.4	16.7	7.2	8.9	10.3	7.2	85.3	98.9	64.2	2.2	4.1	1.0
7	17.2	25.1	11.6	15.6	23.4	9.4	9.0	14.2	7.1	73.4	91.6	46.3	2.6	5.2	1.0
8	17.5	24.8	12.4	14.3	19.8	9.5	9.0	11.1	6.8	78.0	96.8	58.6	3.5	5.2	2.1
9	16.5	20.3	14.3	16.5	23.4	13.3	13.2	18.6	7.9	84.4	96.1	73.0	5.4	8.7	3.2
10	16.3	17.8	11.6	14.8	18.9	9.1	12.1	18.6	3.9	88.8	95.2	78.6	6.0	8.2	3.3
11	13.1	19.6	7.6	9.1	14.6	3.2	3.5	6.8	2.0	76.5	94.7	53.8	3.4	4.9	0.5
12	14.5	21.3	9.9	11.5	17.8	5.9	6.8	9.0	5.1	80.1	99.0	59.0	1.8	3.5	0.5
13	13.8	14.7	12.3	12.7	13.9	10.7	10.9	13.2	8.2	90.3	97.6	78.1	3.5	5.2	1.5
14	15.5	18.1	14.0	15.0	17.6	13.1	13.7	14.4	13.2	92.9	97.6	84.8	2.8	5.2	0.4
15	17.4	22.4	14.6	18.6	25.3	14.3	16.6	20.4	13.9	89.0	96.1	71.8	5.3	8.1	2.6
16	16.8	21.1	14.0	17.6	22.9	14.1	14.8	20.6	9.2	88.1	94.8	73.6	5.2	13.0	1.4
17	13.4	15.8	11.2	10.6	14.8	7.2	7.5	11.5	4.7	87.0	95.8	78.9	5.6	9.1	1.8
18	11.1	14.1	7.4	9.8	14.0	3.8	7.1	13.1	0.3	87.9	96.5	64.7	7.1	11.0	2.6
19	7.4	10.7	5.1	3.5	6.7	0.6	0.2	1.2	-0.7	85.1	95.6	68.3	5.4	6.6	3.8
20	7.5	12.5	4.6	3.2	7.1	0.4	0.7	2.2	-0.3	88.6	97.1	74.7	3.6	4.4	2.0
21	9.0	15.5	4.2	7.6	15.1	1.2	2.8	5.6	-0.8	78.6	91.4	59.6	5.1	8.0	2.5
22	10.6	16.6	5.9	11.5	17.7	5.2	5.9	8.9	4.1	75.6	95.5	52.0	6.9	10.5	4.3
23	9.2	11.4	5.1	7.9	13.3	2.7	4.7	10.7	0.4	85.7	93.8	76.0	7.9	10.2	4.2
24	7.6	14.1	3.3	4.4	10.5	-0.4	0.5	2.1	-1.6	81.2	98.2	51.9	3.3	5.1	1.6
25	7.6	12.6	3.4	6.4	11.4	1.1	2.8	6.3	0.8	83.2	98.6	62.1	5.4	7.8	3.1
26	7.5	9.3	4.3	5.5	8.1	0.8	4.3	7.6	0.7	94.1	98.4	89.6	6.6	7.9	5.0
27	4.0	8.4	1.9	0.3	2.0	-0.7	-0.2	0.7	-1.7	97.3	99.9	91.8	5.9	7.3	2.9
28	4.5	9.3	1.2	1.3	5.6	-2.0	-1.5	0.8	-2.8	85.5	98.0	63.2	4.4	7.2	3.0
29	4.9	11.1	0.8	1.0	5.4	-2.6	-2.5	0.1	-3.9	84.1	96.3	60.6	4.9	8.2	0.5
30	3.0	4.9	1.0	2.2	6.0	-0.7	1.5	6.1	-2.4	95.0	97.8	90.8	5.5	9.0	1.9
Ave	12.0	25.1	0.8	10.1	25.3	-2.6	6.5	20.6	-3.9	84.3	99.9	40.2	4.7	13.0	0.4

Notes: (1) Soil Temperature is an average of the top 10 cm, measured at 2 and 8 cm.
(2) Air Temperature and Relative Humidity was measured at 2 m above tailings surface.
(3) Dew point was measured at approximately 1 and 2.5 m above the tailings surface and presented as a composite average.
(4) Wind was measured at 3 m above the tailings surface.

Meterological summary at Kidd Creek thickened tailings site, October 1991

Day	Soil Temperature Ave (C)	Soil Temperature Max (C)	Soil Temperature Min (C)	Air Temperature Ave (C)	Air Temperature Max (C)	Air Temperature Min (C)	Dew Point Temperature Ave (C)	Dew Point Temperature Max (C)	Dew Point Temperature Min (C)	Relative Humidity Ave (%)	Relative Humidity Max (%)	Relative Humidity Min (%)	Wind Speed Ave (m/s)	Wind Speed Max (m/s)	Wind Speed Min (m/s)
1	6.6	10.9	2.9	7.6	12.4	3.0	4.4	5.9	2.7	83.6	97.3	59.2	5.2	8.1	3.1
2	8.6	12.5	6.6	9.4	14.1	6.8	8.1	11.1	4.6	91.8	96.6	81.8	4.0	5.5	1.4
3	9.8	15.4	5.7	8.9	13.4	4.3	5.6	7.8	3.3	84.4	97.3	62.1	2.3	4.5	0.8
4	9.0	15.3	5.0	5.4	9.9	0.3	2.5	5.5	1.0	85.5	99.0	63.2	2.6	4.6	1.1
5	6.9	10.4	5.2	6.5	14.1	3.2	4.7	13.6	1.1	88.8	97.4	71.9	7.1	11.5	4.1
6	4.9	7.4	2.5	2.9	5.7	-0.1	0.5	2.2	-0.5	87.0	96.8	81.2	8.2	10.3	5.7
7	2.3	5.0	1.1	-0.3	1.3	-1.9	-2.5	-0.6	-3.8	88.6	96.9	76.9	6.6	9.3	2.3
8	5.8	11.5	2.0	6.3	13.7	0.9	2.4	5.5	-1.7	80.0	96.1	57.5	3.5	4.6	2.1
9	8.3	12.0	6.3	10.1	13.2	8.2	4.7	8.2	0.7	73.4	92.7	45.0	5.1	8.8	2.0
10	5.2	7.6	3.3	3.3	8.0	1.3	1.1	2.5	-0.0	87.1	96.8	66.2	3.1	4.5	0.8
11	4.9	8.7	2.3	2.9	6.1	-0.3	1.1	2.8	-0.5	89.3	97.8	74.3	2.8	3.9	0.9
12	4.5	7.2	2.8	2.7	5.0	0.5	-0.3	2.5	-3.0	83.2	96.7	63.7	4.4	5.7	3.0
13	3.1	8.0	0.9	0.4	3.3	-1.0	-3.2	-1.5	-4.4	79.3	92.1	67.0	3.6	5.3	1.4
14	1.8	3.8	0.2	1.3	4.7	-2.3	0.5	4.6	-3.5	92.8	96.8	87.9	6.0	7.8	3.8
15	5.0	7.4	2.0	3.8	5.9	-1.4	2.9	6.2	-4.3	93.5	97.3	85.8	5.5	7.1	2.8
16	2.0	3.9	0.6	1.2	7.0	-2.6	-1.3	4.1	-4.5	85.7	93.4	77.4	5.9	9.1	2.2
17	6.8	12.4	2.5	11.1	19.9	4.2	9.2	20.2	2.0	73.8	91.6	51.5	7.4	11.8	3.7
18	5.6	9.7	2.3	3.8	13.1	-0.3	-2.0	12.3	-6.3	64.9	75.5	56.6	5.0	9.5	1.2
19	2.8	7.3	0.5	-0.7	1.6	-3.2	-7.6	-4.1	-10.4	63.4	77.6	47.2	3.4	4.9	1.1
20	0.8	2.4	0.2	-0.9	1.9	-3.2	-3.5	0.5	-7.7	84.1	93.3	62.3	4.4	6.2	3.0
21	0.1	0.3	0.0	-1.6	1.5	-3.6	-1.6	2.9	-4.7	96.1	98.8	91.3	3.5	6.0	1.5
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ave	5.0	15.4	0.0	4.0	19.9	-3.6	1.2	20.2	-10.4	83.6	99.0	45.0	4.7	11.8	0.8

Notes: (1) Soil Temperature is an average of the top 10 cm, measured at 2 and 8 cm.
(2) Air Temperature and Relative Humidity was measured at 2 m above tailings surface.
(3) Dew point was measured at approximately 1 and 2.5 m above the tailings surface and presented as a composite average.
(4) Wind was measured at 3 m above the tailings surface.

Meterological summary at Kidd Creek thickened tailings site, June 1992

Day	Soil Temperature Ave (C)	Soil Temperature Max (C)	Soil Temperature Min (C)	Air Temperature Ave (C)	Air Temperature Max (C)	Air Temperature Min (C)	Dew Point Temperature Ave (C)	Dew Point Temperature Max (C)	Dew Point Temperature Min (C)	Relative Humidity Ave (%)	Relative Humidity Max (%)	Relative Humidity Min (%)	Wind Speed Ave (m/s)	Wind Speed Max (m/s)	Wind Speed Min (m/s)
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	14.3	19.1	10.5	13.8	17.8	10.0	-	-	-	86.5	94.6	72.6	5.1	8.7	3.2
6	18.5	24.8	12.2	17.3	21.5	13.9	-	-	-	88.2	94.8	74.8	2.5	4.4	0.8
7	16.9	20.9	13.5	15.4	18.9	12.8	-	-	-	84.8	95.1	62.1	2.7	5.1	1.3
8	14.8	17.4	11.1	13.0	15.6	9.5	-	-	-	74.2	92.3	58.2	4.2	6.8	1.6
9	13.9	19.7	7.7	12.3	18.1	6.9	-	-	-	62.0	86.8	40.4	4.6	7.6	1.1
10	18.2	24.6	8.3	15.9	22.9	7.5	-	-	-	60.5	93.9	34.2	2.4	6.0	0.5
11	22.0	29.0	13.0	19.7	26.9	11.9	-	-	-	59.5	89.8	36.4	3.2	5.9	1.1
12	22.4	27.3	18.5	20.6	25.0	16.1	-	-	-	57.3	84.7	28.6	4.4	6.5	1.1
13	19.3	24.2	13.4	17.2	22.3	12.0	-	-	-	58.3	86.2	32.1	5.2	9.1	0.8
14	11.6	16.6	4.9	8.8	13.8	2.5	-	-	-	59.6	89.1	39.4	4.5	5.7	2.7
15	15.5	23.5	5.5	12.1	19.5	3.7	-	-	-	51.2	92.0	23.6	2.3	3.9	0.7
16	20.4	29.3	10.5	17.8	25.5	9.3	-	-	-	44.5	71.8	20.9	3.3	4.5	1.8
17	22.7	30.4	14.6	20.8	28.0	12.5	-	-	-	49.3	65.4	28.6	7.0	12.4	3.2
18	-	-	-	19.2	24.1	8.1	-	-	-	81.7	95.5	61.9	9.4	12.6	4.4
19	5.2	10.1	1.4	3.5	7.7	0.3	-	-	-	87.8	97.8	66.6	7.6	9.1	6.3
20	4.6	10.3	0.3	2.9	8.8	-1.2	-	-	-	78.6	93.0	59.6	7.8	8.9	6.1
21	7.5	14.6	0.6	5.7	12.4	-0.7	-	-	-	70.8	94.7	47.0	6.3	8.2	4.4
22	12.1	20.5	2.4	9.6	17.5	0.5	-	-	-	58.4	91.7	34.6	3.1	4.8	0.9
23	17.3	23.7	9.0	14.8	20.0	8.2	-	-	-	52.1	87.8	25.5	3.4	5.3	0.7
24	18.9	24.4	11.1	16.3	21.3	9.3	-	-	-	49.3	78.4	27.9	2.8	4.4	1.0
25	19.7	26.3	11.4	16.8	22.3	9.5	-	-	-	47.6	79.0	30.2	1.8	3.0	0.5
26	18.8	28.3	10.9	15.6	23.3	8.9	-	-	-	68.7	91.8	34.1	2.7	6.4	0.7
27	15.3	22.6	9.3	13.2	19.8	7.9	-	-	-	74.4	95.6	32.3	3.1	4.8	1.5
28	15.0	17.4	11.2	13.4	16.0	9.1	-	-	-	77.9	88.7	62.0	5.6	9.5	2.4
29	15.3	19.0	11.5	13.0	16.6	9.1	-	-	-	74.4	93.9	46.9	4.1	6.8	1.1
30	13.1	16.1	9.5	11.2	14.3	7.6	-	-	-	66.5	76.2	49.5	5.6	7.4	2.4
Ave	15.7	30.4	0.3	13.9	28.0	-1.2	-	-	-	66.3	97.8	20.9	4.4	12.6	0.5

Notes: (1) Soil Temperature is an average of the top 10 cm, measured at 2 and 8 cm.
(2) Air Temperature and Relative Humidity was measured at 2 m above tailings surface.
(3) Dew point was measured at approximately 1 and 2.5 m above the tailings surface and presented as a composite average.
(4) Wind was measured at 3 m above the tailings surface.

Meterological summary at Kidd Creek thickened tailings site, July 1992

Day	Soil Temperature			Air Temperature			Dew Point Temperature			Relative Humidity			Wind Speed		
	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (%)	Max (%)	Min (%)	Ave (m/s)	Max (m/s)	Min (m/s)
1	13.5	20.6	4.5	10.7	16.8	2.7	-	-	-	63.8	94.4	42.7	2.3	3.6	0.8
2	16.7	21.5	10.2	14.5	18.9	8.5	-	-	-	57.9	81.1	36.5	3.6	5.1	1.7
3	14.4	17.6	12.2	13.7	16.1	12.4	-	-	-	82.0	95.7	55.9	4.9	7.6	1.7
4	47.7	-	8.3	12.7	15.8	8.7	-	-	-	89.6	95.7	76.4	5.2	7.2	3.1
5	14.0	18.5	9.7	12.7	16.3	10.1	-	-	-	90.6	96.0	78.7	2.8	4.3	0.5
6	16.0	20.0	13.5	15.0	18.8	12.9	-	-	-	88.0	94.6	69.7	4.3	6.2	1.1
7	19.2	24.4	12.3	17.2	21.7	11.7	-	-	-	77.6	95.3	56.2	2.1	5.4	0.7
8	19.1	22.1	16.6	17.6	20.7	15.3	-	-	-	84.3	91.2	72.5	4.6	8.4	1.3
9	18.0	22.1	14.1	17.0	20.5	15.2	-	-	-	88.8	94.9	72.2	4.5	7.0	1.3
10	50.2	21.4	10.0	14.2	19.5	8.6	-	-	-	89.7	94.7	81.9	4.0	7.0	1.3
11	14.3	21.2	5.3	11.3	17.7	3.6	-	-	-	74.2	96.9	47.8	2.4	5.5	1.1
12	17.1	21.5	10.6	15.0	18.9	9.9	-	-	-	71.7	88.2	57.6	4.3	6.6	1.8
13	17.4	22.4	13.4	15.0	19.1	11.4	-	-	-	73.1	95.8	47.9	2.9	5.2	1.6
14	20.0	26.3	13.0	18.2	24.0	11.9	-	-	-	59.4	90.7	36.6	2.6	4.4	0.6
15	18.0	24.3	10.2	15.3	21.6	7.3	-	-	-	51.0	82.0	31.3	3.5	4.5	2.3
16	17.6	20.9	15.1	16.3	19.6	13.7	-	-	-	71.1	90.8	47.0	4.9	8.6	3.3
17	20.0	25.0	15.9	18.0	21.8	15.1	-	-	-	85.4	93.3	71.1	3.2	6.2	0.9
18	18.8	25.0	11.5	16.7	22.2	9.9	-	-	-	70.4	95.9	41.4	2.9	5.7	1.8
19	21.0	26.1	13.5	18.8	23.7	12.1	-	-	-	68.1	88.7	50.1	4.2	6.6	1.9
20	12.7	20.4	7.8	11.1	18.3	5.8	-	-	-	90.9	95.1	78.1	6.2	8.3	1.4
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	21.4	32.3	12.8	18.7	24.8	11.6	-	-	-	55.8	82.7	33.7	3.6	4.5	2.2
24	23.5	33.6	15.3	20.3	26.4	13.0	-	-	-	54.0	87.6	25.8	4.3	7.3	2.1
25	22.1	30.3	16.7	19.0	24.6	14.6	-	-	-	63.1	93.7	47.1	3.4	6.0	2.1
26	20.1	24.4	17.7	17.8	22.2	15.2	-	-	-	88.6	94.0	72.8	4.9	8.1	1.3
27	16.3	20.7	13.7	13.4	19.2	9.8	-	-	-	84.5	94.5	63.0	5.1	6.0	3.1
28	15.2	19.6	11.4	13.6	18.0	8.8	-	-	-	83.3	94.1	61.6	3.2	6.1	1.2
29	14.8	18.3	12.3	11.6	13.6	9.9	-	-	-	88.2	93.7	79.3	5.6	8.3	2.8
30	15.3	20.5	10.6	13.2	18.7	8.3	-	-	-	79.4	94.1	59.7	4.3	6.7	1.4
31	19.3	28.7	11.7	16.7	22.4	9.2	-	-	-	68.3	94.9	40.0	2.3	4.1	0.7
Ave	19.8	33.6	4.5	15.4	26.4	2.7	-	-	-	75.6	96.9	25.8	3.9	8.6	0.5

Notes: (1) Soil Temperature is an average of the top 10 cm, measured at 2 and 8 cm.
(2) Air Temperature and Relative Humidity was measured at 2 m above tailings surface.
(3) Dew point was measured at approximately 1 and 2.5 m above the tailings surface and presented as a composite average.
(4) Wind was measured at 3 m above the tailings surface.

Meterological summary at Kidd Creek thickened tailings site, August 1992

Day	Soil Temperature			Air Temperature			Dew Point Temperature			Relative Humidity			Wind Speed		
	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (%)	Max (%)	Min (%)	Ave (m/s)	Max (m/s)	Min (m/s)
1	17.7	22.3	15.4	16.4	20.6	13.7	-	-	-	82.2	93.0	63.4	3.7	6.3	2.1
2	16.9	21.5	13.5	15.0	18.7	12.4	-	-	-	90.1	94.0	76.5	4.3	5.9	3.0
3	15.7	21.0	11.7	13.3	16.6	10.0	-	-	-	91.7	94.3	89.3	3.6	5.6	1.5
4	14.2	21.7	10.1	11.8	18.1	5.6	-	-	-	85.1	94.6	33.3	2.3	7.4	1.0
5	15.4	21.6	11.4	14.9	21.0	8.5	-	-	-	85.2	95.5	57.5	3.3	4.8	2.1
6	18.5	27.7	0.5	17.4	24.6	11.6	-	-	-	81.5	91.0	43.2	2.6	7.8	1.5
7	19.9	30.0	14.2	19.1	25.8	13.5	-	-	-	66.4	87.6	37.1	3.5	6.1	2.6
8	17.4	21.3	16.5	16.7	20.4	16.6	-	-	-	92.1	90.9	66.4	2.1	5.4	2.6
9	22.5	34.0	14.5	20.9	26.7	12.4	-	-	-	80.1	94.3	54.6	4.6	4.2	1.6
10	16.1	32.6	17.4	9.7	26.6	11.4	-	-	-	93.6	93.8	41.3	7.5	8.4	3.7
11	12.0	16.1	11.6	8.7	9.8	6.5	-	-	-	91.0	93.6	83.4	3.2	7.5	2.8
12	15.2	23.9	10.8	11.7	16.3	7.9	-	-	-	66.8	92.9	44.0	1.5	4.2	1.9
13	15.1	22.9	11.3	12.0	17.6	7.8	-	-	-	74.3	90.0	40.0	0.6	2.8	0.6
14	17.0	-	10.9	13.7	20.2	7.3	-	-	-	82.3	92.0	38.6	2.0	3.5	0.6
15	18.8	30.8	12.1	15.1	22.6	9.0	-	-	-	65.9	90.2	32.8	2.6	5.1	1.5
16	18.8	28.0	13.1	15.8	22.7	9.3	-	-	-	71.2	89.7	35.3	2.1	4.9	1.7
17	18.9	27.2	13.3	17.2	24.3	10.8	-	-	-	73.1	86.8	40.8	3.7	8.4	2.1
18	12.8	18.9	13.5	9.4	17.2	9.8	-	-	-	94.2	94.7	73.1	7.5	7.8	2.1
19	11.6	15.6	10.5	9.1	14.4	7.8	-	-	-	94.5	94.3	68.5	0.7	7.8	0.5
20	16.0	23.7	8.5	16.6	23.2	5.4	-	-	-	76.1	95.6	48.0	3.6	5.1	0.5
21	13.9	18.4	14.2	9.5	18.3	10.3	-	-	-	94.2	93.8	76.1	3.9	6.3	3.4
22	15.0	17.8	10.9	15.9	16.5	6.3	-	-	-	91.9	95.0	88.9	5.0	5.3	3.1
23	17.9	24.0	13.6	19.6	25.7	14.9	-	-	-	84.8	91.9	61.0	5.0	8.8	3.6
24	19.3	26.7	16.4	15.9	28.1	17.4	-	-	-	86.7	90.7	60.2	4.2	9.4	3.5
25	13.5	19.3	13.8	10.4	15.9	10.3	-	-	-	93.6	93.9	86.7	3.3	4.3	2.5
26	11.3	15.8	11.8	8.1	12.3	8.5	-	-	-	93.3	94.1	90.8	2.2	5.9	2.1
27	12.7	18.5	8.8	10.8	14.1	3.6	-	-	-	82.8	95.1	65.6	1.6	2.9	0.6
28	11.4	14.8	10.3	9.7	13.8	8.3	-	-	-	92.2	91.1	66.9	3.3	6.7	1.6
29	10.4	15.2	9.8	10.0	17.1	8.5	-	-	-	78.0	93.0	49.0	2.6	8.5	2.0
30	12.0	16.6	8.7	9.0	16.1	7.2	-	-	-	93.4	93.7	78.0	5.8	5.8	0.5
31	9.2	13.7	9.3	7.4	9.7	6.9	-	-	-	91.6	93.5	87.5	2.9	8.2	1.3
Ave	15.4	34.0	0.5	13.2	28.1	3.6	-	-	-	84.5	95.6	32.8	3.4	9.4	0.5

Notes: (1) Soil Temperature is an average of the top 10 cm, measured at 2 and 8 cm.
(2) Air Temperature and Relative Humidity was measured at 2 m above tailings surface.
(3) Dew point was measured at approximately 1 and 2.5 m above the tailings surface and presented as a composite average.
(4) Wind was measured at 3 m above the tailings surface.

Meterological summary at Kidd Creek thickened tailings site, September 1992

Day	Soil Temperature			Air Temperature			Dew Point Temperature			Relative Humidity			Wind Speed		
	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (%)	Max (%)	Min (%)	Ave (m/s)	Max (m/s)	Min (m/s)
1	12.4	20.2	6.2	10.5	16.5	3.4	-	-	-	81.1	94.5	45.7	1.7	5.0	1.7
2	13.5	18.1	8.3	14.1	19.3	6.4	-	-	-	83.0	91.0	62.9	7.6	8.2	1.7
3	11.4	18.3	12.2	9.2	18.4	10.1	-	-	-	87.4	92.7	71.6	3.4	9.0	3.3
4	13.0	20.1	8.6	13.8	19.5	6.7	-	-	-	78.5	94.2	55.4	4.6	6.9	0.5
5	13.7	22.0	11.8	16.5	24.8	13.3	-	-	-	51.3	80.5	45.1	6.3	10.0	4.6
6	13.9	18.6	12.9	10.8	21.3	11.1	-	-	-	93.1	93.3	51.3	4.2	7.7	3.6
7	13.0	18.1	10.8	11.4	12.7	7.1	-	-	-	90.2	93.2	84.7	3.9	4.6	2.3
8	10.7	16.6	11.3	9.7	15.5	10.7	-	-	-	80.8	92.4	71.3	5.4	11.0	3.6
9	11.1	13.6	8.0	10.4	12.6	6.6	-	-	-	93.0	93.1	72.7	6.8	7.9	3.3
10	7.2	15.9	7.6	2.6	15.1	2.9	-	-	-	93.4	93.7	61.6	5.1	10.0	3.3
11	8.7	16.7	4.4	6.9	12.4	1.5	-	-	-	78.2	94.9	51.4	3.7	5.1	2.7
12	12.4	14.9	6.4	14.6	18.1	5.5	-	-	-	88.1	91.4	74.5	3.9	7.8	2.6
13	13.3	19.6	11.2	13.3	21.8	12.5	-	-	-	90.8	91.1	50.1	8.7	10.6	3.2
14	15.5	17.5	12.7	16.9	19.0	13.3	-	-	-	91.1	91.9	87.7	4.4	8.7	4.2
15	14.7	22.5	13.6	14.5	22.4	13.3	-	-	-	80.2	92.2	37.8	1.4	6.3	1.4
16	15.4	17.9	12.5	16.1	19.0	11.8	-	-	-	91.2	92.5	80.2	2.8	6.7	1.4
17	14.3	20.0	14.6	11.5	18.2	11.8	-	-	-	91.0	91.4	83.9	2.8	6.4	2.8
18	8.3	16.1	8.9	3.6	17.0	4.0	-	-	-	87.7	91.6	86.2	7.2	10.3	0.8
19	6.5	12.4	6.0	4.4	8.9	2.5	-	-	-	84.7	92.1	55.3	3.4	8.1	1.9
20	8.9	14.3	4.1	10.7	15.4	2.1	-	-	-	78.3	92.8	58.3	6.4	10.6	3.3
21	12.2	16.3	8.9	13.1	17.8	10.7	-	-	-	89.2	89.9	69.1	4.1	8.0	3.8
22	3.6	12.2	4.2	-0.5	13.7	0.1	-	-	-	85.6	90.4	68.6	4.4	8.5	3.8
23	5.8	13.7	2.0	3.6	8.5	-1.1	-	-	-	72.1	85.9	40.9	3.4	6.2	1.7
24	9.8	17.9	3.9	11.5	18.9	3.1	-	-	-	55.1	89.4	40.7	7.2	10.7	3.4
25	11.0	20.3	6.9	11.3	19.4	8.0	-	-	-	66.9	85.6	42.0	4.0	8.8	4.2
26	14.5	20.6	7.1	16.0	19.9	6.9	-	-	-	83.4	86.3	63.2	4.4	8.9	3.0
27	9.9	14.8	10.2	6.8	16.0	7.4	-	-	-	92.4	92.3	83.4	5.8	9.8	2.4
28	5.4	10.2	6.8	0.4	9.1	1.6	-	-	-	93.5	93.1	90.6	9.3	9.8	1.8
29	3.2	5.8	2.4	0.9	1.0	-1.9	-	-	-	94.0	94.2	84.9	4.7	9.3	2.9
30	3.7	11.2	2.9	0.9	6.8	0.5	-	-	-	89.5	94.0	59.8	0.7	6.8	0.6
Ave	10.6	22.5	2.0	9.5	24.8	-1.9	-	-	-	83.8	94.9	37.8	4.7	11.0	0.5

Notes: (1) Soil Temperature is an average of the top 10 cm, measured at 2 and 8 cm.
(2) Air Temperature and Relative Humidity was measured at 2 m above tailings surface.
(3) Dew point was measured at approximately 1 and 2.5 m above the tailings surface and presented as a composite average.
(4) Wind was measured at 3 m above the tailings surface.

Meterological summary at Kidd Creek thickened tailings site, October 1992															
Day	Soil Temperature			Air Temperature			Dew Point Temperature			Relative Humidity			Wind Speed		
	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (%)	Max (%)	Min (%)	Ave (m/s)	Max (m/s)	Min (m/s)
1	9.8	14.4	1.7	13.4	17.4	-0.2	-	-	-	76.8	94.0	51.0	4.5	7.3	0.7
2	10.1	18.1	8.4	9.4	18.8	9.9	-	-	-	76.0	90.7	60.4	7.2	6.1	2.1
3	5.0	13.0	4.3	2.5	9.8	0.8	-	-	-	68.3	93.3	41.2	1.9	7.8	1.7
4	4.0	12.8	1.3	1.1	6.4	-2.3	-	-	-	79.1	92.7	59.1	2.1	4.7	1.0
5	6.5	15.5	1.5	5.7	11.0	-1.6	-	-	-	67.7	94.7	47.3	3.3	3.4	0.6
6	10.4	13.0	3.7	12.5	16.0	3.5	-	-	-	79.8	90.0	59.4	2.1	8.1	2.0
7	7.2	10.4	7.2	6.4	12.5	4.6	-	-	-	93.2	93.4	79.8	1.3	4.7	2.1
8	8.4	13.1	5.5	7.1	11.1	5.4	-	-	-	92.0	95.2	86.9	3.1	4.6	1.3
9	8.4	12.4	8.1	7.4	12.7	7.1	-	-	-	90.4	92.0	84.6	4.7	6.6	3.1
10	8.0	11.7	7.3	7.5	10.6	6.9	-	-	-	89.4	91.6	79.7	3.2	6.5	2.1
11	6.9	10.3	6.7	5.7	9.3	6.2	-	-	-	91.9	92.0	83.8	2.7	4.0	1.3
12	2.6	6.9	2.7	0.3	6.2	0.4	-	-	-	92.7	92.9	89.8	4.7	7.8	2.3
13	3.2	6.9	1.0	1.9	2.0	-0.8	-	-	-	91.2	93.4	87.7	4.2	6.0	2.6
14	4.6	6.5	3.0	4.1	5.3	1.6	-	-	-	90.2	93.1	83.9	1.6	4.8	0.7
15	4.1	6.5	4.0	2.8	4.8	3.0	-	-	-	90.8	92.6	89.6	5.9	5.7	0.7
16	0.8	4.1	0.9	-1.8	2.8	-1.5	-	-	-	93.4	93.6	90.8	9.2	9.7	5.5
17	0.4	0.8	0.4	-3.9	-1.0	-4.3	-	-	-	87.6	93.4	76.5	5.1	10.3	4.3
18	-0.0	0.4	0.0	-5.3	-3.8	-6.6	-	-	-	89.1	93.3	73.0	2.9	5.8	2.7
19	-0.2	-0.0	-0.2	-3.7	-3.4	-5.6	-	-	-	71.5	89.8	54.9	4.1	3.9	2.1
20	0.2	0.1	-0.3	0.2	2.5	-3.7	-	-	-	93.1	94.0	71.5	4.6	7.0	3.6
21	1.0	1.4	0.2	1.7	3.6	-0.3	-	-	-	91.5	93.1	86.2	5.2	4.6	1.0
22	5.9	8.4	0.8	8.3	9.6	1.1	-	-	-	81.8	91.9	77.2	5.4	8.4	3.8
23	5.0	10.0	5.4	1.4	14.2	2.3	-	-	-	92.3	92.3	81.8	5.7	7.6	3.7
24	1.8	5.4	1.8	-1.0	1.6	-1.0	-	-	-	92.6	92.8	89.9	4.1	5.7	3.3
25	0.7	5.1	0.7	-0.7	0.5	-3.4	-	-	-	84.7	92.9	82.7	6.8	6.5	1.2
26	1.5	5.6	0.5	-0.4	3.9	-0.7	-	-	-	91.1	93.5	84.7	2.6	7.3	2.5
27	0.7	3.8	0.6	-1.7	0.1	-1.4	-	-	-	85.4	93.2	81.6	3.3	4.8	2.2
28	0.2	0.7	0.2	-3.7	-1.7	-3.7	-	-	-	87.6	90.4	77.4	3.2	4.7	2.5
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-0.5	-	-	-2.7	-	-	-	-	-	78.7	-	-	3.0	-	-
31	-0.5	-0.2	-0.6	-4.2	-0.7	-4.0	-	-	-	79.3	87.5	71.2	3.1	4.7	2.3
Ave	3.9	18.1	-0.6	2.3	18.8	-6.6	-	-	-	85.6	95.2	41.2	4.0	10.3	0.6

Notes: (1) Soil Temperature is an average of the top 10 cm, measured at 2 and 8 cm.
(2) Air Temperature and Relative Humidity was measured at 2 m above tailings surface.
(3) Dew point was measured at approximately 1 and 2.5 m above the tailings surface and presented as a composite average.
(4) Wind was measured at 3 m above the tailings surface.

Meterological summary at Kidd Creek thickened tailings site, November 1992

Day	Soil Temperature			Air Temperature			Dew Point Temperature			Relative Humidity			Wind Speed		
	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (C)	Max (C)	Min (C)	Ave (%)	Max (%)	Min (%)	Ave (m/s)	Max (m/s)	Min (m/s)
1	-0.8	-0.2	-0.9	-4.4	-1.1	-5.9	-	-	-	89.3	89.4	74.4	4.0	4.2	2.6
2	-0.8	-0.8	-1.1	-0.5	-1.3	-5.1	-	-	-	92.7	93.9	83.4	6.5	8.7	3.9
3	-0.4	-0.4	-0.8	2.1	4.1	-0.5	-	-	-	91.3	93.5	90.7	3.7	6.7	4.5
4	-0.2	-0.2	-0.4	-0.0	2.1	0.1	-	-	-	91.5	92.4	90.9	4.6	5.6	2.2
5	-0.2	-0.1	-0.2	-7.1	-0.0	-6.6	-	-	-	91.2	92.0	86.5	5.8	6.5	3.4
6	-0.8	-0.2	-0.8	-7.7	-7.1	-9.6	-	-	-	91.4	92.3	83.9	5.1	6.3	3.4
7	-0.9	-0.6	-0.9	-7.7	-4.5	-7.7	-	-	-	83.6	93.3	67.4	2.3	5.1	2.0
8	-1.0	-0.9	-1.4	-2.5	-0.6	-10.3	-	-	-	86.0	91.3	67.9	3.9	4.7	2.3
9	-0.7	-0.7	-1.0	0.3	1.5	-2.6	-	-	-	90.2	92.8	86.0	6.1	8.3	3.7
10	-0.3	-0.3	-0.7	5.3	5.2	0.2	-	-	-	90.5	92.5	90.2	6.5	7.5	5.6
11	-0.5	-0.2	-0.5	0.3	5.5	0.3	-	-	-	83.0	90.5	59.8	5.4	9.1	3.2
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-0.3	-	-	-6.1	-	-	-	-	-	89.9			5.5	-	-
14	-0.3	-0.3	-0.3	-10.2	-6.1	-9.7	-	-	-	92.9	93.0	83.1	2.0	6.5	1.9
15	-0.2	-0.2	-0.3	-12.3	-7.4	-12.1	-	-	-	92.4	92.9	86.5	2.3	3.6	1.2
16	-0.2	-0.2	-0.2	-15.6	-7.6	-14.9	-	-	-	91.7	92.5	85.5	1.8	4.2	0.8
17	-0.2	-0.2	-0.3	-19.4	-4.9	-21.6	-	-	-	90.2	91.7	66.7	0.4	2.3	0.4
18	-0.2	-0.2	-0.3	-10.5	-8.8	-22.8	-	-	-	89.7	90.7	77.9	2.8	3.0	0.4
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ave	-0.5	-0.1	-1.4	-5.6	5.5	-22.8	-	-	-	89.9	93.9	59.8	4.0	9.1	0.4

Notes: (1) Soil Temperature is an average of the top 10 cm, measured at 2 and 8 cm.
(2) Air Temperature and Relative Humidity was measured at 2 m above tailings surface.
(3) Dew point was measured at approximately 1 and 2.5 m above the tailings surface and presented as a composite average.
(4) Wind was measured at 3 m above the tailings surface.

Appendix B

Precipitation data

Precipitation at Kidd Creek and regional meteorological stations.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun-Oct	Jan-Dec
Kidd Creek thickened tailings														
1991 rainfall (mm)	-	-	-	-	-	-	-	80.8	87.4	61.8	-	-	345	-
1992 rainfall (mm)	-	-	-	-	-	48.0	91.7	142.5	135.4	35.6	-	-	453	-
1992 month-end snow cover (cm)	-	-	60	-	-	-	-	-	-	-	-	-	-	-
1992 month-end snow cover (mm water)	-	-	170	-	-	-	-	-	-	-	-	-	-	-
Kidd Creek metallurgical site														
Normal precipitation, 1984-92 (mm)	44.5	32.1	46.5	36.7	59.5	78.7	89.5	96.8	83.2	72.6	79.0	60.8	421	780
1991 precipitation	45.0	20.0	75.0	31.0	44.6	44.8	69.8	67.8	83.0	63.5	85.0	64.0	329	694
1992 precipitation	61.8	37.5	16.7	52.5	55.0	41.5	75.0	100.0	110.0	40.0	72.2	81.0	367	743
Timmins airport normals (1955-90)														
Precipitation (mm)	53.9	43.9	58.4	49.4	69.7	90.6	93.5	91.5	91.3	71.0	78.6	64.8	438	857
Precipitation, standard deviation (mm)	23.2	21.9	30.4	21.1	28.9	42.1	38.8	39.4	26.1	27.8	31.4	19.3	-	90
Precipitation (% of annual)	6	5	7	6	8	11	11	11	11	8	9	8	-	-
Rainfall (mm)	2.5	1.4	12.9	25.9	63	90.4	93.5	91.5	89.9	58.8	30.2	6.4	424	566
Rainfall (% of precipitation)	5	3	22	52	90	100	100	100	98	83	38	10	97	66
Snowfall (cm)	62.9	50.0	52.1	25.0	7.0	0.2	0.0	0.0	1.4	13.5	57.2	70.6	-	344
Month-end snow cover (cm)	69	69	44	3	0	0	0	0	0	0	21	51	-	-
Timmins airport (1991)														
Precipitation (mm)	38.7	20.3	88.9	38.5	51.8	54.2	61.8	86.1	89.3	99.2	68.3	56.3	391	753
Precipitation (% of normal)	72	46	152	78	74	60	66	94	98	140	87	87	89	88
Precipitation (no. of sta. dev. from mean)	-0.66	-1.08	1.00	-0.52	-0.62	-0.86	-0.82	-0.14	-0.08	1.01	-0.33	-0.44	-	-1.2
Precipitation (general classification)	N	D	W	N	N	N	N	N	N	W	N	N	D	D
Timmins airport (1992)														
Precipitation (mm)	63.0	32.5	20.3	69.1	44.8	53.2	95.4	159.4	114.5	48.5	79.6	76.0	471	856
Precipitation (% of normal)	117	74	35	140	64	59	102	174	125	68	101	117	108	100
Precipitation (no. of sta. dev. from mean)	0.39	-0.52	-1.25	0.93	-0.86	-0.89	0.05	1.72	0.89	-0.81	0.03	0.58	-	-0.0
Precipitation (general classification)	N	N	D	N	N	N	N	W	N	N	N	N	N	N
Month-end snow cover (cm)	56	59	56	0	0	0	0	0	0	0	20	65	-	-

General Classification: Normal = within 1 standard deviation (sd) from the mean; 2 sd < Dry < 1 sd; 1 sd < Wet < 2 sd.

Total precipitation (mm) at Timmins Airport, Ontario

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	% of Mean	No. of SD from Mean
1955	M	M	M	42.2	56.9	18.3	76.7	72.4	57.2	118.1	111.3	96.3	804.5	94	-0.6
1956	39.9	30.5	25.7	50.8	94.5	92.7	101.1	38.9	94.7	22.6	84.3	71.1	746.8	87	-1.2
1957	20.8	19.1	37.1	58.7	22.4	149.9	45.7	57.2	118.6	38.4	106.2	63.5	737.6	86	-1.3
1958	35.6	49.3	13.2	16.3	56.4	74.9	38.6	136.9	75.9	79.8	62.2	54.6	693.7	81	-1.8
1959	79.0	34.3	64.3	42.2	57.7	21.6	26.9	125.2	105.4	79.5	109.0	70.9	816.0	95	-0.5
1960	77.5	73.9	34.0	67.8	136.7	65.5	77.5	102.6	74.2	58.4	98.3	39.9	906.3	106	0.6
1961	20.8	95.5	65.8	37.1	103.4	100.6	147.6	156.2	168.7	45.7	106.2	81.3	1128.9	132	3.0
1962	109.7	75.7	31.5	40.1	61.2	40.1	84.3	140.5	80.3	35.3	19.6	74.9	793.2	93	-0.7
1963	25.9	40.9	63.5	58.4	39.4	94.5	67.8	138.9	60.7	37.1	92.7	57.7	777.5	91	-0.9
1964	89.7	39.9	85.3	32.3	98.8	110.2	48.5	76.7	97.0	66.0	116.3	53.6	914.3	107	0.6
1965	52.1	82.3	16.3	14.0	113.3	76.2	123.2	126.7	127.0	74.7	58.7	52.8	917.3	107	0.7
1966	55.4	22.9	77.7	58.7	35.6	48.0	120.9	88.9	85.1	153.9	142.2	59.4	948.7	111	1.0
1967	103.4	42.2	73.4	59.9	67.3	88.4	74.9	86.4	60.2	62.7	105.9	54.6	879.3	103	0.3
1968	27.4	76.7	59.9	58.9	23.1	181.1	186.9	46.5	81.0	89.9	60.2	95.8	987.4	115	1.5
1969	52.1	24.6	66.3	59.2	57.7	110.2	84.6	115.3	60.7	96.0	97.3	40.9	864.9	101	0.1
1970	40.9	36.6	27.7	33.5	94.2	116.6	106.2	87.1	84.3	34.8	74.7	41.1	777.7	91	-0.9
1971	78.5	45.0	71.1	23.9	85.6	84.6	86.6	64.5	113.3	56.6	79.0	106.9	895.6	105	0.4
1972	80.8	56.4	86.9	6.1	97.5	110.5	78.0	75.2	75.4	71.4	31.5	78.5	848.2	99	-0.1
1973	46.0	41.4	55.9	53.3	111.0	111.8	91.2	73.9	109.5	52.3	59.4	70.9	876.6	102	0.2
1974	65.0	41.4	25.4	78.5	64.3	105.2	117.3	56.4	123.4	90.2	24.6	42.7	834.4	97	-0.2
1975	56.4	34.3	66.3	46.2	76.5	82.0	54.9	61.7	87.9	88.4	117.9	70.6	843.1	98	-0.2
1976	54.4	65.3	109.0	103.9	60.2	47.2	125.5	25.1	94.5	53.3	46.2	62.5	847.1	99	-0.1
1977	37.0	57.6	81.3	51.3	30.1	101.9	90.9	94.9	90.1	37.9	79.0	86.7	838.7	98	-0.2
1978	59.8	14.1	42.8	49.9	64.7	131.2	133.0	87.7	55.3	86.3	66.1	57.4	848.3	99	-0.1
1979	47.1	27.1	155.6	69.8	62.9	138.9	58.4	81.5	93.5	96.0	40.4	27.8	899.0	105	0.5
1981	46.6	9.6	36.6	54.9	54.7	25.7	103.4	111.5	111.3	58.4	60.7	45.0	718.4	84	-1.5
1981	21.9	65.5	49.8	100.9	91.3	94.3	46.7	68.1	61.9	111.1	48.7	56.7	816.9	95	-0.4
1982	84.9	18.3	34.1	73.9	21.2	69.1	131.5	54.2	141.1	132.7	62.8	89.4	913.2	107	0.6
1983	54.7	62.4	120.1	41.8	120.3	67.2	122.2	75.3	116.8	79.4	78.2	69.1	1007.5	118	1.7
1984	37.2	39.7	40.4	33.8	56.9	216.1	95.4	49.8	83.4	55.8	68.7	77.2	854.4	100	-0.0
1985	36.0	60.8	48.4	65.4	57.1	44.0	133.8	67.4	103.2	50.8	82.1	86.8	835.8	98	-0.2
1986	30.8	14.5	62.6	48.6	70.7	66.6	54.1	165.0	87.0	102.7	62.1	34.1	798.8	93	-0.6
1987	35.1	20.8	22.4	29.1	47.5	89.2	144.5	109.5	60.2	87.7	46.2	87.4	779.6	91	-0.9
1988	51.8	54.6	81.5	46.2	44.5	62.5	44.0	202.2	99.2	73.7	150.0	66.3	976.5	114	1.3
1989	58.3	14.1	67.6	44.3	76.2	94.1	72.2	101.7	58.8	70.9	103.1	45.2	806.5	94	-0.6
1990	77.2	52.1	45.4	28.0	99.1	131.5	174.2	37.1	78.6	158.0	70.8	62.6	1014.6	118	1.8
1991	38.7	20.3	88.9	38.5	51.8	54.2	61.8	86.1	89.3	99.2	68.3	56.3	753.4	88	-1.2
1992	63.0	32.5	20.3	69.1	44.8	53.2	95.4	159.4	114.5	48.5	79.6	76.0	856.3	100	-0.0
Mean	53.8	43.0	58.2	49.7	68.6	88.7	92.8	92.2	91.6	75.1	78.2	64.9	856.8	-	-
SD	22.8	21.8	30.7	20.9	28.6	41.8	38.2	40.0	25.4	31.9	30.2	18.7	89.6	-	-
n	37	37	37	38	38	38	38	38	38	38	38	38	38	-	-

Note: Monthly means were used to calculate the annual total where there are missing data (M).

Precipitation (mm) at Kidd Creek thickened tailings meteorological station (extened record).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	% of Mean	No. of SD from Mean
1955	M	M	M	34.8	49.4	11.1	69.0	64.7	49.7	110.0	103.3	88.4	713.1	93	-0.6
1956	32.5	23.2	18.5	43.3	86.6	84.9	93.2	31.5	86.8	15.4	76.5	63.5	656.0	86	-1.2
1957	13.6	11.9	29.8	51.2	15.2	141.5	38.3	49.7	110.5	31.0	98.2	55.9	646.9	85	-1.3
1958	28.3	41.8	6.1	9.1	48.9	67.2	31.2	128.7	68.2	72.1	54.6	47.1	603.3	79	-1.8
1959	71.3	27.0	56.7	34.8	50.2	14.4	19.6	117.1	97.4	71.8	101.0	63.3	724.5	95	-0.5
1960	69.8	66.2	26.7	60.2	128.5	57.9	69.8	94.7	66.5	50.9	90.4	32.5	814.0	106	0.6
1961	13.6	87.6	58.2	29.8	95.5	92.7	139.3	147.8	160.2	38.3	98.2	73.6	1034.6	135	3.0
1962	101.7	68.0	24.2	32.7	53.6	32.7	76.5	132.2	72.6	28.0	12.4	67.2	702.0	92	-0.7
1963	18.7	33.5	55.9	50.9	32.0	86.6	60.2	130.6	53.1	29.8	84.9	50.2	686.4	90	-0.9
1964	81.9	32.5	77.5	25.0	90.9	102.2	41.1	69.0	89.1	58.4	108.2	46.1	822.0	107	0.6
1965	44.6	74.6	9.1	6.9	105.3	68.5	115.1	118.6	118.8	67.0	51.2	45.3	824.9	108	0.7
1966	47.9	15.7	70.0	51.2	28.3	40.6	112.8	81.1	77.3	145.5	133.9	51.9	856.1	112	1.0
1967	95.5	34.8	65.7	52.4	59.7	80.6	67.2	78.6	52.6	55.1	97.9	47.1	787.3	103	0.3
1968	20.1	69.0	52.4	51.4	15.9	172.5	178.2	39.1	73.3	82.1	52.6	87.9	894.4	117	1.5
1969	44.6	17.4	58.7	51.7	50.2	102.2	76.8	107.3	53.1	88.1	89.4	33.5	773.0	101	0.1
1970	33.5	29.3	20.4	26.2	86.3	108.5	98.2	79.3	76.5	27.5	67.0	33.7	686.6	90	-0.9
1971	70.8	37.6	63.5	16.7	77.8	76.8	78.8	56.9	105.3	49.1	71.3	98.9	803.4	105	0.4
1972	73.1	48.9	79.1	0.0	89.6	102.5	70.3	67.5	67.7	63.7	24.2	70.8	757.4	99	-0.1
1973	38.6	34.0	48.4	45.8	103.0	103.8	83.4	66.2	101.5	44.8	51.9	63.3	784.6	103	0.2
1974	57.4	34.0	18.2	70.8	56.7	97.2	109.2	48.9	115.3	82.4	17.4	35.3	742.8	97	-0.2
1975	48.9	27.0	58.7	38.8	68.8	74.3	47.4	54.1	80.1	80.6	109.8	63.0	751.4	98	-0.2
1976	46.9	57.7	101.0	96.0	52.6	39.8	117.4	17.9	86.6	45.8	38.8	54.9	755.4	99	-0.1
1977	29.7	50.1	73.6	43.8	22.8	94.0	83.1	87.0	82.3	30.5	71.3	78.9	747.0	98	-0.2
1978	52.3	7.0	35.4	42.4	57.1	123.0	124.8	79.9	47.8	78.5	58.5	49.9	756.6	99	-0.1
1979	39.7	19.8	147.2	62.2	55.3	130.6	50.9	73.8	85.6	88.1	33.0	20.5	806.8	105	0.5
1981	39.2	2.5	29.3	47.4	47.2	18.5	95.5	103.5	103.3	50.9	53.1	37.6	627.8	82	-1.5
1981	14.7	57.9	42.3	93.0	83.5	86.4	39.3	60.5	54.3	103.1	41.3	49.2	725.4	95	-0.4
1982	77.1	11.1	26.8	66.2	14.0	61.5	123.3	46.7	132.8	124.5	55.2	81.6	820.9	107	0.6
1983	47.2	54.8	112.0	34.4	112.2	59.6	114.1	67.6	108.7	71.7	70.5	61.5	914.3	120	1.7
1984	29.9	32.3	33.0	26.5	49.4	207.1	87.5	42.3	75.6	48.3	61.1	69.5	762.6	100	-0.0
1985	28.7	53.2	41.0	57.8	49.6	36.6	125.6	59.8	95.3	43.3	74.4	79.0	744.2	97	-0.2
1986	23.5	7.4	55.0	41.2	63.1	59.0	46.6	156.5	79.2	94.8	54.5	26.8	707.5	92	-0.6
1987	27.8	13.6	15.2	21.8	40.1	81.4	136.2	101.5	52.6	79.9	38.8	79.6	688.5	90	-0.9
1988	44.3	47.1	73.8	38.8	37.1	54.9	36.6	193.4	91.3	66.0	141.6	58.7	883.6	116	1.3
1989	50.8	7.0	60.0	36.9	68.5	86.2	64.5	93.8	51.3	63.3	95.2	37.8	715.1	93	-0.6
1990	69.5	44.6	38.0	20.7	91.2	123.3	165.6	29.8	70.9	149.6	63.2	55.0	921.4	120	1.8
1991	31.3	13.1	81.1	31.1	44.3	46.7	54.2	78.3	81.5	91.3	60.7	48.8	662.5	87	-1.2
1992	55.4	25.2	13.1	61.5	37.4	45.7	87.5	151.0	106.5	41.1	71.9	68.3	764.5	100	-0.0
Mean	46.3	35.6	50.7	42.2	61.0	80.9	85.0	84.4	83.7	67.4	70.5	57.3	765.0	-	-
SD	22.6	21.6	30.4	20.7	28.3	41.4	37.8	39.6	25.2	31.6	29.9	18.5	88.8	-	-
n	37	37	37	38	38	38	38	38	38	38	38	38	38	-	-

Notes: (1) Monthly totals measured at the BREB meteorological station located on the KCTTD were correlated to the Timmins airport station measurements. The regression, Y = -7.009 + 0.991 X, which was used to extend the KKTTD station record, has an R2 of 0.82.

(2) Monthly means were used to calculate the annual total where there are missing data (M).

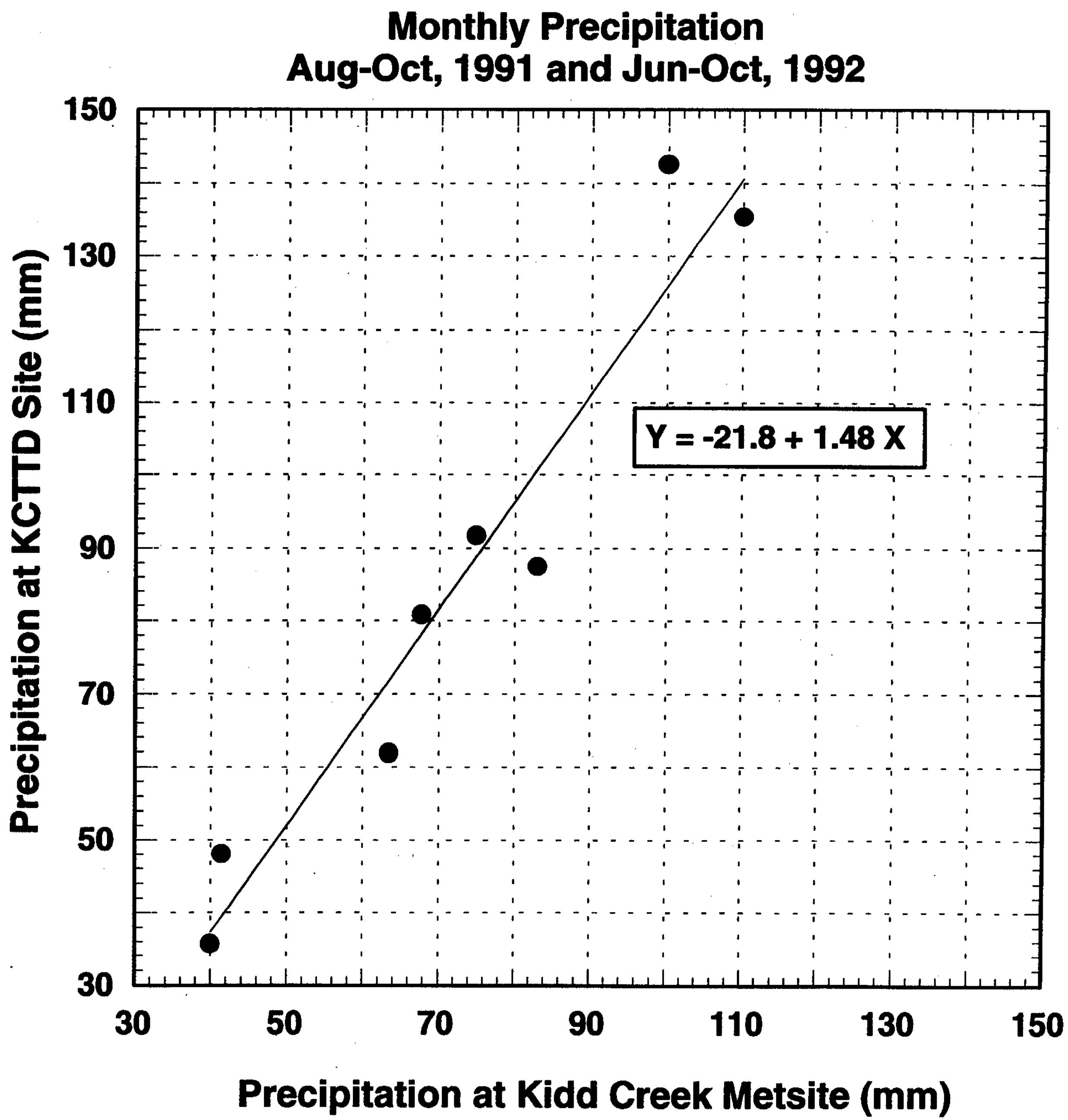
Total precipitation (mm) at Kidd Creek metallurgical site.

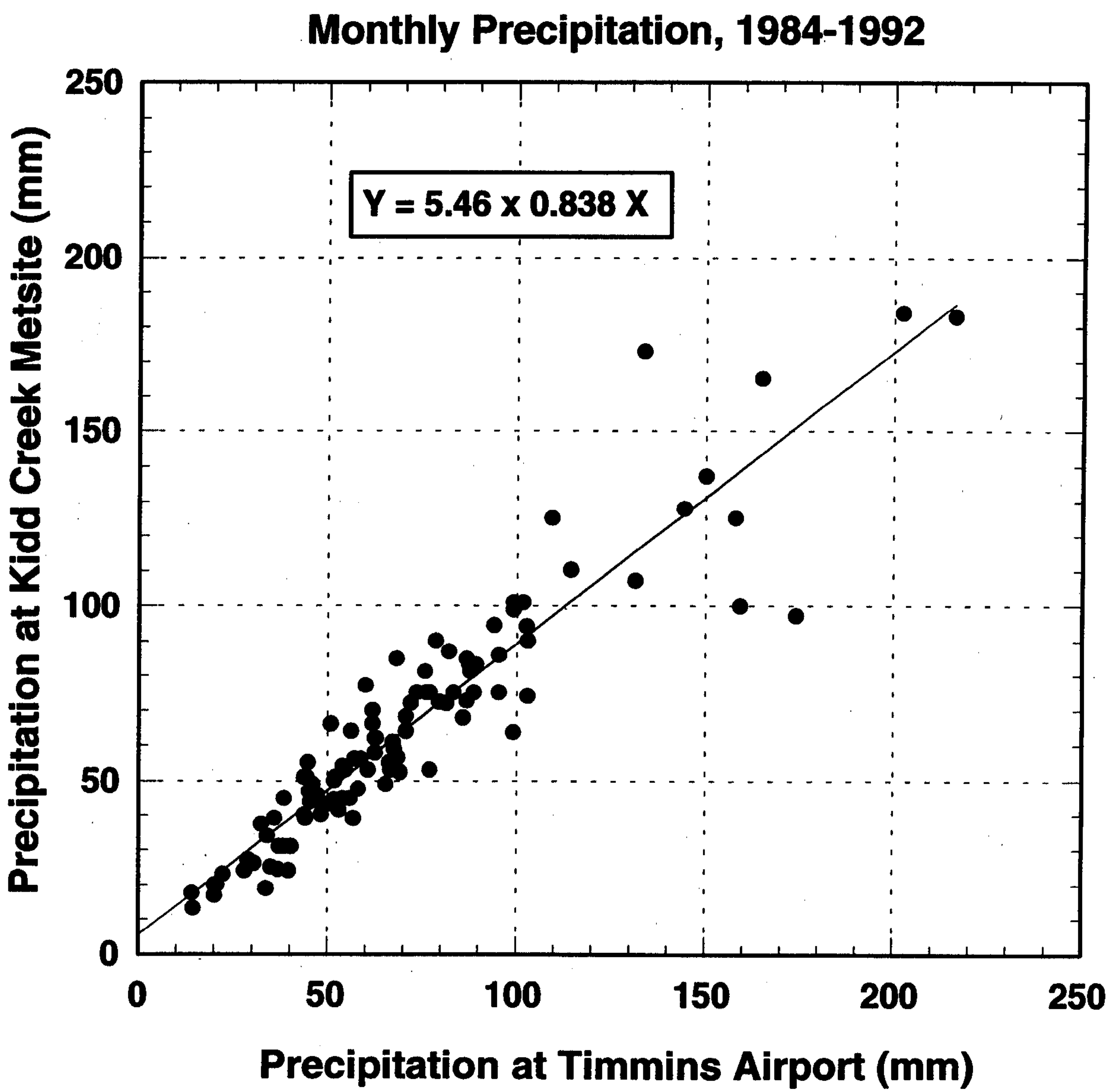
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	% of Mean
1984	31.0	24.0	31.0	19.0	39.0	183.0	86.0	43.0	75.0	45.0	56.5	53.0	686	88
1985	39.0	53.0	40.0	49.0	56.0	40.0	173.0	61.0	74.0	66.0	87.0	72.5	811	104
1986	26.0	13.0	58.0	43.0	68.0	53.0	54.0	165.0	85.0	94.0	66.0	34.0	759	97
1987	25.0	20.0	23.0	27.0	46.0	83.0	128.0	125.0	77.0	81.0	49.0	83.0	767	98
1988	50.0	53.0	72.0	46.0	51.2	62.0	51.0	184.0	99.0	75.0	137.0	55.0	935	120
1989	47.5	17.5	59.0	39.0	75.0	94.3	72.0	101.0	56.0	64.0	90.0	47.0	762	98
1990	75.0	51.0	44.0	24.0	101.0	107.0	97.0	24.3	90.0	125.0	68.0	58.0	864	111
1991	45.0	20.0	75.0	31.0	44.6	44.8	69.8	67.8	83.0	63.5	85.0	64.0	694	89
1992	61.8	37.5	16.7	52.5	55.0	41.5	75.0	100.0	110.0	40.0	72.2	81.0	743	95
Mean	44.5	32.1	46.5	36.7	59.5	78.7	89.5	96.8	83.2	72.6	79.0	60.8	780	-
SD	16.6	16.6	20.9	11.9	19.2	46.0	39.0	54.0	15.6	25.8	25.8	16.0	80	-

Precipitation at the Kidd Creek thickened tailings BREB meteorolgical station.

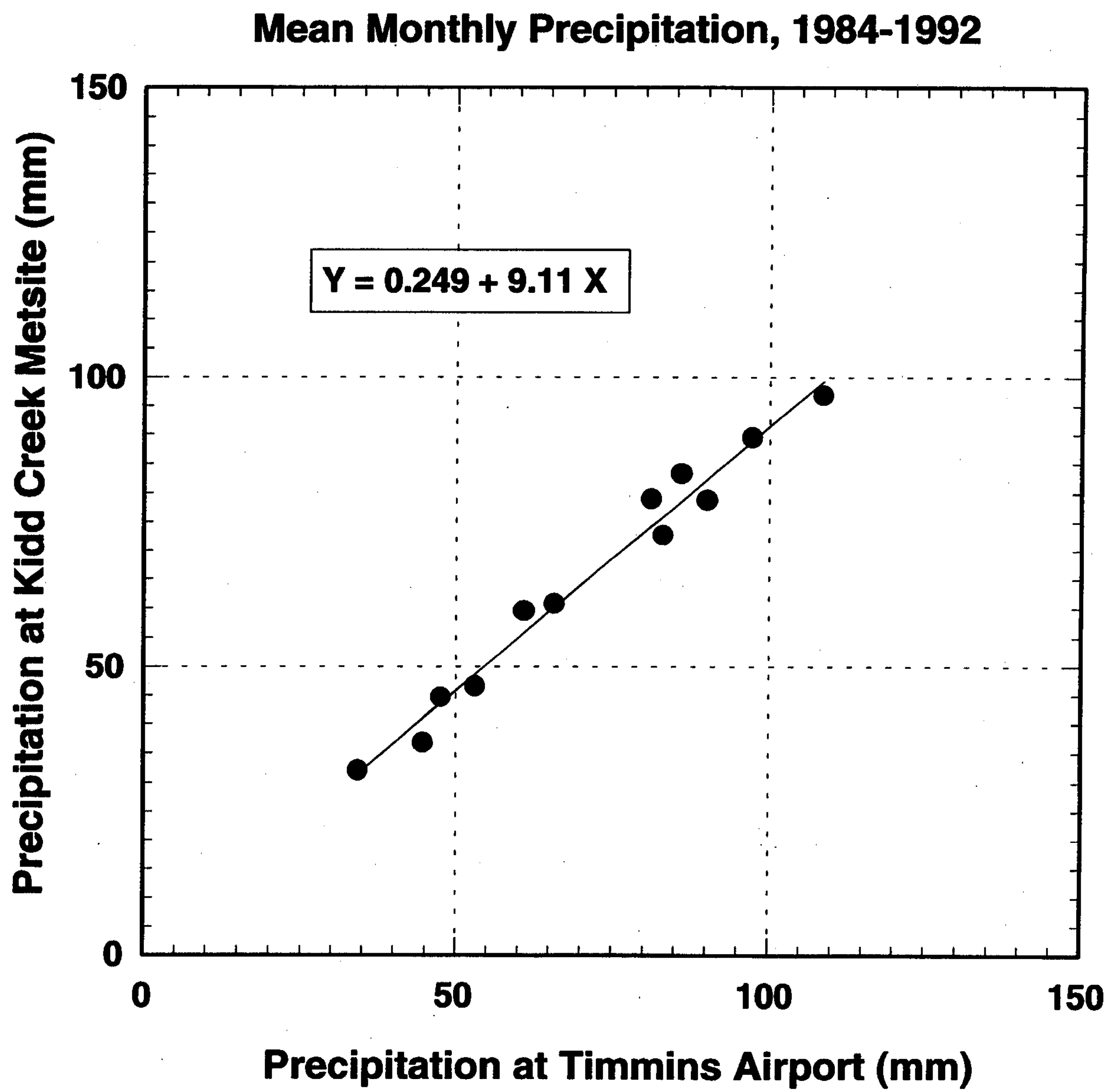
DAY	1991 JUN	JUL	AUG	SEP	OCT	1992 JUN	JUL	AUG	SEP	OCT
1	-	-	1.3	0.0	0.0	0.0	0.0	17.0	0.0	0.0
2	-	-	0.0	0.0	2.8	0.3	0.0	6.4	0.8	0.0
3	-	-	0.0	9.9	0.0	2.5	15.0	3.3	13.2	0.0
4	-	-	0.5	4.1	2.0	0.5	6.1	0.0	0.0	0.0
5	-	-	0.0	0.5	7.9	17.3	5.1	5.6	0.0	0.0
6	-	-	0.0	0.3	0.5	0.0	0.3	0.0	2.8	0.0
7	-	-	0.0	0.0	0.0	11.7	0.0	0.0	0.0	3.0
8	-	-	1.5	0.0	0.0	0.5	4.8	0.3	21.6	0.3
9	-	-	0.3	3.6	0.0	0.0	5.3	0.0	4.6	5.1
10	-	-	0.0	6.9	0.0	0.0	0.0	13.7	5.3	1.8
11	-	-	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0
12	-	-	0.0	0.0	0.8	0.0	0.0	0.0	0.0	6.4
13	-	-	0.0	0.8	0.0	0.0	0.0	0.0	7.1	1.8
14	-	-	0.0	0.0	9.1	0.0	0.0	0.0	0.8	0.0
15	-	-	11.2	21.3	1.3	0.0	0.0	0.0	0.0	0.0
16	-	-	0.8	5.3	1.8	0.0	2.5	0.0	21.6	7.9
17	-	-	10.7	0.8	0.0	1.3	9.6	0.0	0.0	1.3
18	-	-	0.0	15.7	0.0	3.3	0.0	39.1	8.1	0.0
19	-	-	0.0	0.0	0.0	6.1	0.0	1.3	1.0	0.0
20	-	-	0.0	0.0	0.0	0.0	15.0	0.0	0.0	0.5
21	-	-	0.0	0.0	11.7	0.0	0.0	18.8	0.3	0.3
22	-	-	4.1	0.0	0.3	0.0	0.0	0.0	0.3	0.0
23	-	-	0.0	1.5	0.8	0.0	0.0	0.0	0.0	0.3
24	-	-	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.8
25	-	-	0.5	1.0	9.3	0.0	3.0	3.8	0.0	0.0
26	-	-	2.0	3.0	0.0	0.8	19.8	8.4	0.0	6.4
27	-	-	44.4	1.5	1.5	0.5	0.8	0.3	40.6	0.0
28	-	-	0.3	0.5	0.0	3.3	1.8	3.6	5.8	0.0
29	-	-	0.0	0.0	0.0	0.0	2.5	9.9	1.5	0.0
30	-	-	3.3	10.7	5.8	0.0	0.0	10.4	0.0	0.0
31	-	-	0.0		0.0		0.0	0.5		0.0
Total	-	-	80.8	87.4	61.8	48.0	91.7	142.5	135.4	35.6
Average	-	-	2.6	2.9	2.0	1.6	3.0	4.6	4.5	1.1
Maximum	-	-	44.4	21.3	11.7	17.3	19.8	39.1	40.6	7.9

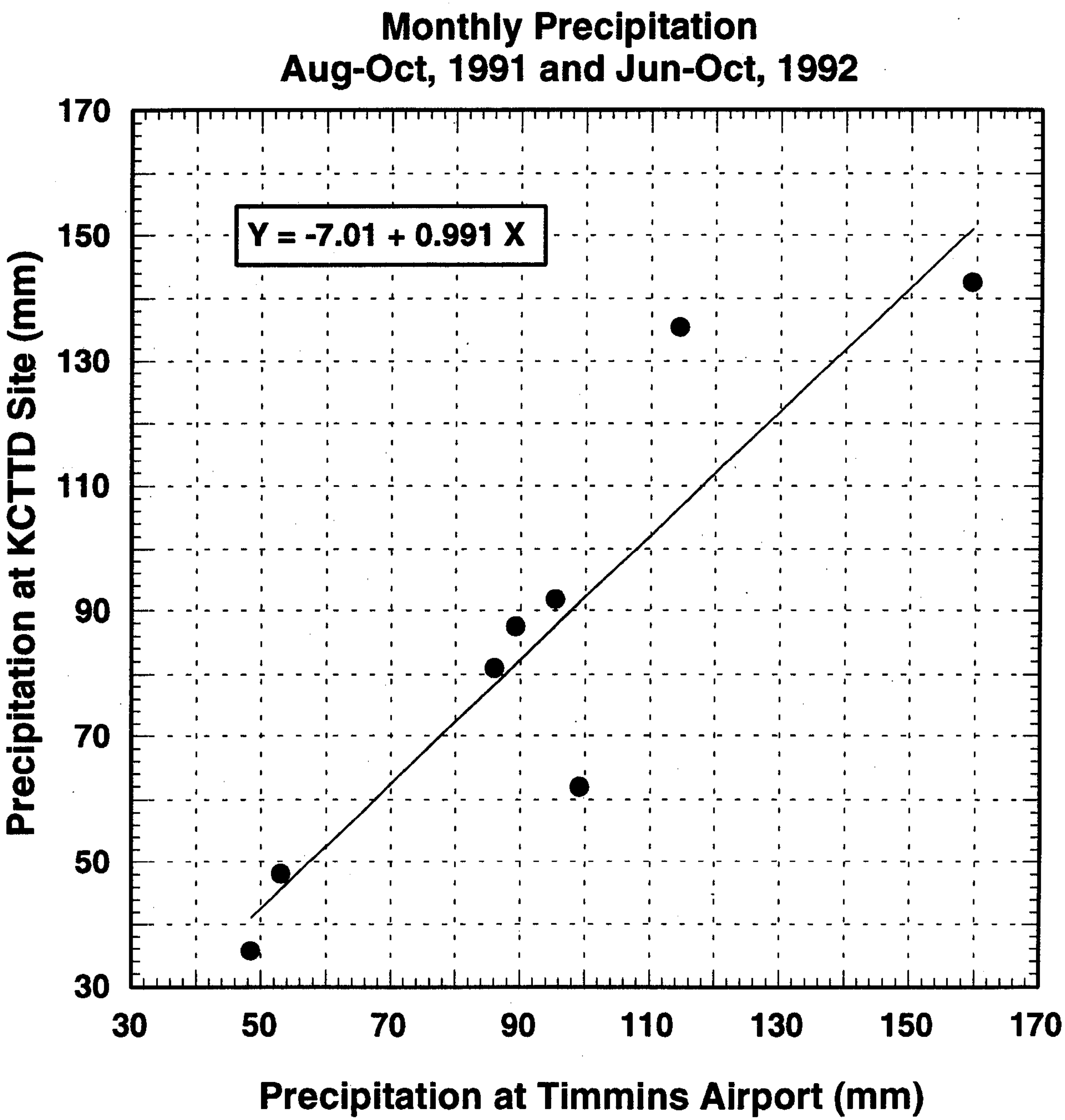
Measurements began August 1991.

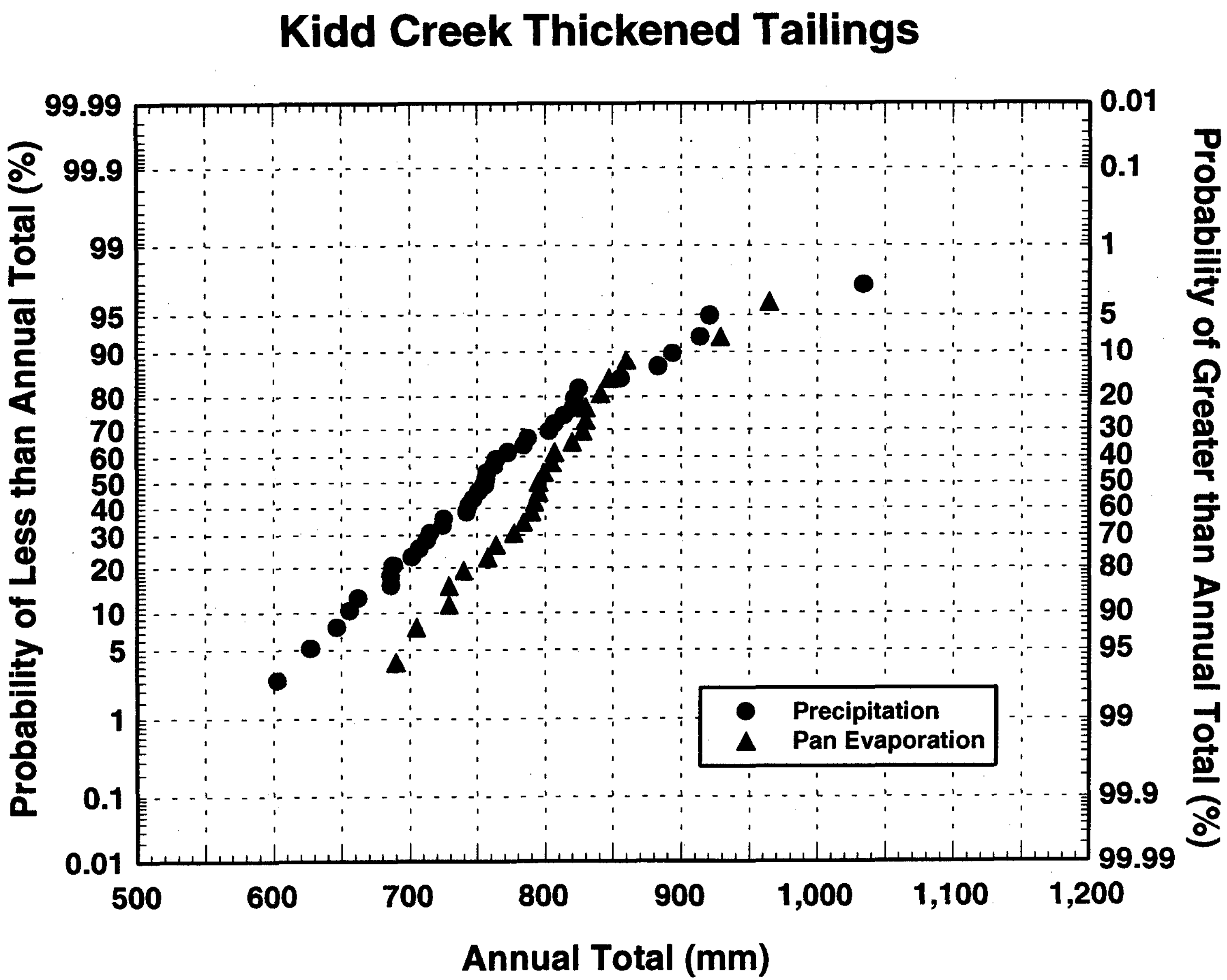

Monthly Precipitation
Aug-Oct, 1991 and Jun-Oct, 1992
Y = -21.8 + 1.48 X
Precipitation at KCTTD Site (mm)
Precipitation at Kidd Creek Metsite (mm)
30
50
70
90
110
130
150

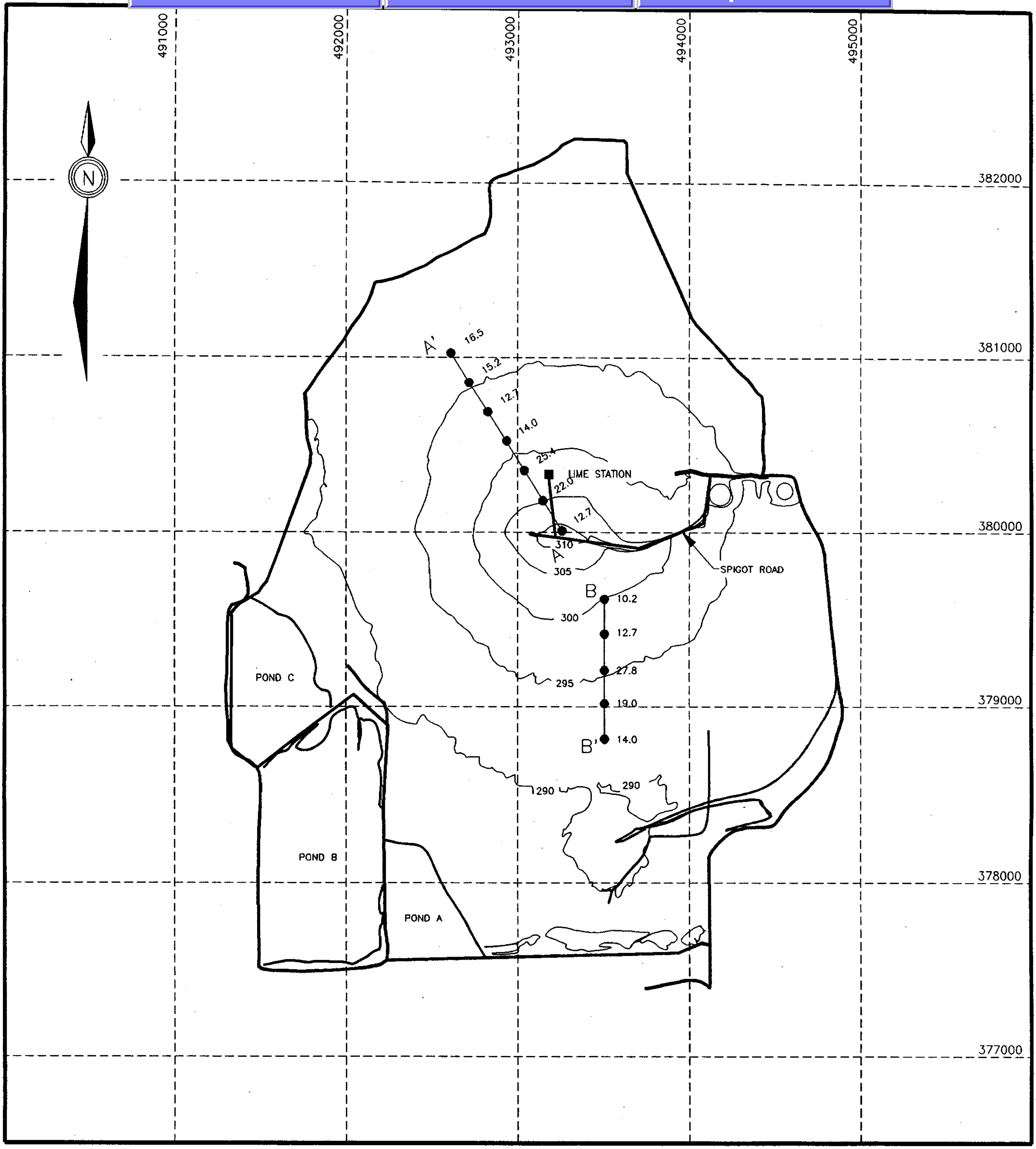


Monthly Precipitation, 1984-1992
Y = 5.46 x 0.838 X
Precipitation at Kidd Creek Metsite (mm)
Precipitation at Timmins Airport (mm)
0
50
100
150
200
250


Mean Monthly Precipitation, 1984-1992
Y = 0.249 + 9.11 X
Precipitation at Kidd Creek Metsite (mm)
Precipitation at Timmins Airport (mm)
0
50
100
150
0
50
100
150


Monthly Precipitation
Aug-Oct, 1991 and Jun-Oct, 1992
Y = -7.01 + 0.991 X
Precipitation at KCTTD Site (mm)
170
150
130
110
90
70
50
30
30
50
70
90
110
130
150
170
Precipitation at Timmins Airport (mm)


Kidd Creek Thickened Tailings
Probability of Less than Annual Total (%)
99.99
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
0.01
Probability of Greater than Annual Total (%)
0.01
0.1
1
5
10
20
30
40
50
60
70
80
90
95
99
99.9
99.99
500
600
700
800
900
1,000
1,100
1,200
Annual Total (mm)
Precipitation
Pan Evaporation



NORANDA TECHNOLOGY CENTER HYDROGEOTECHNICAL GROUP	SNOW DEPTH SURVEY ON MARCH 25, 1992 EXPRESSED IN WATER EQUIVALENCE (cm) TAILINGS DISPOSAL AREA KIDD CREEK MINE LTD.	
DRAWN BY: KSS	DATE: MAY 1993	SCALE 0.0 1.0 Km

Appendix C

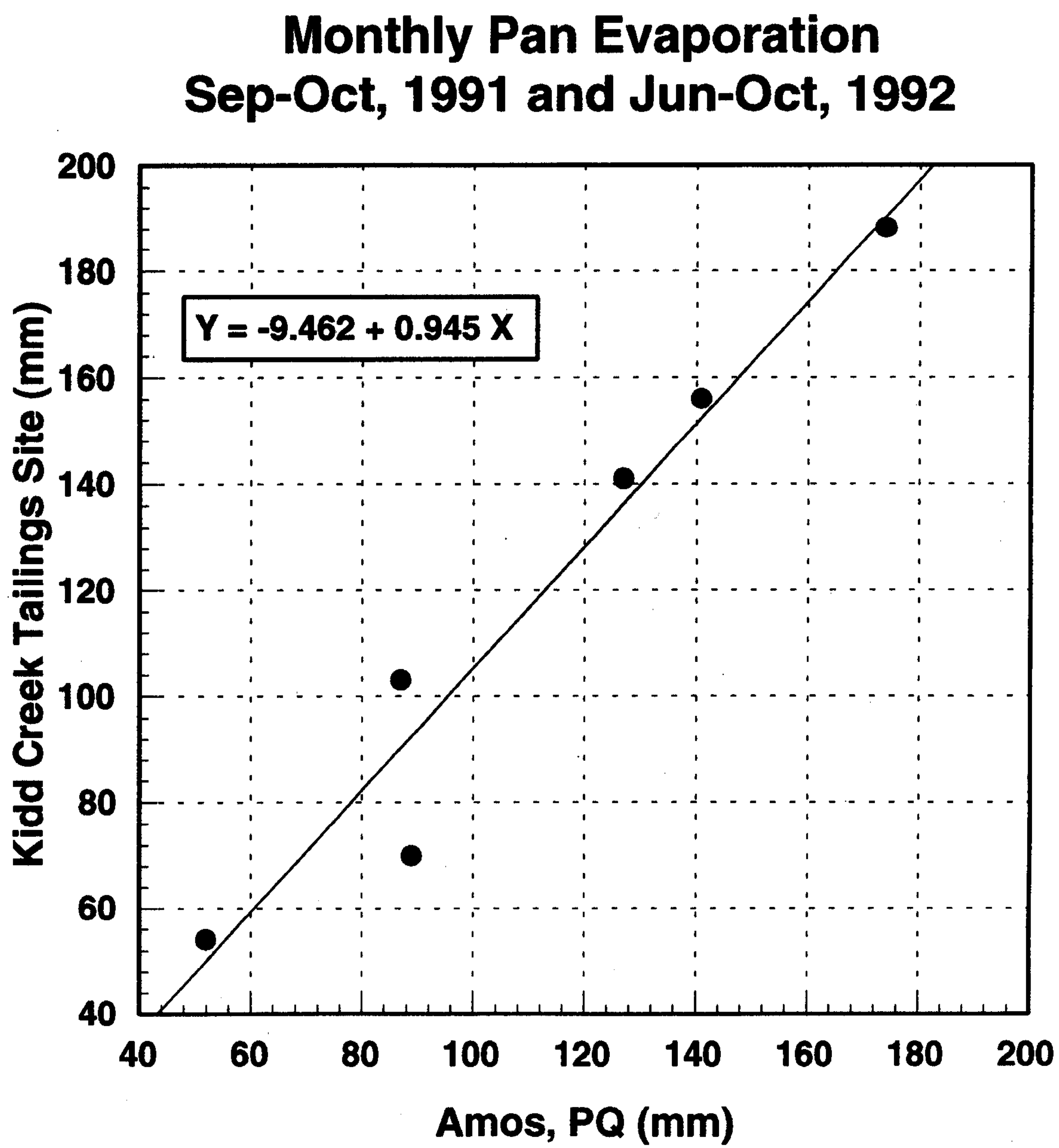
Evaporation data and Bowen ratio energy balance method

Evaporation at Kidd Creek thickened tailings and Amos, Quebec.

Station	May	Jun	Jul	Aug	Sep	Oct	Total
Soil evaporation from Kidd Creek tailings (BREB method)							
1991 total (mm)	-	-	-	58	46	25	129
1992 total (mm)	-	-	-	-	-	-	-
Pan evaporation at Kidd Creek tailings							
1991 total (mm)	-	-	-	158	70	54	282
1992 total (mm)	-	188	156	141	103	25	614
Normal pan evaporation at Amos, Quebec							
Monthly mean, 1968-92 (mm)	148	161	172	135	79	51	746
Standard deviation (mm)	36	23	38	12	13	12	55
Pan evaporation at Amos, PQ (1991)							
Total (mm)	163	213	194	146	89	52	857
Percent of mean	110	132	112	108	113	102	115
Number of sta. dev. from mean	0.4	2.3	0.6	0.9	0.8	0.1	2.0
General classification	N	VH	N	N	N	N	H
Pan evaporation at Amos, PQ (1992)							
Total (mm)	207	174	141	127	87	-	736
Percent of mean	140	88	74	64	110	-	99
Number of sta. dev. from mean	1.6	0.6	-0.8	-0.6	0.6	-	-0.2
General classification	H	N	N	N	N	-	N

General Classification: Normal = within 1 standard deviation (sd) from the mean;
2 sd < Low < 1 sd; 1 sd < High < 2 sd; outside of 2 sd, Very Low and Very High.

Pan evaporation at Kidd Creek during Aug 1991 was determined by correlation to Amos, PQ.



Monthly Pan Evaporation
Sep-Oct, 1991 and Jun-Oct, 1992
Y = -9.462 + 0.945 X
Kidd Creek Tailings Site (mm)
Amos, PQ (mm)
40
60
80
100
120
140
160
180
200

Pan Evaporation at Amos, Quebec.

Year	May (mm)	May (days)	May (mm) (adj)	Jun (mm)	Jul (mm)	Aug (mm)	Sep (mm)	Oct (mm)	Oct (days)	Oct (mm) (adj)	Total (mm)	% of Normal
1968	143	31	143	122	147	130	83	47	24	60	684	92
1969	118	31	118	129	153	145	63	23	17	41	648	87
1970	117	31	117	168	156	156	66	31	15	64	726	97
1971	160	31	160	207	151	135	94	50	31	50	797	107
1972	168	31	168	152	161	125	87				744	100
1973	109	31	109	143	184	130	67	42	26	50	682	91
1974				162	163	147	66				737	99
1975	175	31	175	169	169	156	56	50	27	57	781	105
1976	119	31	119	201	152	141	67				731	98
1977	120	15	248	135	183	108	72	16	15	32	778	104
1978	139	25	172	153	169	149	79				773	104
1979	119	24	154	181	281	120	104				891	119
1980	155	31	155	143	184	129	84	16	11	46	739	99
1981	97	21	143	159	201	122	76	42	17	77	777	104
1982	119	23	160	152	181	125	71	27	16	52	741	99
1983	105	26	126	175	178	146	84	31	17	56	765	103
1984	88	31	88	146	162	129	86				662	89
1985	146	31	146	147	153	128	84	23	14	50	708	95
1986	134	26	160	153	158	130	63				715	96
1987	129	31	129	162	151	135	82	10	10	31	690	92
1988	167	31	167	156	171	125	78				749	100
1989	79	31	79	172	198	133	107				741	99
1990	150	31	150	153	169	146	81				751	101
1991	163	31	163	213	194	146	89	24	14	52	857	115
1992	180	27	207	174	141	127	87				787	106
Normal	133		148	161	172	134	79	31		51	746	-
Sta. Dev.	28		36	23	28	12	13	13		12	55	-
n	24		24	25	25	25	25	14		14	25	-

(days) = The number of days of measurement during the month.
(adj) = Adjusted values to correct for incomplete monthly data;
the monthly average was multiplied by the number of days for the month.
Total = The total from May through Oct; the monthly average or adjusted values were used where incomplete data were encountered.
Data source: Direction de Reseaux Atmospheriques, St. Foy, PQ G1V 4H2; (418) 644-3482

Pan evaporation at Kidd Creek thickened tailings deposit, near Timmins, ON (extended record).

Year	May (mm)	May (days)	May (mm) (adj)	Jun (mm)	Jul (mm)	Aug (mm)	Sep (mm)	Oct (mm)	Oct (days)	Oct (mm) (adj)	Total (mm)	% of Normal
1968	155	31	155	130	159	139	86	47	24	60	729	91
1969	126	31	126	138	166	156	62	23	17	41	690	86
1970	124	31	124	183	170	170	66	31	15	64	777	97
1971	174	31	174	228	163	146	98	50	31	50	860	107
1972	183	31	183	165	175	134	90				799	100
1973	116	31	116	154	202	139	68	42	26	50	729	91
1974				176	177	160	67				790	99
1975	191	31	191	185	185	169	54	50	27	57	841	105
1976	127	31	127	221	165	152	67				784	98
1977	128	15	265	146	201	114	73	16	15	32	830	104
1978	150	25	185	166	185	162	81				830	104
1979	127	24	165	199	313	128	109				965	121
1980	168	31	168	154	201	138	87	16	11	46	795	99
1981	101	21	150	173	221	131	77	42	17	77	828	104
1982	127	23	171	165	199	134	72	27	16	52	792	99
1983	111	26	133	191	195	159	87	31	17	56	820	103
1984	91	31	91	158	176	139	89				705	88
1985	158	31	158	159	167	138	87	23	14	50	758	95
1986	144	26	172	167	172	140	63				764	95
1987	139	31	139	176	164	145	85	10	10	31	740	92
1988	183	31	183	169	187	134	80				805	101
1989	81	31	81	188	218	144	113				795	99
1990	163	31	163	166	185	158	84				807	101
1991	178	31	178	235	213	158	93	24	14	52	929	116
1992	198	27	227	190	153	136	90				847	106
Normal	143		159	175	188	145	81	31		51	800	-
Sta. Dev.	32		40	26	32	14	14	13		12	62	-
n	24		24	25	25	25	25	14		14	25	-

Notes: (1) (days) = The number of days of measurement during the month.

(2) (adj) = Adjusted values to correct for incomplete monthly data; the monthly average was multiplied by the number of days for the month.

(3) Total = The total from May through Oct; the monthly average or adjusted values were used where incomplete data were encountered.

(4) Using observed monthly totals, Amos meteorological station was correlated to the KCTTD station. The regression, Y = -9.462 + 0.945 X, which was used to extend the KCTTD station record, has an R2 of 0.95.

Soil evaporation at the Kidd Creek thickened tailings BREB meteorolgical station.

DAY	1991 JUN	JUL	AUG	SEP	OCT	1992 JUN	JUL	AUG	SEP	OCT
1	-	-		2.1	1.3	-	-	-	-	-
2	-	-		2.6	0.1	-	-	-	-	-
3	-	-	1.1	0.9	1.6	-	-	-	-	-
4	-	-	1.9	2.1	1.0	-	-	-	-	-
5	-	-	2.6	2.0	0.0	-	-	-	-	-
6	-	-	1.6	2.3	0.7	-	-	-	-	-
7	-	-	1.5	2.6	1.0	-	-	-	-	-
8	-	-	1.1	1.2	0.5	-	-	-	-	-
9	-	-	0.6	1.0	2.6	-	-	-	-	-
10	-	-	1.2	2.2	0.8	-	-	-	-	-
11	-	-	0.6	2.6	0.7	-	-	-	-	-
12	-	-	1.5	1.6	0.8	-	-	-	-	-
13	-	-	1.0	0.5	0.8	-	-	-	-	-
14	-	-		0.7	0.2	-	-	-	-	-
15	-	-	1.9	1.1	0.2	-	-	-	-	-
16	-	-	1.2	0.9	0.5	-	-	-	-	-
17	-	-	1.7	1.5	0.4	-	-	-	-	-
18	-	-	1.7	1.6	1.9	-	-	-	-	-
19	-	-	3.1	1.6	1.5	-	-	-	-	-
20	-	-	2.9	1.2	0.4	-	-	-	-	-
21	-	-	2.4	2.1	0.2	-	-	-	-	-
22	-	-	1.4	1.9		-	-	-	-	-
23	-	-	1.4	1.9		-	-	-	-	-
24	-	-	1.6	1.8		-	-	-	-	-
25	-	-	0.9	1.8		-	-	-	-	-
26	-	-	1.2	0.7		-	-	-	-	-
27	-	-	2.1	0.5		-	-	-	-	-
28	-	-	4.6	1.4		-	-	-	-	-
29	-	-	4.5	1.2		-	-	-	-	-
30	-	-	2.6	0.3		-	-	-	-	-
31	-	-	2.5			-	-	-	-	-
Total	-	-	52.6	46.0	17.1	-	-	-	-	-
n	-	-	28	30	21	-	-	-	-	-
Adj. Total	-	-	58.2	46.0	25.2	-	-	-	-	-

Measurements began August 1991.
The adjusted total is the monthly average multiplied by the total number of days for the month.

Energy flux balance at Kidd Creek thickened tailings surface, August 1991							
Day	Total Q* (MJ/m2)	Total G (MJ/m2)	Total H (MJ/m2)	Total Le (MJ/m2)	Q*-G-H-Le (MJ/m2)	Error (% of Q*)	Bowen Ratio (H/Le)
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	6.36	-1.69	5.04	2.63	0.38	5.96	1.92
4	8.16	-1.32	3.89	4.57	1.01	12.38	0.85
5	11.20	0.45	4.31	6.31	0.13	1.14	0.68
6	10.21	1.82	4.14	3.95	0.30	2.96	1.05
7	10.30	2.54	3.41	3.68	0.68	6.55	0.93
8	8.86	-0.66	5.88	2.77	0.86	9.70	2.12
9	8.27	-0.20	6.11	1.40	0.95	11.54	4.36
10	11.18	1.59	6.60	2.86	0.12	1.09	2.31
11	12.42	2.67	7.76	1.50	0.50	4.01	5.17
12	11.18	3.97	2.97	3.76	0.48	4.26	0.79
13	10.30	2.50	5.09	2.49	0.21	2.06	2.04
14	7.10	0.85	7.10	-1.19	0.34	4.79	-5.96
15	6.31	-3.24	4.75	4.53	0.27	4.36	1.05
16	4.04	-3.69	4.37	2.98	0.38	9.53	1.47
17	3.06	-1.30	0.06	4.27	0.04	1.28	0.01
18	3.74	-3.77	2.26	4.26	0.99	26.46	0.53
19	13.45	1.10	4.41	7.53	0.41	3.03	0.59
20	13.34	2.46	3.04	7.11	0.72	5.38	0.43
21	10.65	1.95	2.82	5.82	0.07	0.67	0.48
22	3.41	-5.51	5.27	3.50	0.14	4.11	1.50
23	7.04	-0.44	3.60	3.51	0.37	5.28	1.03
24	11.99	2.55	4.93	4.03	0.48	4.00	1.22
25	4.04	-0.49	1.81	2.27	0.44	10.97	0.80
26	8.09	3.96	1.09	2.98	0.05	0.67	0.37
27	8.09	2.05	0.84	5.16	0.04	0.51	0.16
28	13.62	2.52	-0.39	11.32	0.17	1.27	-0.03
29	11.99	1.40	-1.25	10.88	0.95	7.93	-0.11
30	9.81	-1.90	4.95	6.42	0.34	3.44	0.77
31	9.04	-5.23	8.06	6.20	-0.00	-0.00	1.30
Ave	9.32	0.43	3.95	4.60	0.34	3.62	0.86
Total	289	13.3	123	143	10.5	3.62	0.86

Note: The monthly average and total evaluates the fluxes on days with an error of less than 10%. To calculate the monthly total, the average was multiplied by the total number of days per month.

Energy flux balance at Kidd Creek thickened tailings surface, September 1991

Day	Total Q* (MJ/m2)	Total G (MJ/m2)	Total H (MJ/m2)	Total Le (MJ/m2)	Q*-G-H-Le (MJ/m2)	Error (% of Q*)	Bowen Ratio (H/Le)
1	10.61	0.88	4.30	5.23	0.20	1.92	0.82
2	9.95	0.86	2.45	6.48	0.16	1.56	0.38
3	1.62	-1.62	0.42	2.33	0.48	29.79	0.18
4	7.93	-1.79	3.97	5.22	0.54	6.86	0.76
5	8.44	-0.31	3.44	4.83	0.48	5.71	0.71
6	8.93	0.42	2.56	5.58	0.37	4.12	0.46
7	10.42	2.29	1.74	6.39	0.00	0.00	0.27
8	9.51	0.11	5.51	2.86	1.03	10.86	1.93
9	4.22	0.28	1.17	2.43	0.33	7.91	0.48
10	5.07	-3.45	2.88	5.37	0.26	5.16	0.54
11	9.33	-0.85	3.36	6.50	0.32	3.38	0.52
12	7.87	1.11	2.50	3.81	0.45	5.70	0.65
13	1.66	-1.12	1.40	1.24	0.14	8.17	1.12
14	3.61	0.91	0.63	1.78	0.29	8.14	0.35
15	6.06	2.54	0.54	2.67	0.30	4.98	0.20
16	2.84	-1.42	0.74	2.26	1.24	43.90	0.33
17	4.98	-2.94	3.70	3.80	0.41	8.31	0.97
18	2.17	-3.75	1.66	4.03	0.23	10.66	0.41
19	4.67	-3.65	3.89	4.08	0.35	7.47	0.95
20	4.85	-1.65	3.43	2.93	0.14	2.82	1.17
21	8.36	0.99	1.54	5.12	0.70	8.35	0.30
22	7.36	1.30	0.72	4.74	0.61	8.26	0.15
23	2.84	-4.58	2.68	4.73	-0.00	-0.02	0.57
24	6.23	-0.37	1.75	4.48	0.36	5.83	0.39
25	5.59	-0.51	0.98	4.35	0.77	13.77	0.22
26	3.07	-3.06	3.30	1.69	1.13	36.95	1.95
27	4.88	-3.44	5.67	1.32	1.32	27.12	4.29
28	7.14	-0.50	3.31	3.40	0.93	13.02	0.98
29	6.67	-1.25	4.08	3.02	0.82	12.24	1.35
30	-0.44	-1.92	-0.00	0.82	0.66	-149.34	-0.00
Ave	6.67	-0.46	2.43	4.37	0.32	4.81	0.56
Total	200	-13.7	73.0	131	9.62	4.81	0.56

Note: The monthly average and total evaluates the fluxes on days with an error of less than 10%. To calculate the monthly total, the average was multiplied by the total number of days per month.

Energy flux balance at Kidd Creek thickened tailings surface, October 1991

Day	Total Q* (MJ/m2)	Total G (MJ/m2)	Total H (MJ/m2)	Total Le (MJ/m2)	Q*-G-H-Le (MJ/m2)	Error (% of Q*)	Bowen Ratio (H/Le)
1	6.27	1.51	0.93	3.27	0.56	8.93	0.28
2	2.51	1.44	0.60	0.26	0.22	8.61	2.29
3	5.69	0.66	0.71	4.03	0.29	5.05	0.18
4	6.06	-0.71	3.84	2.42	0.51	8.43	1.59
5	0.80	-1.93	1.93	-0.19	1.01	125.01	-9.97
6	3.38	-3.67	4.48	1.70	0.88	26.06	2.64
7	3.13	-2.64	3.09	2.39	0.29	9.38	1.29
8	4.51	2.44	0.68	1.12	0.27	5.99	0.61
9	4.86	0.93	-2.14	6.34	-0.28	-5.68	-0.34
10	0.19	-3.37	1.04	1.93	0.58	312.26	0.54
11	3.73	-0.05	1.50	1.67	0.62	16.50	0.90
12	2.22	-2.30	2.06	2.10	0.37	16.54	0.98
13	1.63	-2.41	2.01	2.03	0.00	0.01	0.99
14	-0.04	-0.36	-0.51	0.56	0.26	-652.12	-0.90
15	2.86	-0.84	2.84	0.41	0.46	16.05	6.94
16	0.82	-0.87	0.07	1.25	0.37	45.50	0.05
17	4.37	3.61	0.07	0.88	-0.19	-4.25	0.07
18	3.53	-3.33	1.97	4.79	0.10	2.94	0.41
19	3.58	-2.45	2.37	3.66	-0.00	-0.00	0.65
20	-0.54	-2.58	0.67	1.08	0.29	-54.08	0.62
21	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-
Ave	4.19	-0.09	1.28	2.84	0.16	3.86	0.45
Total	130	-2.68	39.8	87.9	5.02	3.86	0.45

Note: The monthly average and total evaluates the fluxes on days with an error of less than 10%. To calculate the monthly total, the average was multiplied by the total number of days per month.

Energy flux balance at Kidd Creek thickened tailings surface, June 1992

Day	Total Q* (MJ/m2)	Total G (MJ/m2)	Total H (MJ/m2)	Total Le (MJ/m2)	Q*-G-H-Le (MJ/m2)	Error (% of Q*)	Bowen Ratio (H/Le)
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	4.77	1.74	-	-	-	-	-
6	10.23	5.76	-	-	-	-	-
7	6.92	0.32	-	-	-	-	-
8	11.02	-2.11	-	-	-	-	-
9	15.64	2.17	-	-	-	-	-
10	17.01	4.58	-	-	-	-	-
11	16.60	5.28	-	-	-	-	-
12	15.52	2.64	-	-	-	-	-
13	13.43	-1.86	-	-	-	-	-
14	13.39	-1.34	-	-	-	-	-
15	12.26	3.66	-	-	-	-	-
16	12.54	4.04	-	-	-	-	-
17	11.08	2.20	-	-	-	-	-
18	12.81	-4.53	-	-	-	-	-
19	7.64	-8.66	-	-	-	-	-
20	9.87	-2.97	-	-	-	-	-
21	14.59	1.84	-	-	-	-	-
22	11.13	2.30	-	-	-	-	-
23	10.53	3.02	-	-	-	-	-
24	8.79	1.25	-	-	-	-	-
25	6.60	1.18	-	-	-	-	-
26	8.12	-1.89	-	-	-	-	-
27	11.21	3.75	-	-	-	-	-
28	2.51	-3.62	-	-	-	-	-
29	11.55	1.74	-	-	-	-	-
30	3.74	-2.42	-	-	-	-	-
Ave	10.75	0.69	-	-	-	-	-
Total	280	18.1	-	-	-	-	-

Energy flux balance at Kidd Creek thickened tailings surface, July 1992

Day	Total Q* (MJ/m2)	Total G (MJ/m2)	Total H (MJ/m2)	Total Le (MJ/m2)	Q*-G-H-Le (MJ/m2)	Error (% of Q*)	Bowen Ratio (H/Le)
1	9.48	3.20	-	-	-	-	-
2	9.80	3.00	-	-	-	-	-
3	0.72	-4.48	-	-	-	-	-
4	9.55	0.30	-	-	-	-	-
5	7.63	1.42	-	-	-	-	-
6	7.51	1.34	-	-	-	-	-
7	12.23	3.83	-	-	-	-	-
8	5.25	-1.00	-	-	-	-	-
9	9.53	1.50	-	-	-	-	-
10	7.24	-4.06	-	-	-	-	-
11	16.80	3.64	-	-	-	-	-
12	9.56	0.65	-	-	-	-	-
13	12.03	2.19	-	-	-	-	-
14	14.89	4.70	-	-	-	-	-
15	11.92	-0.03	-	-	-	-	-
16	4.57	-1.20	-	-	-	-	-
17	9.92	1.37	-	-	-	-	-
18	13.59	2.57	-	-	-	-	-
19	10.81	2.23	-	-	-	-	-
20	5.72	-8.76	-	-	-	-	-
21	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-
23	13.93	1.10	-	-	-	-	-
24	13.25	1.69	-	-	-	-	-
25	7.83	0.79	-	-	-	-	-
26	9.87	0.68	-	-	-	-	-
27	7.04	-0.69	-	-	-	-	-
28	5.09	-1.07	-	-	-	-	-
29	9.33	-0.23	-	-	-	-	-
30	11.63	-0.58	-	-	-	-	-
31	14.74	1.07	-	-	-	-	-
Ave	9.70	0.52	-	-	-	-	-
Total	281	15.2	-	-	-	-	-

Energy flux balance at Kidd Creek thickened tailings surface, August 1992

Day	Total Q* (MJ/m2)	Total G (MJ/m2)	Total H (MJ/m2)	Total Le (MJ/m2)	Q*-G-H-Le (MJ/m2)	Error (% of Q*)	Bowen Ratio (H/Le)
1	4.51	0.26	-	-	-	-	-
2	7.64	0.35	-	-	-	-	-
3	5.73	-0.51	-	-	-	-	-
4	15.58	-4.93	-	-	-	-	-
5	10.11	0.03	-	-	-	-	-
6	14.15	5.31	-	-	-	-	-
7	13.13	2.65	-	-	-	-	-
8	3.98	-1.01	-	-	-	-	-
9	14.09	4.89	-	-	-	-	-
10	10.62	-1.87	-	-	-	-	-
11	4.10	-5.04	-	-	-	-	-
12	9.11	1.52	-	-	-	-	-
13	5.74	0.07	-	-	-	-	-
14	8.57	1.53	-	-	-	-	-
15	10.76	2.22	-	-	-	-	-
16	8.73	0.86	-	-	-	-	-
17	8.19	0.61	-	-	-	-	-
18	0.47	-4.33	-	-	-	-	-
19	5.49	-2.44	-	-	-	-	-
20	14.43	2.65	-	-	-	-	-
21	2.66	-1.01	-	-	-	-	-
22	5.50	-0.21	-	-	-	-	-
23	12.64	3.11	-	-	-	-	-
24	11.19	2.64	-	-	-	-	-
25	2.10	-3.85	-	-	-	-	-
26	3.63	-2.40	-	-	-	-	-
27	7.26	0.11	-	-	-	-	-
28	4.29	-1.63	-	-	-	-	-
29	5.57	-1.14	-	-	-	-	-
30	3.69	0.12	-	-	-	-	-
31	5.33	-2.15	-	-	-	-	-
Ave	7.71	-0.12	-	-	-	-	-
Total	239	-3.59	-	-	-	-	-

Energy flux balance at Kidd Creek thickened tailings surface, September 1992							
Day	Total Q* (MJ/m2)	Total G (MJ/m2)	Total H (MJ/m2)	Total Le (MJ/m2)	Q*-G-H-Le (MJ/m2)	Error (% of Q*)	Bowen Ratio (H/Le)
1	11.92	1.63	-	-	-	-	-
2	8.86	0.68	-	-	-	-	-
3	6.08	-0.41	-	-	-	-	-
4	11.75	0.92	-	-	-	-	-
5	9.51	1.21	-	-	-	-	-
6	2.33	0.51	-	-	-	-	-
7	6.17	-0.84	-	-	-	-	-
8	4.68	-1.33	-	-	-	-	-
9	3.49	-1.05	-	-	-	-	-
10	5.94	-2.14	-	-	-	-	-
11	9.15	-0.34	-	-	-	-	-
12	3.08	1.15	-	-	-	-	-
13	9.54	1.82	-	-	-	-	-
14	3.10	1.72	-	-	-	-	-
15	10.04	1.28	-	-	-	-	-
16	1.24	0.35	-	-	-	-	-
17	5.87	0.57	-	-	-	-	-
18	1.92	-3.45	-	-	-	-	-
19	4.32	-3.45	-	-	-	-	-
20	5.49	-0.25	-	-	-	-	-
21	4.04	2.01	-	-	-	-	-
22	2.89	-5.20	-	-	-	-	-
23	7.37	-0.90	-	-	-	-	-
24	7.58	1.82	-	-	-	-	-
25	6.90	1.37	-	-	-	-	-
26	6.96	2.27	-	-	-	-	-
27	0.71	-1.85	-	-	-	-	-
28	0.58	-3.90	-	-	-	-	-
29	2.78	-4.25	-	-	-	-	-
30	4.90	-1.00	-	-	-	-	-
Ave	5.64	-0.37	-	-	-	-	-
Total	169	-11.1	-	-	-	-	-

Energy flux balance at Kidd Creek thickened tailings surface, October 1992

Day	Total Q* (MJ/m2)	Total G (MJ/m2)	Total H (MJ/m2)	Total Le (MJ/m2)	Q*-G-H-Le (MJ/m2)	Error (% of Q*)	Bowen Ratio (H/Le)
1	7.56	2.77	-	-	-	-	-
2	6.00	1.78	-	-	-	-	-
3	5.71	-3.76	-	-	-	-	-
4	5.18	-2.12	-	-	-	-	-
5	6.12	0.55	-	-	-	-	-
6	4.56	1.56	-	-	-	-	-
7	0.52	-2.17	-	-	-	-	-
8	4.36	0.66	-	-	-	-	-
9	2.32	0.19	-	-	-	-	-
10	2.25	-0.42	-	-	-	-	-
11	1.15	-1.19	-	-	-	-	-
12	0.53	-3.75	-	-	-	-	-
13	3.15	-1.79	-	-	-	-	-
14	1.61	-0.32	-	-	-	-	-
15	0.79	-0.92	-	-	-	-	-
16	0.62	-3.68	-	-	-	-	-
17	1.74	-2.31	-	-	-	-	-
18	1.20	-2.16	-	-	-	-	-
19	1.29	-1.73	-	-	-	-	-
20	3.56	-1.42	-	-	-	-	-
21	2.83	-0.28	-	-	-	-	-
22	5.01	2.91	-	-	-	-	-
23	1.08	0.95	-	-	-	-	-
24	2.44	-2.71	-	-	-	-	-
25	1.11	-1.94	-	-	-	-	-
26	2.97	-0.50	-	-	-	-	-
27	1.91	-1.47	-	-	-	-	-
28	0.67	-1.76	-	-	-	-	-
29	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-
Ave	2.79	-0.89	-	-	-	-	-
Total	78.2	-25.0	-	-	-	-	-

Energy Balance at the Soil Surface by Bowen Ratio Method
(after Campbell Sci., 1988 and Oke, 1987)

An energy budget at the soil surface is given by:

$$Q^* = Q_G + Q_H + Q_E \tag{1}$$

where, Q^* = Net all-wave radiation[1] flux density (R_n),
Q_G = Soil sensible heat flux density (G),
Q_H = Air sensible heat flux density (H),
Q_E = Air latent heat flux density (L_e).

The budget assumes steady state conditions along a mean vertical concentration gradient. The sign convention used is R_n positive into the surface and G, H, and L_e positive away from the surface.

At a few meters from the soil surface, the water-vapor mass-flux density (E) and heat-flux density (H) may be expressed as:

$$E = k_v \frac{\partial q}{\partial z} \tag{2}$$

$$H = \rho c_p k_H \frac{\partial T}{\partial z} \tag{3}$$

where, ρ = Air density
c_p = Specific heat of air,
q = Vapor density
T = Air temperature,
z = Vertical height,
k_v = Eddy diffusivity for vapor,
k_H = Eddy diffusivity for heat.

---

[1]Net radiation is defined as the sum of all incoming radiation less the sum of all outgoing radiation. It is the energy retained by the surface for heating, plant growth, and evaporation. Radiation is principal to evaporation and evapotranspiration, although in arid regions advected heat (i.e., the transference of heat by horizontal currents of air) may be a more pronounced mechanism.

Air density and the specific heat of air theoretically should account for the pressure of water vapor but the use of standard dry air values causes negligible error. The eddy diffusivities[1] are a function of height, and the vapor and temperature gradients reflect temporal and spacial averages.

Applying the Universal Gas Law[2] to Equation 2 and using the latent heat of vaporization to convert to units of energy, the latent heat flux density (L_e) in terms of vapor pressure is:

$$L_e = \frac{\lambda \rho \varepsilon k_v}{p} \frac{\partial e}{\partial z} \qquad (4)$$

where, λ = Latent heat of vaporization,
ε = Ratio of molecular weight of water to the molecular weight of dry air,
p = Atmospheric pressure,
e = Vapor pressure.

In practice, finite gradients are measured and an effective eddy diffusivity are assumed over the vertical gradient:

$$L_e = \frac{\lambda \rho \varepsilon k_v (e_1 - e_2)}{p(z_1 - z_2)} \qquad (5)$$

$$H = \frac{\rho c_p k_H (T_1 - T_2)}{(z_1 - z_2)} \qquad (6)$$

---

[1]Eddy diffusion is the turbulent diffusion of properties. An extension of the case of pure diffusion where eddies are considered to play the role of molecules (Oke, 1987).

[2]The Universal Gas Law is: $e = \rho R T$
where, e = vapor pressure, ρ = vapor density, R = 461.5 J kg^{-1} $°K^{-1}$, and T = kelvins;

therefore, $\rho = 2.17 \frac{e}{T}$.

In general, k_v and k_H are not known but under specific conditions they can be assumed equal and the ratio of H to L_e is used to partition available energy at the surface into sensible and latent heat flux. This technique first proposed by Bowen (1926).

The Bowen ratio (β) is obtained from Equations 5 and 6:

$$\beta = \frac{H}{L_e} = \frac{\rho c_p k_H \frac{\Delta T}{\Delta z}}{\frac{\lambda \rho \varepsilon c_v}{p} \frac{\Delta e}{\Delta z}} = \frac{p c_p (T_1 - T_2)}{\lambda \varepsilon (e_1 - e_2)} \tag{7}$$

where $pc_p/\lambda\varepsilon$ is the psychometric constant. Substituting $L_e\beta$ for H in Equation 1 and solving for L_e yields:

$$L_e = \frac{R_n - G}{1 + \beta} \tag{8}$$

When the Bowen ratio approaches -1, the calculated latent heat flux approaches infinity and Equation 8 fails. Fortunately, this condition usually occurs at night when there is little available energy (R_n-G), i.e., when R_n-G approaches 0. In practice, when β is close to -1 (e.g., -1.25 < β < -0.75), L_e and H are assumed to be negligible and not calculated.

Table 1. Typical Values of β.

Tropical Oceans: 0.1
Tropical Wet Jungles: 0.1-0.3
Temperate Forests and Grasslands: 0.4-0.8
Semi-arid Areas: 2-6
Deserts: 10

If β is greater than 1, H is larger than L_e as a channel for dissipating heat. This may be found over surfaces where water is to some extent limited. Since a majority of the heat being convected into the atmosphere is in the sensible form, the climate is likely to be relatively warm. On the other hand, if β is less than 1, L_e is larger than H, and the heat input into the atmosphere is mainly in the latent form. This will not directly contribute to warming of the lower atmosphere, but may increase its humidity; therefore, the climate is likely to be relatively cool and moist.

In the absence of atmospheric advection, β can vary between infinity for a dry surface with no evaporation to 0 for an evaporation wet surface with no sensible heat loss. If there is atmospheric heat advection, β may become negative, indicating a flow of heat from the surface. A negative β is common at night when the sensible heat flux is downward (negative), but evaporation (L_e) continues away from the surface (positive).

Measurements of T and *e* at two heights above the surface in addition to R_n and G are required to estimate the sensible (H) and latent (L_e) heat fluxes above the soil surface. The measurements are conducted with the Bowen Ratio System Instrumentation (Campbell Scientific, Inc., Fig. 1). R_n is measured with a net radiometer, T is measured with fine-wire thermocouples, *e* is calculated by measuring the dew point temperature with a single cooled-mirror dew-point hygrometer (equation described by Lowe, 1976), and G is measured with a soil heat flux plate and a two point averaging thermocouple to measure soil heat storage. All instruments were attached to a data logger which controls the system processing.

The distance from the sensors to the upwind edge of the surface type being studied is known as the fetch. Generally, advection can be neglected if the fetch is at least 100

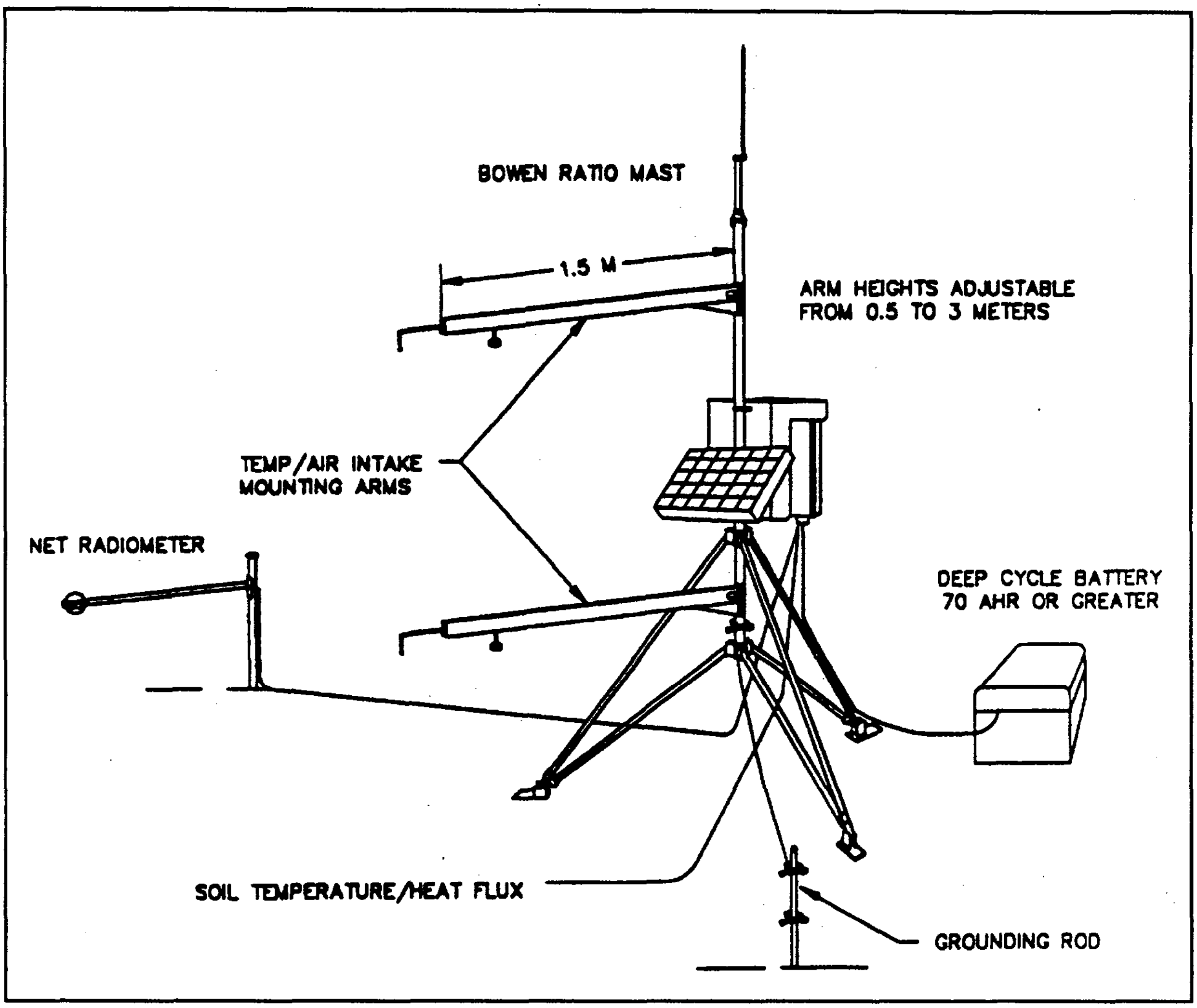


Fig. 1. CSI Bowen Ratio System.

times the instrument height (Campbell, 1977, p.40). It is assumed that there are no obvious large-scale heterogeneities in the surface within the fetch.

With the measurements of T and *e*, β is calculated with Equation 7. The psychometric constant ($pc_p/\lambda\varepsilon$) consists of:

* (1) p = Atmospheric pressure (kPa) which is obtained from a near by station and corrected for elevation;

(2) c_p = Specific heat of air (1.01 kJ kg^{-1} $°C^{-1}$);

(3) λ = Latent heat of vaporization (kJ/kg), a function of soil-water temperature at the surface,
($\lambda = 2500 - 2.45\ C + 3.326E{-}03\ C^2 + 8.19E{-}05\ C^3$),
2464 at 15° C.

(4) ε = the ratio of molecular weight of water to the molecular weight of dry air (0.622).

The soil heat flux (G) at the surface is calculated by the sum of heat flux below the surface (W m^{-2}) and the energy stored in the soil layer above the plate (W m^{-2}). The heat flux (F) is measured with a heat flux plate (transducer), and the stored energy (S) is calculated by the product of four items, where S=(1)/(2)(3)(4):

(1) Change of temperature per time (°C s^{-1}),

* (2) Soil bulk density (kg m^{-3}),

(3) Flux plate depth (m),

(4) Specific heat of soil (J kg^{-1} $°C^{-1}$) = $C_s + C_w\ \theta_{dw}$

* where, C_s = Specific heat of dry soil (J kg^{-1} $°C^{-1}$),
800 for sandy soil and 890 for clay soil;

C_w = Specific heat of water (4180 J kg^{-1} $°C^{-1}$);

* θ_{dw} = Soil-water content by dry weight.

The site specific values (marked by *) are:

(1) Atmospheric pressure,

(2) Soil bulk density,

(3) Specific heat of dry soil,

(4) Soil-water content.

Net all-wave radiation is measured with a net radiometer (W m^{-2}). Latent heat flux (L_e) is calculated with Equation 8 and sensible heat flux (H) is calculated with Equation 1 ($H=R_n-G-L_e$). The latent heat flux density is converted to mass flux density by:

$$E = \frac{L_e}{\lambda}$$

where, E = Rate of evaporation (g m^{-2} s^{-1})
L_e = Latent heat flux density (W m^{-2})
λ = Latent heat of vaporization (J g^{-1}).

Given that the density of water (ρ_w) is 1000 kg m^{-3}, a mass of 1 kg of water spread over an area of 1 m^2 would produce a layer 1 mm deep. At 20° C, λ is 2.45 MJ kg^{-1}, thus 1 mm of evaporation requires an energy density of 2.45 MJ m^{-2}. Therefore, an evaporation rate of 1 mm h^{-1} is 680 W m^{-2}, or 1 mm d^{-1} is 28.3 W m^{-2}. Both ρ_w and λ change with temperature but the commonly encountered range from 0°C to 40°C this conversion is accurate within 2.5%.

References

Bowen, I.S. (1926). The ratio of heat losses by conduction and by evaporation from any water surface. Phys. Rev. 27: 779-787.

Campbell, G.S. (1977). An introduction to environmental biophysics. New York, Springer-Verlag, 159 p.

Campbell Scientific, Inc. (1988). CSI Bowen Ration Instrumentation Instruction Manual.

Lowe, P.R. (1976). An approximating polynomial for computation of saturation vapor pressure. J. Appl. Meteor. 16:100-103.

Oke, T.R. (1987). Boundary Layer Climates. Methuen & Co., NY.

Appendix D

Hydrogeologic methods and data

Hydrogeologic methods

Vertical hydraulic head gradients were measured with piezometer nests, and horizontal gradients, with a piezometer nest cross-section. The cross-section extended 600 m northwest from the top of the cone and a detailed vertical section was located at the BREB meteorological station. The piezometer nest locations are shown in Figure 6.

Piezometer section A-A': In 1991, two piezometer nests were established near the top of the cone; NTC-A1 was located near BH1 and NTC-A2, near BH2. Three piezometers were installed at different depths at A1, and four at A2. Specifications are shown in NTC (1992). In 1992, two additional nests (A3 and A4) were installed further down the cone to establish piezometer section A-A'. The nests were located approximately 200 m apart.

Evaporation/Infiltration monitoring station: A detailed piezometer nest was established near BH1 which consisted of five piezometers located at different depths. This vertical profile nest was extended across the water table by placing three tensiometers above the piezometers. Tensiometers measure the negative pressure (or suction) and were installed at 1, 2 and 3 m below the surface. At the monitoring nest the BREB meteorological station was established to measure evaporation.

TTD runoff channel monitoring stations: In order to observe any effect of tailings discharge on saturated flow, two piezometer nests were established in a active runoff channel, downstream of a discharge spigot, where thickened tailings were flowing. One nest (C1), consisting 3 piezometers, was located above end of the channel, i.e., the point where the flow begins to spread and forms a depositional fan. The channel at C1 was entrenched about 0.6 m into the cone. The other nest (C2), which consisted of 2 piezometers, was located approximately 300 m downstream of C1 at the right (north) edge of the fan. C2 was placed where tailings were actively being deposited.

The piezometers were constructed using 2.5 cm (1.0 in) I.D. schedule 40 PVC pipe, and 1.9 (0.75 in) I.D., 30 cm (12 in) long tips. The piezometer tips were made of a porous plastic (Vion) sleeve sealed inside a perforated section of PVC, and are manufactured by Solinst Canada Ltd of Burlington, Ont. The piezometers were manually driven into the tailings with a sledge hammer. Water in each monitoring well was flushed several times after installation to ensure proper settling of the tailings around the well tip, and to remove any fine tailings material that entered the well tip during installation.

Depth of the water table is given by the distance between ground level and the level of water in the shallowest well at each station. Water levels in the piezometers were measured using an electric water level meter. Weekly recordings were performed mine personnel. In Appendix D the piezometer data are presented as total hydraulic head with mean sea level as the datum (z=0).

Piezometer specifications at NTC section A-A'.

Specification	Nest #1 A1-1 (m)	A1-2 (m)	A1-3 (m)	Nest #2 A2-1 (m)	A2-2 (m)	A2-3 (m)	A2-4 (m)	Nest #3 A3-1 (m)	A3-2 (m)	A3-3 (m)	Nest #4 A4-1 (m)	A4-2 (m)	A4-3 (m)
Top of piezometer, 1992	310.48	310.78	310.64	305.48	305.38	305.34	305.11	301.64	301.63	301.60	298.75	298.71	298.66
Surface elevation, 1992	309.74	-	-	304.19	-	-	-	300.70	-	-	297.86	-	-
Surface elevation, 1991	309.69	309.76	309.75	304.33	304.27	304.16	304.12	n/i	n/i	n/i	n/i	n/i	n/i
Piezometer tip	293.53	298.54	302.46	292.34	293.80	296.55	300.85	293.39	295.07	296.56	291.71	293.10	294.77
Depth from piezometer top	16.95	12.24	8.19	13.15	11.59	8.79	4.26	8.25	6.56	5.04	7.04	5.61	3.89
Depth from surface	16.22	11.20	7.29	11.86	10.40	7.64	3.34	7.31	5.63	4.14	6.15	4.76	3.09

Hydraulic head measurements at NTC section A-A'.

Date	Time	Nest #1 A1-1 (m)	A1-2 (m)	A1-3 (m)	Nest #2 A2-1 (m)	A2-2 (m)	A2-3 (m)	A2-4 (m)	Nest #3 A3-1 (m)	A3-2 (m)	A3-3 (m)	Nest #4 A4-1 (m)	A4-2 (m)	A4-3 (m)
920605	1000	303.84	303.82	303.76	300.46	300.84	300.37	dry	n/i	n/i	n/i	n/i	n/i	n/i
920722	1300	304.23	304.24	304.27	301.54	301.50	301.54	dry	n/i	n/i	n/i	n/i	n/i	n/i
920723	1100	303.99	304.15	304.36	301.22	301.30	301.17	dry	295.98	296.15	297.96	292.95	293.76	dry
920724	800	303.74	303.54	303.29	296.31	300.85	299.36	dry	-	-	296.82	292.91	293.68	dry
920730	1400	304.45	304.66	304.82	298.28	301.91	301.82	301.44	297.81	297.85	297.92	294.73	294.73	dry
920804	1430	305.00	305.23	305.53	299.21	302.68	302.87	303.36	298.52	298.44	298.83	295.36	295.52	295.69
920806	1300	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
920813	900	304.54	304.67	304.74	300.58	302.19	302.14	301.85	298.14	298.16	298.18	295.08	295.04	295.06
920820	1030	304.98	305.16	305.48	301.03	302.44	302.54	303.44	298.49	298.60	298.77	295.58	295.87	296.41
920825	1100	305.66	306.11	306.29	301.71	302.98	302.87	302.51	299.19	299.22	299.28	296.42	296.36	296.10
920904	1100	306.28	306.70	307.14	302.68	303.50	303.55	303.82	299.91	299.95	300.04	297.33	297.25	297.04
920910	930	306.34	306.68	306.99	302.96	303.60	303.63	303.99	299.90	299.95	299.99	297.11	297.15	297.41
920917	1030	306.45	306.76	307.14	303.26	303.76	303.74	304.00	300.04	300.08	300.12	297.28	297.30	297.41
920923	1030	306.20	306.78	307.21	303.33	303.49	303.29	302.97	299.85	299.85	299.86	297.03	296.91	296.70
921001	1030	306.72	307.15	307.60	303.76	303.70	303.72	303.76	300.10	300.15	300.19	297.22	297.25	297.26
921009	1230	305.89	306.10	306.44	303.00	302.96	302.91	303.21	299.52	299.52	299.50	296.57	296.53	296.66
921015	1230	306.38	306.72	307.05	303.77	303.73	303.75	303.78	300.14	300.18	300.23	297.53	297.55	297.62
921022	1330	306.54	306.88	307.36	303.78	303.66	303.69	303.99	300.12	300.17	300.19	n/a	n/a	n/a
921029	1030	306.78	307.29	307.70	303.80	303.90	303.80	303.21	300.32	300.42	300.32	n/a	n/a	n/a
921105	1330	305.97	306.18	306.67	303.13	302.99	302.99	303.83	299.70	299.75	299.78	n/a	n/a	n/a
921112	1030	306.29	306.46	306.60	303.57	303.43	303.44	303.88	299.97	300.03	n/a	297.60	297.56	297.62
921118	-	306.38	306.38	307.00	303.87	303.83	303.82	303.78	300.34	300.37	n/a	297.59	n/a	n/a

n/a = not able to take measurement; n/i = not installed at this time; datum (z=0): sea level elevation.

Piezometer specifications at NTC meteorological station (piezometer nest B1).

Specifications	Piezometers B1-1 (m)	B1-2 (m)	B1-3 (m)	B1-4 (m)	B1-5 (m)	Tensiometers B1-T1 (m)	B1-T2 (m)	B1-T3 (m)
Top of piezometer	303.28	303.20	303.18	303.17	303.17	-	-	-
Surface elevation, 1992.	302.32	-	-	-	-	302.32	302.32	302.32
Piezometer tip	293.64	295.02	296.50	297.42	298.51	301.32	300.32	299.32
Depth from piezometer top	9.65	8.19	6.69	5.75	4.66	-	-	-
Depth from surface	8.69	7.31	5.83	4.90	3.81	1.00	2.00	3.00

Specifications of TTD channel piezometers.

Specifications	Nest #1 C1-1 (m)	C1-2 (m)	C1-3 (m)	Nest #2 C2-1 (m)	C2-2 (m)
Top of Piezometer	301.94	301.91	301.82	298.12	298.07
Surface elevation, 1992.	300.94	301.19	301.20	297.22	297.22
Channel bed	300.58	300.59	300.58	-	-
Piezometer tip	295.64	297.11	298.69	293.42	294.96
Depth from piezometer top	6.30	4.80	3.14	4.70	3.11
Depth from surface	5.30	4.08	2.52	3.80	2.26

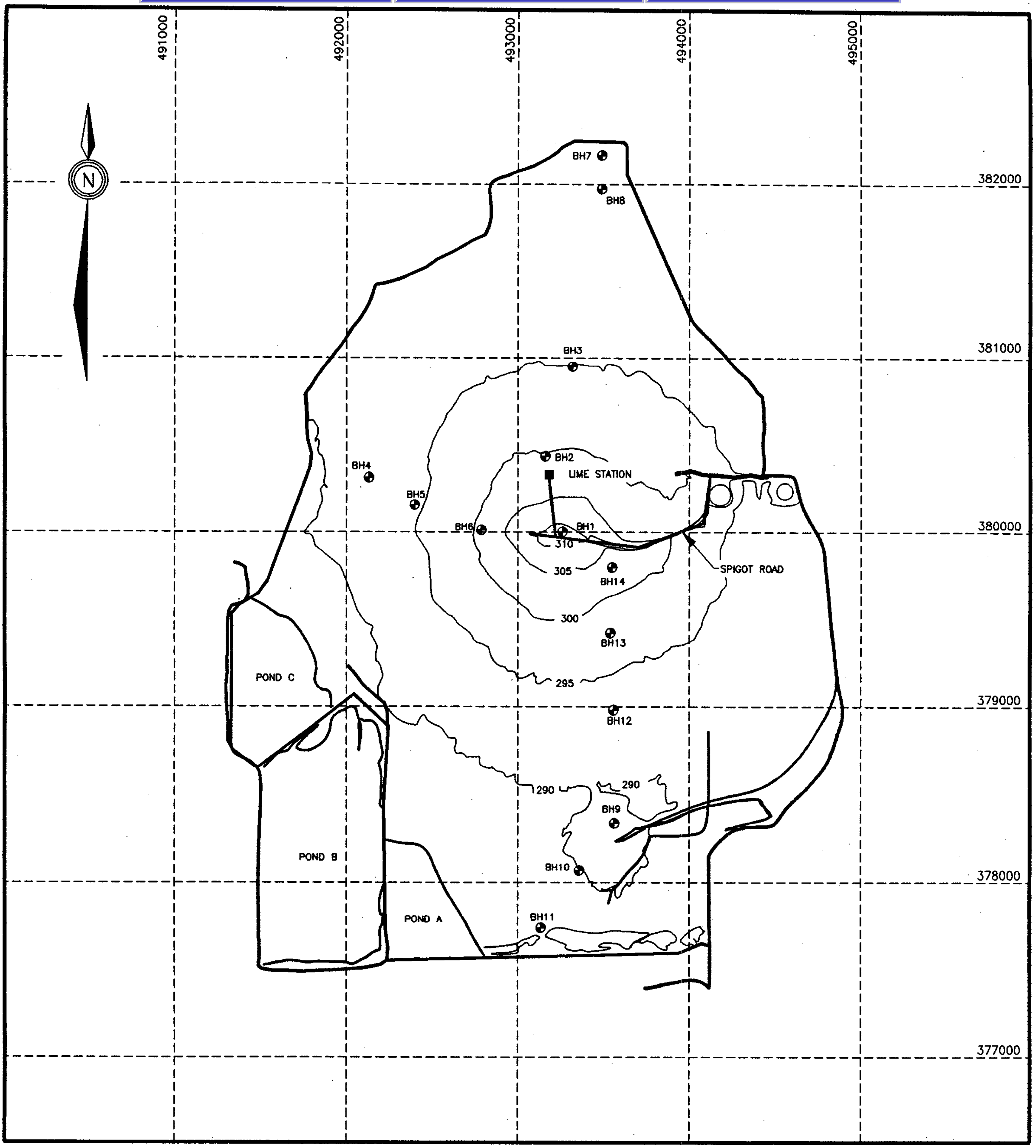
Hydraulic head measurements at NTC meteorological station (piezometer nest B1).

Date	Time	B1-1 (m)	B1-2 (m)	B1-3 (m)	B1-4 (m)	B1-5 (m)	B1-T1 (m)	B1-T2 (m)	B1-T3 (m)
920723	1300	298.23	297.37	297.82	298.22	dry	297.85	n/a	298.10
920724	800	297.68	296.28	297.17	297.77	dry	297.55	n/a	297.69
920730	1400	298.66	298.60	298.72	298.82	298.62	298.67	n/a	298.30
920804	1100	299.26	299.18	299.38	299.62	300.15	300.61	300.42	300.24
920806	1300	299.34	299.35	299.48	n/a	n/a	300.10	299.81	299.73
920813	900	298.98	298.99	299.01	299.10	299.01	299.28	299.20	299.12
920820	1400	299.44	299.24	299.51	-	-	298.67	298.59	298.61
920820	1030	299.40	299.19	299.46	299.71	300.47	301.12	300.63	300.55
920824	900	300.12	300.13	300.34	-	-	300.71	300.42	300.34
920825	1100	299.96	300.04	300.15	300.23	299.89	300.20	300.02	300.04
920904	1100	300.92	300.86	301.04	301.17	301.35	301.73	301.44	301.36
920910	930	301.14	300.96	301.09	301.22	301.73	302.14	301.95	301.87
920917	1030	301.33	301.17	301.26	301.36	301.67	301.93	301.65	301.57
920923	1030	301.07	301.14	301.12	301.09	300.82	301.02	300.83	300.75
921001	1030	301.37	301.20	301.35	301.43	301.45	301.63	301.55	301.36
921009	1230	300.71	300.55	300.55	300.65	300.78	301.12	300.83	300.85
921015	1230	301.28	301.22	301.31	301.41	301.41	301.73	301.55	301.57
921022	1330	301.37	301.24	301.32	301.47	301.79	302.55	302.06	301.87
921029	1030	301.54	301.52	301.53	301.55	301.14	302.55	301.24	301.16
921105	1330	300.90	300.64	300.69	300.82	301.42	302.55	301.65	302.38
921112	1030	301.23	300.96	301.09	301.27	301.68	302.55	302.46	302.38
921118	-				301.51	301.44	302.55	302.46	302.38

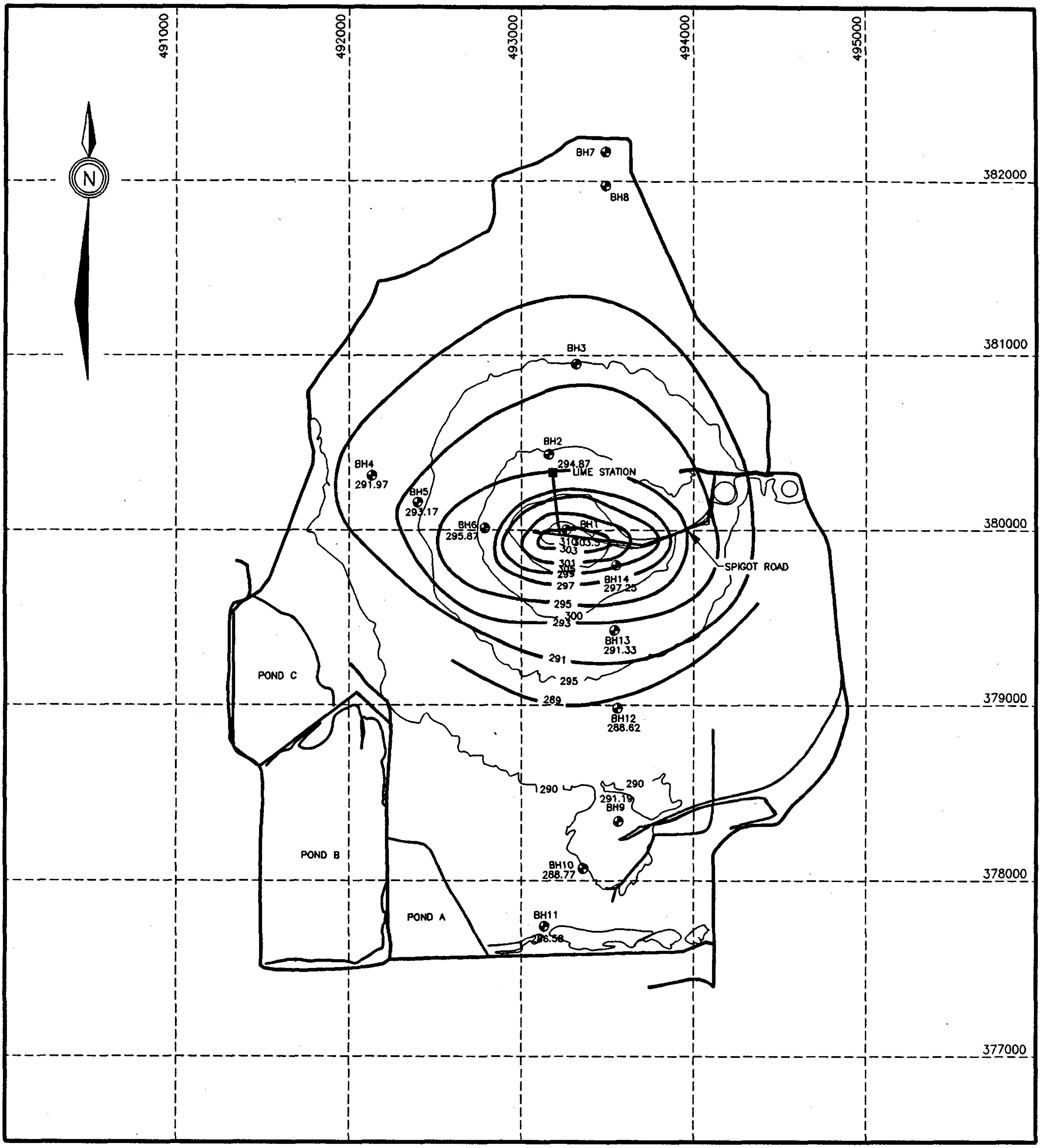
Hydraulic head measurements at TTD channel piezometers.

Date	Time	C1-1 (m)	C1-2 (m)	C1-3 (m)	C2-1 (m)	C2-2 (m)
920605	1000	n/i	n/i	n/i	n/i	n/i
920722	1300	n/i	n/i	n/i	n/i	n/i
920723	1100	n/i	n/i	n/i	n/i	n/i
920724	800	297.71	298.46	299.23	295.84	295.48
920730	1400	300.03	300.10	300.25	297.08	296.94
920804	1430	300.50	300.56	300.52	297.02	297.00
920806	1300	n/a	n/a	n/a	n/a	n/a
920813	900	299.31	299.24	299.24	295.97	295.90
920820	1030	299.42	299.51	299.62	296.12	296.42
920825	1100	299.78	299.64	299.69	296.07	296.19
920904	1100	300.39	300.38	300.36	296.92	296.84
920910	930	300.34	300.36	300.29	296.94	296.77
920917	1030	300.45	300.43	300.38	297.02	296.86
920923	1030	300.07	300.01	300.02	296.38	296.49
921001	1030	300.52	300.47	299.62	296.84	296.77
921009	1230	299.50	299.47	299.44	296.19	296.06
921015	1230	300.44	300.43	300.42	296.90	296.88
921022	1330	300.44	300.51	300.42	296.92	296.97
921029	1030	300.48	300.36	n/a	296.62	296.88
921105	1330	299.46	299.48	n/a	296.50	296.07
921112	1030	300.05	300.06	n/a	296.76	296.28
921118	-	300.50	300.47	300.53	296.94	296.92

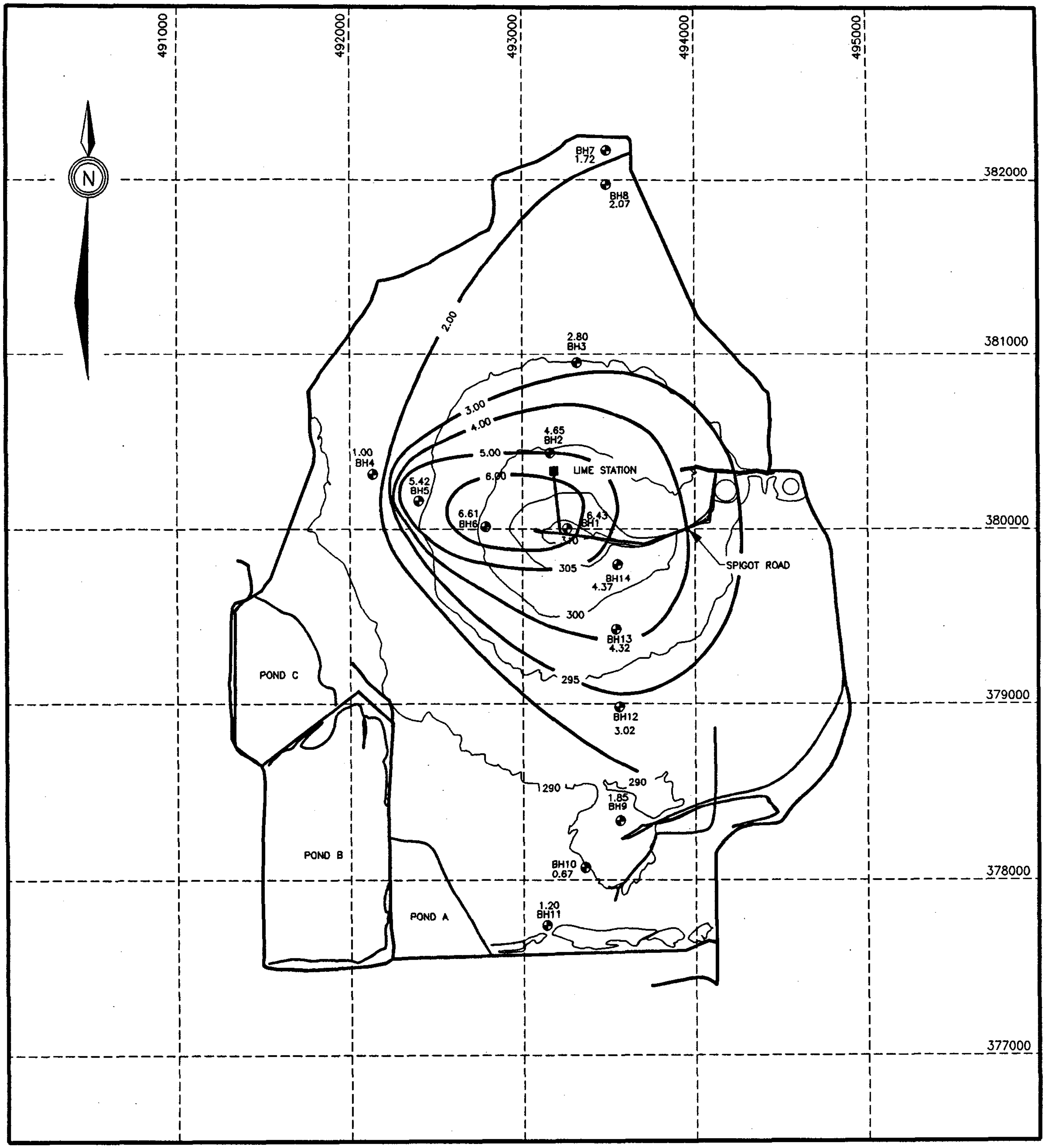
n/a = not able to take measurement; n/i = not installed at this time; datum (z=0): sea level elevation.



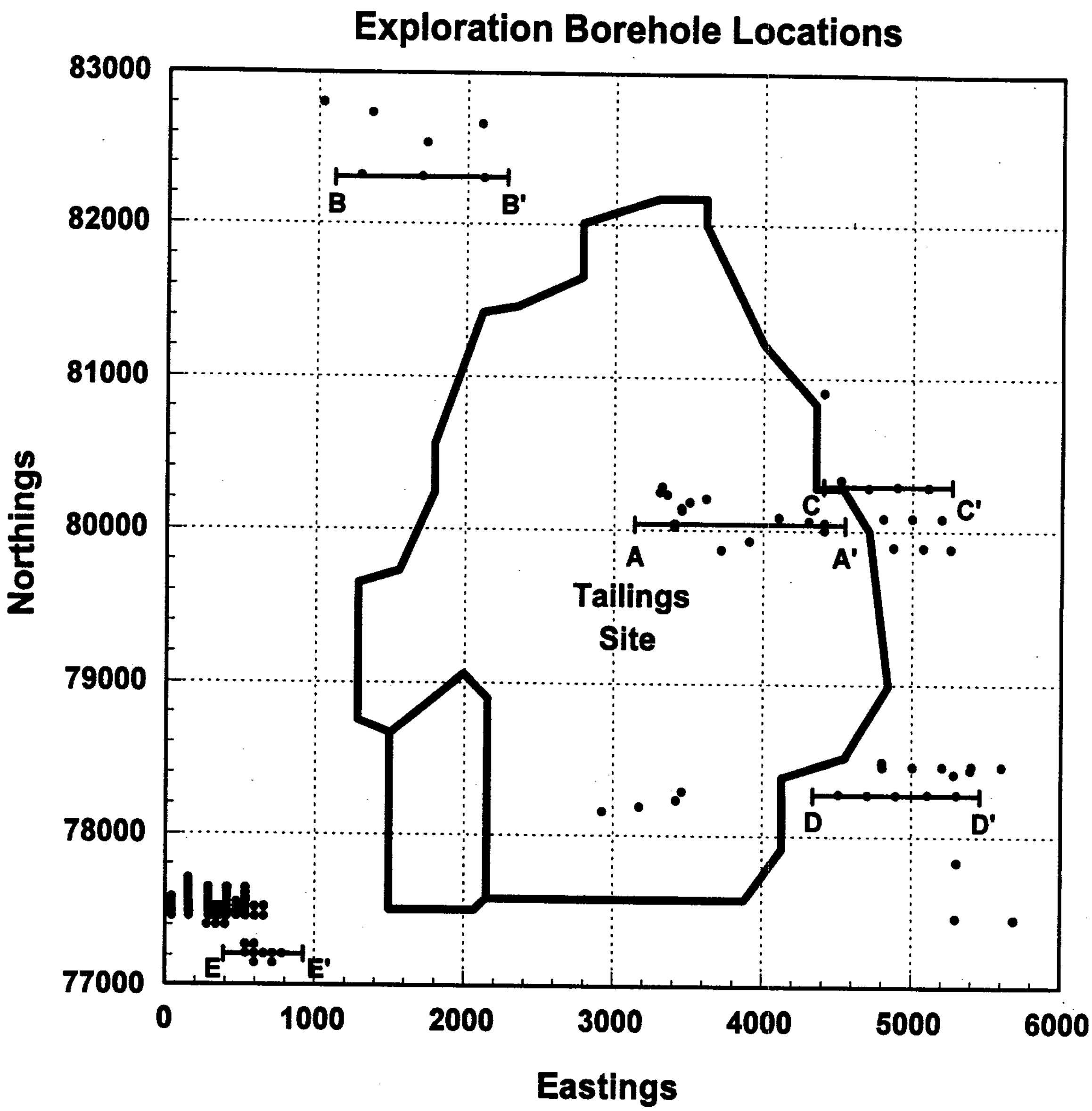
NORANDA TECHNOLOGY CENTER HYDROGEOTECHNICAL GROUP	TOPOGRAPHIC CONTOURS TAILINGS DISPOSAL AREA KIDD CREEK MINE LTD.	
DRAWN BY: KSS	DATE: MAY 1993	SCALE 0.0 – 1.0 Km



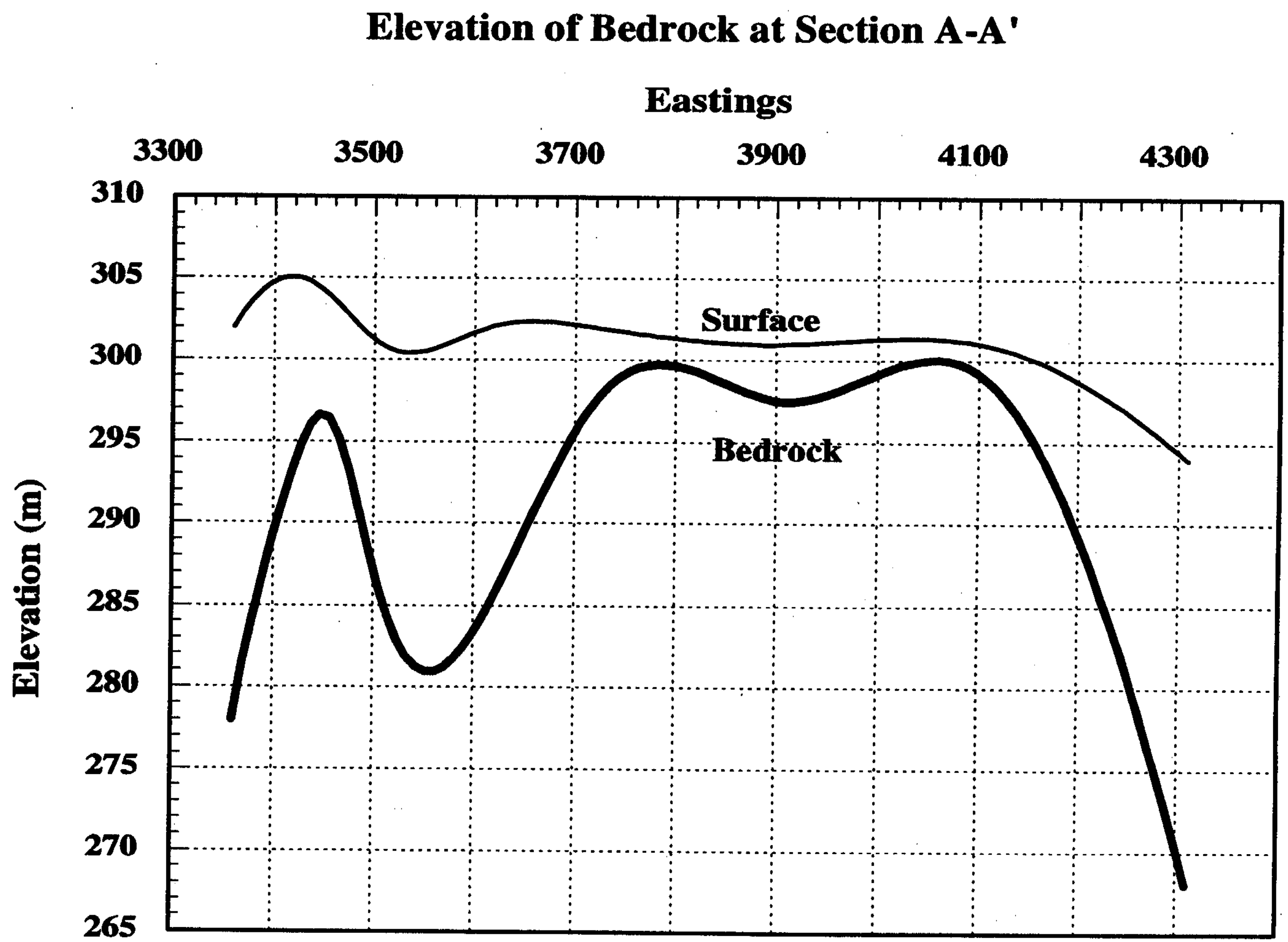
NORANDA TECHNOLOGY CENTER HYDROGEOTECHNICAL GROUP	HYDRAULIC HEAD CONTOUR MAP TAILINGS DISPOSAL AREA KIDD CREEK MINE LTD.
DRAWN BY: KSS	DATE: MAY 1993 — SCALE 0.0 — 1.0 Km



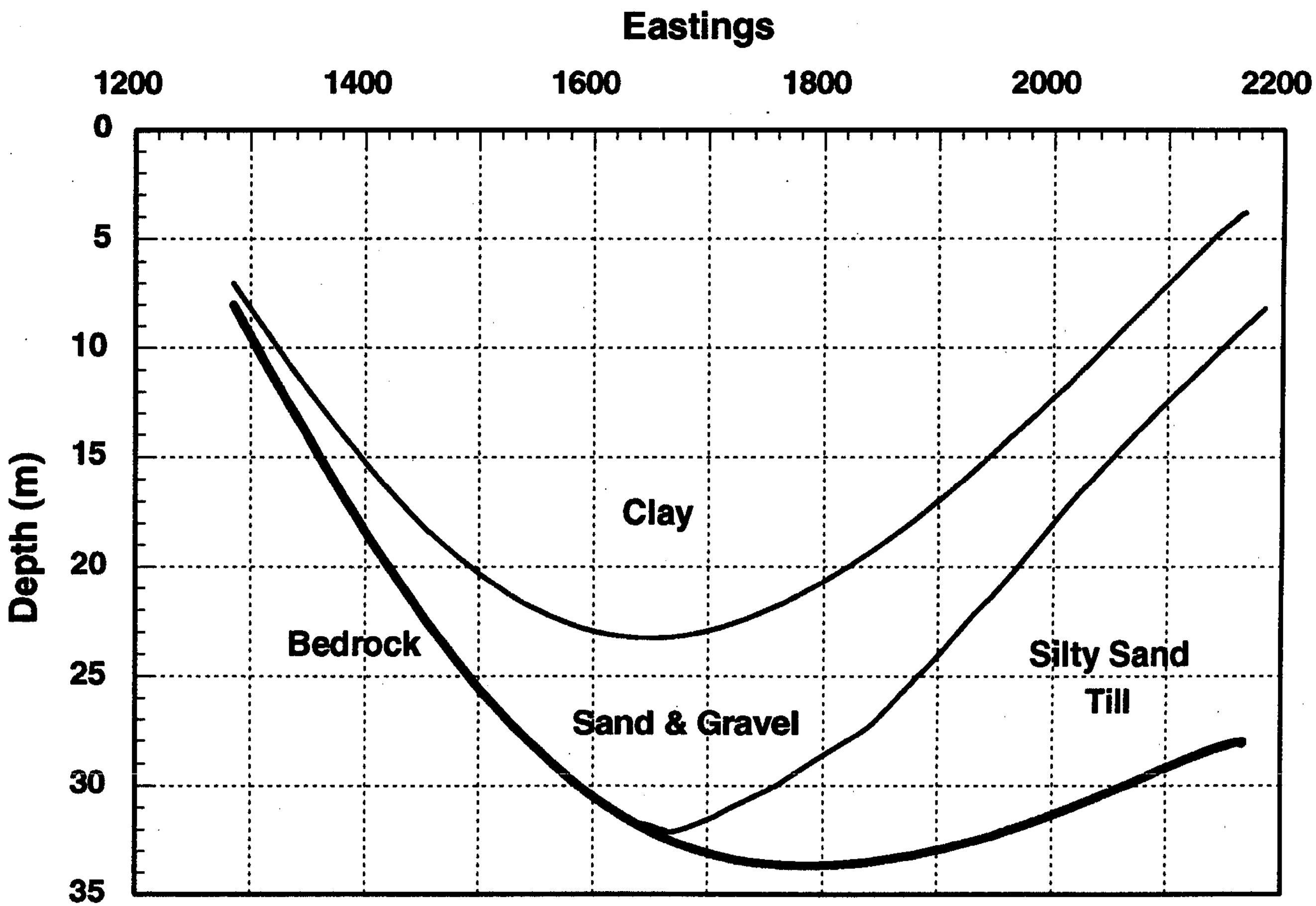
NORANDA TECHNOLOGY CENTER HYDROGEOTECHNICAL GROUP	DEPTH TO WATER TABLE CONTOUR MAP TAILINGS DISPOSAL AREA KIDD CREEK MINE LTD.
DRAWN BY: KSS	DATE: MAY 1993 / SCALE 0.0 — 1.0 Km

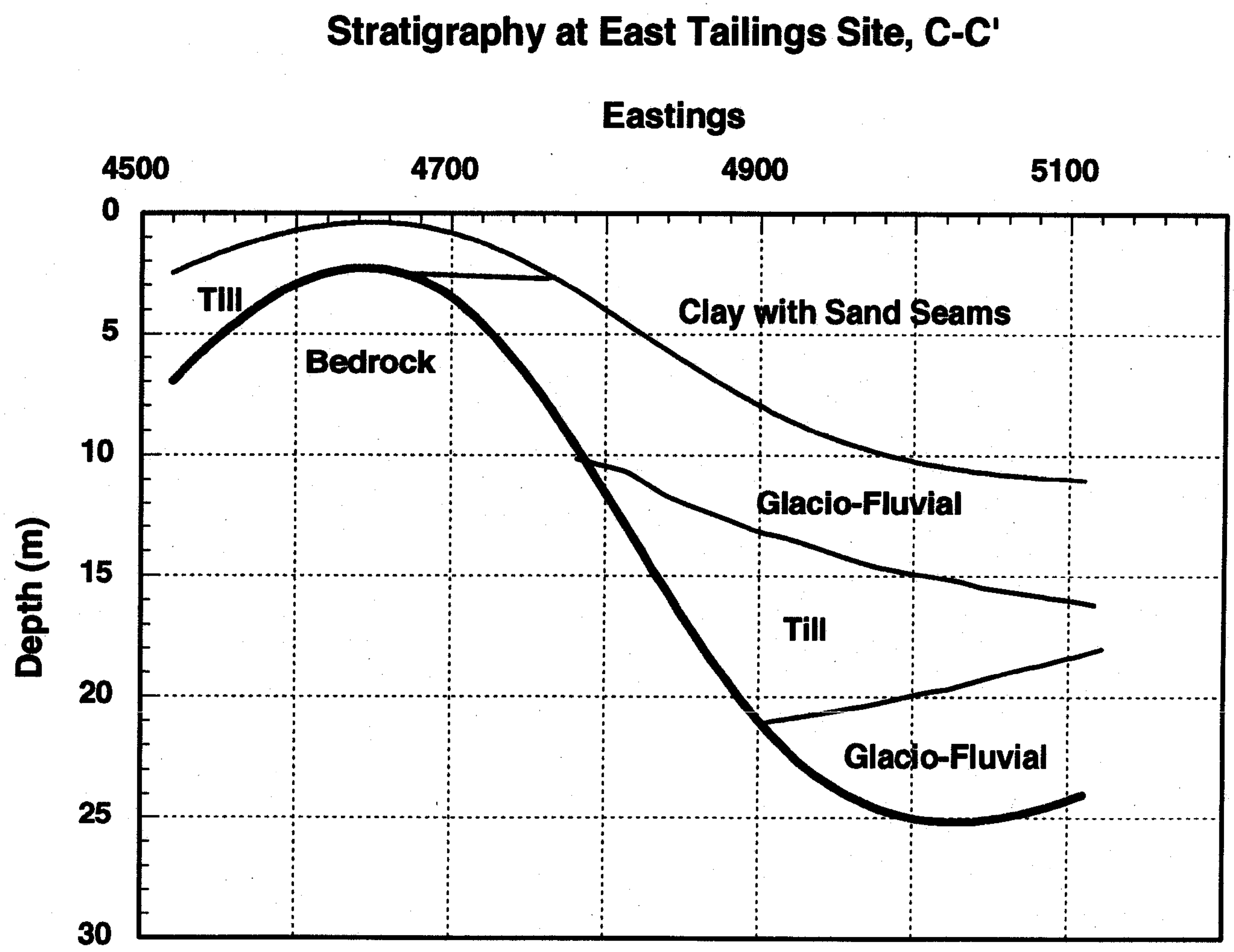


Source: Exploration Division of Falconbridge Ltd.


Elevation of Bedrock at Section A-A'
Eastings
3300
3500
3700
3900
4100
4300
310
305
300
295
290
285
280
275
270
265
Elevation (m)
Surface
Bedrock

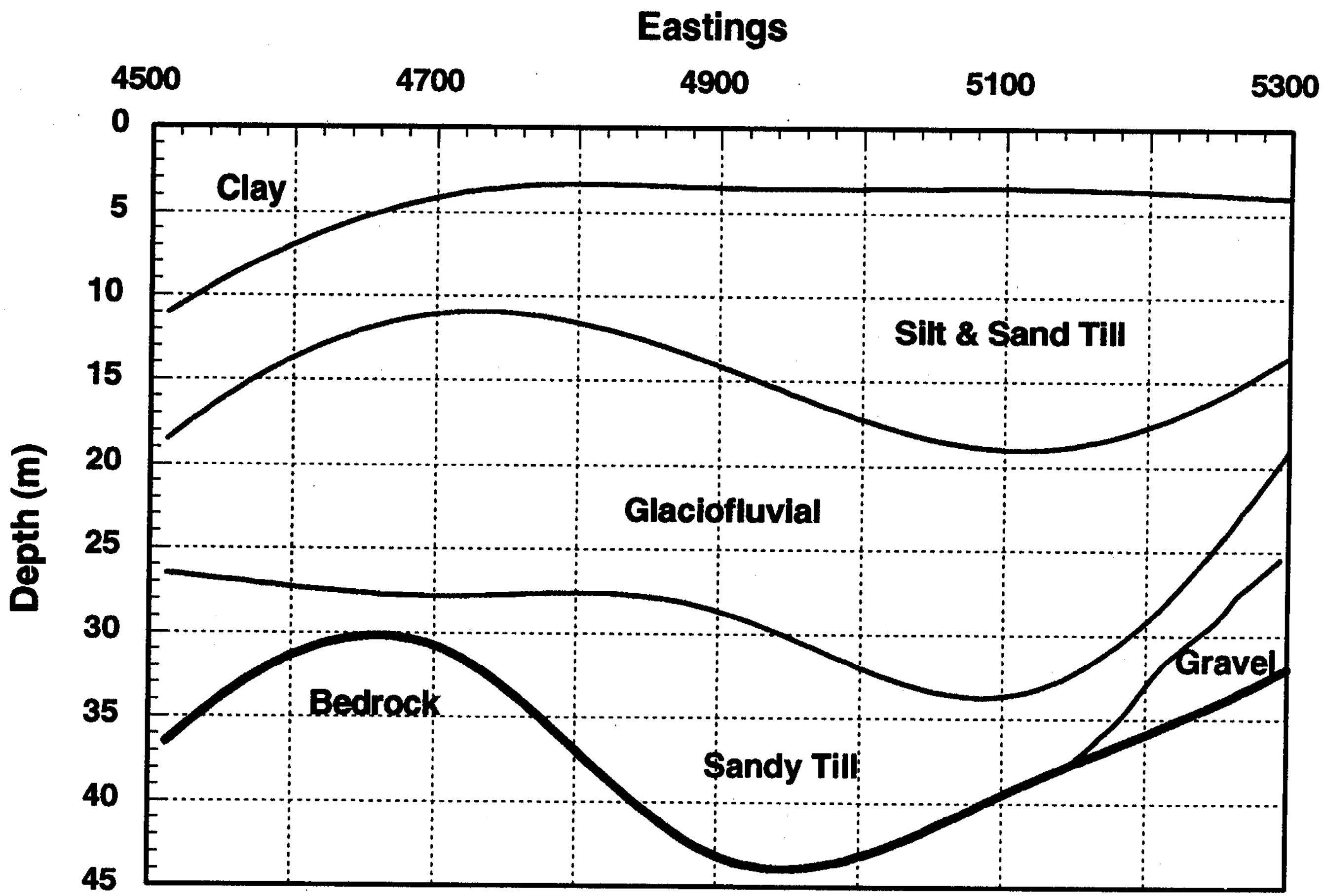
Stratigraphy at Northern Tailings Site, B-B'

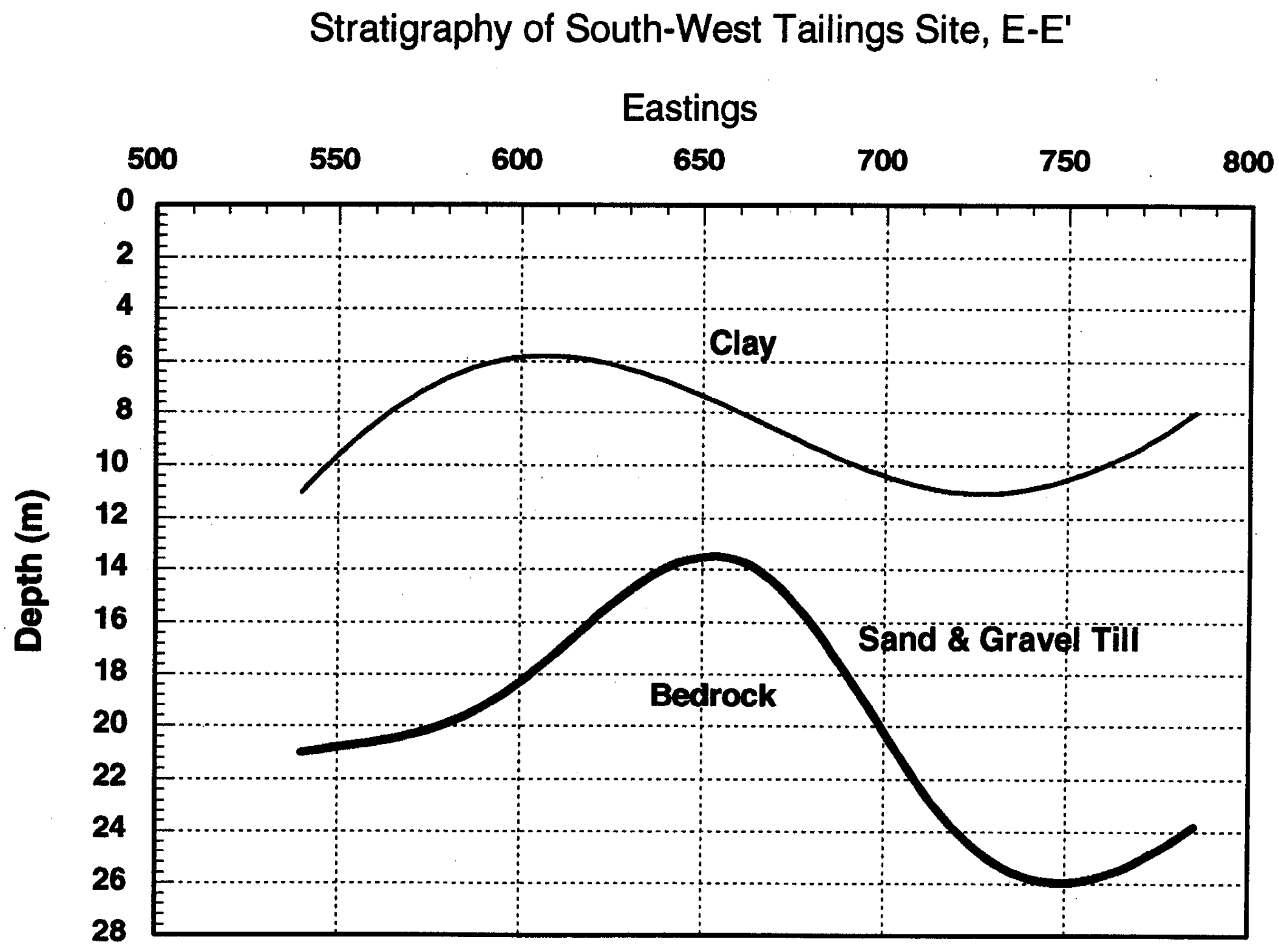




Stratigraphy at East Tailings Site, C-C'
Eastings
4500
4700
4900
5100
Depth (m)
0
5
10
15
20
25
30
Till
Bedrock
Clay with Sand Seams
Glacio-Fluvial
Till
Glacio-Fluvial

Stratigraphy at South-East Tailings Site, D-D'




Stratigraphy of South-West Tailings Site, E-E'
Eastings
500
550
600
650
700
750
800
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Clay
Sand & Gravel Till
Bedrock

Appendix E

Geochemical methods and data

Geochemical methods

Sampling of the saturated zone pore water were conducted in each monitoring well using a peristaltic pump after the purging of at least three well volumes. The samples were filtered using in-line 0.45 µm (ACRO 5A) disposable filters and stored in polypropylene sampling bottles. Measurements of pH, temperature, redox potential, and specific conductance were made immediately after sample collection. A split of each sample was acidified with 2% volume of reagent grade hydrochloric acid for preservation. A non-acidified portion of each sample was carried back to the mine environmental laboratory where pH measurements were repeated and titrations for acidity and alkalinity were performed.

Pore water was extracted from unsaturated samples recovered in 1991 at the surface of the tailings at stations A1 and A2 using 10.2 cm (4 in) I.D. ABS plastic tubes. The samples were sealed immediately after recovery with paraffine wax and vinyl tape and transported to the analytical laboratory. Pore water extraction was performed by putting the sample in a stainless steel loading cell and applying a pressure of 12 MPa using a pneumatic apparatus.

Selected metal and major ion analysis were done at NTC analytical laboratories using inductively-coupled plasma spectrophotometry (ICP 61E), except for ferrous iron (Fe^{2+}) and chloride (Cl^-) which were done by turbidimetry.

Major metal and ion concentrations in unsaturated zone pore water, August 1991.																			
		Metals											*Cations*				*Anions*		*Other Elements*
Station	Depth (m)	Al (mg/L)	As (mg/L)	Cd (mg/L)	Cu mg/L	Fe (T) mg/L	Fe(+2) mg/L	Fe(+3) (mg/L)	Mn (mg/L)	Pb mg/L	Se (mg/L)	Zn mg/L	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SO4 (mg/L)	S (mg/L)
A1	0-3				5.77	0.19	0.03			<0.25		92.00						1840.00	
	40.0				0.94	< 0.02	<0.02			<0.25		16.00						1570.00	
	70.0				0.37	< 0.02	<0.02			<0.25		5.54						1410.00	
A2	0-3				0.11	< 0.02	<0.02			<0.25		7.35						1430.00	
	40.0				0.45	< 0.02	<0.02			<0.25		14.20						1250.00	

Major metal and ion concentrations in saturated zone pore water, October 1991.																			
		Metals											*Cations*				*Anions*		*Other Elements*
Piezometer Number	Depth from Surface	Al (mg/L)	As (mg/L)	Cd (mg/L)	Cu (mg/L)	Fe (T) (mg/L)	Fe(+2) (mg/L)	Fe(+3) (mg/L)	Mn (mg/L)	Pb (mg/L)	Se (mg/L)	Zn (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SO4 (mg/L)	S (mg/L)
A1.1	16.2	0.71			< 0.02	52.93	0.41			< 0.25		< 0.02					4.50	212.18	
A1.2	11.2	0.60			< 0.02	2.34	0.23			< 0.25		0.24					10.20	622.06	
A1.3	7.3	0.76			< 0.02	64.49	0.31			< 0.25		0.81					10.60	1430.00	
A2.1	11.9	0.68			< 0.02	0.75	< 0.02			< 0.25		< 0.02						567.93	
A2.2	10.4	0.61			< 0.02	0.35	< 0.02			< 0.25		< 0.02					8.38	527.16	
A2.3	7.6	0.51			< 0.02	4.17	0.11			< 0.25		< 0.02					10.60	705.81	
A2.4	3.3	0.62			< 0.02	119.86	0.83			< 0.25		5.44					12.10	1390.00	

Major metal and ion concentrations in unsaturated zone pore water, October 1991.																			
		Metals											*Cations*				*Anions*		*Other Elements*
Station	Depth (m)	Al (mg/L)	As (mg/L)	Cd (mg/L)	Cu mg/L	Fe (T) mg/L	Fe(+2) mg/L	Fe(+3) (mg/L)	Mn (mg/L)	Pb mg/L	Se (mg/L)	Zn mg/L	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SO4 (mg/L)	S (mg/L)
A1	0-3				5.36	1.13	1.68			<0.25		5.22						950.00	
A1	10.0				5.13	13.70	16.90			<0.25		13.76						980.00	
A1	15.0				184.00	125.00	121.50			<0.25		533.00						2020.00	

Physico-chemical parameter values, October 1991								
Piezometer Number	Depth from Surface	Temp (C)	pH (field)	pH (lab)	Eh (mV)	Cond. (uS/cm)	Acidity (mg/L CaCO3)	Alkalinity (mg/L CaCO3)
A1.1	16.2	1.4	7.66	6.60	469	2220	250	700
A1.2	11.2	2.4	7.96	7.01	457	2880	1100	100
A1.3	7.3	1.4	6.53	6.96	476	6990	150	200
A2.1	11.9	3.1	5.87	6.03	418	2690	>50	>100
A2.2	10.4	3	6.02	6.02	432	2590	>50	>50
A2.3	7.6	2.5	6.54	6.81	459	3150	>50	>50
A2.4	3.3	2.4	6.73	6.95	456	6760	250	400

Major metal and ion concentrations in saturated pore water, August 1992.

		Metals											*Cations*				*Anions*		*Other Elements*
Piezometer Number	Depth from Surface	Al (mg/L)	As (mg/L)	Cd (mg/L)	Cu (mg/L)	Fe (T) (mg/L)	Fe(+2) (mg/L)	Fe(+3) (mg/L)	Mn (mg/L)	Pb (mg/L)	Se (mg/L)	Zn (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SO4 (mg/L)	S (mg/L)
A1.1	16.2	0.72	< 0.25	< 0.02	< 0.02	2.21		1.28	8.26	< 0.25	< 0.50	< 0.02	80.85	10.18	317.21	85.18	115.00	500.00	160.56
A1.2	11.2	< 0.25	< 0.25	< 0.02	< 0.02	4.29		4.68	0.94	< 0.25	< 0.50	< 0.02	83.72	26.27	426.01	97.08	16.40	1490.00	499.26
A1.3	7.3	6.98	0.34	< 0.02	0.23	134.91		101.00	0.99	0.46	< 0.50	2.70	899.06	41.96	370.72	379.96	15.60	4440.00	1360.00
A2.1	11.9	0.58	< 0.25	< 0.02	< 0.02	3.22		2.94	0.66	< 0.25	< 0.50	< 0.02	87.82	23.40	411.38	115.52	29200.00	3940.00	513.39
A2.2	10.4	1.06	< 0.25	< 0.02	0.04	3.48		3.62	0.42	< 0.25	< 0.50	< 0.02	93.32	13.61	478.65	88.81	66.10	3000.00	554.46
A2.2 dup.	10.4							3.50									15.50	1800.00	
A2.3	7.6	0.48	< 0.25	< 0.02	< 0.02	5.73		6.00	0.67	< 0.25	< 0.50	< 0.02	121.09	27.96	475.65	190.92	17.40	2090.00	707.43
A2.3 dup.	7.6							5.99									24.10	2090.00	
A3.1	7.30	0.47	< 0.25	< 0.02	< 0.02	5.29		4.93	0.46	< 0.25	< 0.50	< 0.02	90.17	18.62	454.46	173.11	40.80	1130.00	651.92
A3.2	5.60	0.54	< 0.25	< 0.02	< 0.02	7.61		6.47	1.36	< 0.25	< 0.50	< 0.02	111.63	27.92	443.30	244.13	22.80	2250.00	738.40
A4.1	6.20	0.70	< 0.25	< 0.02	< 0.02	16.81		14.60	0.88	< 0.25	< 0.50	0.72	135.10	19.29	548.69	199.94	17.10	2040.00	795.76
A4.2	4.80	< 0.25	< 0.25	< 0.02	< 0.02	14.14		13.10	1.70	< 0.25	< 0.50	1.36	220.49	32.94	483.93	265.11	53500.00	4970.00	872.96
A4.3	3.10	0.55	< 0.25	< 0.02	< 0.02	< 0.025		0.07	< 0.005	< 0.25	< 0.50	< 0.02	14.04	< 5.00	1.52	< 0.50	193.00	210.00	1.09
B1.1	8.70	0.48	< 0.25	< 0.02	< 0.02	19.80		18.90	0.73	< 0.25	< 0.50	< 0.02	114.30	25.74	491.63	215.33	17.60	2060.00	733.83
B1.2	7.30	0.34	< 0.25	< 0.02	< 0.02	0.03		0.12	0.86	< 0.25	< 0.50	< 0.02	119.16	27.52	514.88	115.84	19.20	1680.00	638.58
B1.3	5.80	1.08	< 0.25	< 0.02	< 0.02	178.60		98.90	2.00	< 0.25	< 0.50	2.46	847.24	57.50	437.18	296.85	19.20	4150.00	1380.00
		Field blank samples																	
A1.3	7.30	0.56	< 0.25	< 0.02	< 0.02	0.27		0.05	< 0.005	< 0.25	< 0.50	< 0.02	7.88	< 5.00	0.79	< 0.50	5.62	11.00	1.04
B1.1	8.70	2.42	< 0.25	< 0.02	0.39	4.27		0.07	0.02	< 0.25	< 0.50	< 0.02	8.39	< 5.00	5.97	1.20	4.53	14.70	3.97
		Spiked samples, analyzed																	
SP-1	-	0.63	< 0.25	< 0.02	< 0.02	114.68			0.25	< 0.25	< 0.50	11.59	122.68	< 5.00	0.93	< 0.50			0.58
SP-2	-	0.60	< 0.25	< 0.02	< 0.02	114.00			0.25	< 0.25	< 0.50	11.38	120.10	< 5.00	0.89	< 0.50			< 0.25
SP-3	-	0.66	< 0.25	< 0.02	< 0.02	113.00			0.25	< 0.25	< 0.50	11.17	21.58	< 5.00	0.82	< 0.50			0.37
SP-4	-	0.64	< 0.25	< 0.02	< 0.02	115.68			0.27	< 0.25	< 0.50	10.76	19.15	< 5.00	2.32	< 0.50			0.38
		Spike samples prepared																	
SP-1	-					100						10	100						
SP-2	-					100						10	100						
SP-3	-					100						10	10						
SP-4	-					100						10	10						

dup. = duplicate sample

Major metal and ion concentrations in surface water grab samples, November 30, 1992.

Location	Metals											Cations				Anions		Other Elements
	Al (mg/L)	As (mg/L)	Cd (mg/L)	Cu (mg/L)	Fe (T) (mg/L)	Fe(+2) (mg/L)	Fe(+3) (mg/L)	Mn (mg/L)	Pb (mg/L)	Se (mg/L)	Zn (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SO4 (mg/L)	S (mg/L)
Perimeter ditch, northern end near PWA flume	0.59	< .25	1.63	0.05	3.46			4.67	< .25	< .50	44.75	86.29	20.98	823.80	25.47			0.77
Discharge from pond C to pond D	0.31	< .25	1.09	0.04	0.26			5.94	< .25	< .50	74.40	151.07	21.49	815.80	27.28			0.83
Metallugical site discharge to ponds (culvert #10	0.39	< .25	1.17	1.86	0.12			7.38	< .25	< .50	99.44	68.39	9.32	295.73	24.78			0.32