TALISMAN ENERGY INC.

South Bay Project

MUD LAKE REPORT

November 25, 1994

EXECUTIVE SUMMARY

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 MUD LAKE DRAINAGE BASIN WATER CHEMISTRY 3

2.1 Estimated Contaminant Loadings 7

3.0 THE SEEPAGE PATHWAY 16

3.1 Summary of Existing Conditions of Mud Lake 24

4.0 DEFINITION OF THE SEEPAGE PATH 26

4.1 Geophysical Baseline Surveys 26

4.2 Test Drilling and Piezometer Installations to Define the bedrock Valley of the Seepage Path 41

5.0 REFERENCES 42

6.0 APPENDICES A-1

Appendix 1 GEOMAR - EM SURVEY COLOUR MAPS A-2

Appendix 2 A. VONHOF DRILLING REPORT A-10

LIST OF TABLES

Table 1	Mud Lake Water Chemistry, 1986 - 1994	3
Table 2	Mud Lake Area Water Chemistry and Flows, August 29, 1994	6
Table 3	Mud Lake Drainage Basin	8
Table 4	Mud Lake Area contaminant loadings, August 29, 1994, adjusted to balance chloride loadings	10
Table 5	Comparison of 1986 and 1994 Mud Lake sediment composition	12
Table 6	Sediment aeration experiment. Initial and final chemistry following 143 hours of aeration	14
Table 7	Historical water quality in piezometers between tailings and Mud Lake	17
Table 8	Piezometer, tailings seepage and Mud Lake groundwater inflow water quality, 1994	23

LIST OF FIGURES

Figure 1 Zinc Concentrations at ML18, MML. C11 and ML22 5

Figure 2 Sediment oxidation experiment pH results 14

Figure 3 Mud Lake area bottom conductivity 18

LIST OF MAPS

Map 1	Mud Lake Area Sampling Locations	4
Map 2	Hydrology of tailings area	8
Map 3	Tailings Piezometer Locations	20
Map 4	Tailings Diversion Ditch. EM31 Survey Vertical Dipole Mode. March 1992	29
Map 5	Tailings Diversion Ditch. EM31 Survey Horizontal Dipole Mode. March 1992	30
Map 6	Tailings Diversion Ditch. EM31 Survey Horizontal Dipole Mode. Sept 1993	31
Map 7	Tailings Diversion Ditch. EM31 Survey Vertical Dipole Mode. Sept 1993	32
Map 8	Mine Site. EM31, Vertical Mode. March. 1992	33
Map 9	Mine Site. EM34-3. Horizontal Mode. March. 1992	34
Map 10	Mine Site. EM31, Horizontal Mode. September 1993	35
Map 11	Mine Site. EM31, Vertical Mode. September 1993	36
Map 12	Tailings Dams. EM31, Vertical Dipole Mode. March 1992	37
Map 13	Tailings Dams. EM31, Horizontal Dipole Mode. September 1993	38
Map 14	Tailings Dams. EM31, Vertical Dipole Mode. September 1993	39
Map 15	Proposed 1995 Survey Grid. Mud Lake Area	40

1.0 INTRODUCTION

As a part of 1993 scope of work, the hydrogeological conditions of the tailing site were re-evaluated. It was concluded that some groundwater is not reporting as expected to the diversion ditch and, therefore, may be leaving the tailings drainage basin in the N-W direction towards the Mud Lake. Mud Lake had been monitored outside the regulatory requirements intermittently since 1988. Generally, the pH was around 7.5, the conductivity of 430 $\mu S.cm^{-1}$ and the water free of contaminants.

Given the disparity in the water balance for the tailings drainage basin, in March of 1994 water samples were collected in Mud Lake through the ice. The pH had dropped to 5.3 and the conductivity had risen to 1,430 $\mu S.cm^{-1}$ (Table 1). No surface flow of contaminated water has been located. These results confirmed that contaminated groundwater was entering Mud Lake. Upon completion of spring run-off, the dissolved iron in Mud Lake water had oxidized and hydrolysed, and the pH of Mud Lake dropped to pH 3.1 by April, 1994. In August, 1994, the pH was 2.7.

The data collected during the March 1994 sampling campaign clearly indicated water quality problems in Mud Lake. A second field trip was organized in April, 1994. Top and bottom water samples were taken in Mud Lake. The data indicated that the entire water body was contaminated with zinc. The conductivity of bottom water samples were generally higher than surface water samples. Given that Mud Lake is shallow, and well mixed by wind-driven circulation during the ice-free season, this suggested that the seepages are emerging from the bottom of the lake through the sediments.

This report documents the background information on Mud Lake and the investigations performed in 1994 so to gain an overall understanding of the seepage path. This site-specific information is then placed in the broader context of the decommissioning objectives for the South Bay Mine site. Ecological Engineering, a low-maintenance approach to close-out, was chosen for this site, as the tailings represents an

environmental liability for a very long period. Since the results from ongoing research and the gradual scale-up were promising, the property has been returned to the Crown with the proviso that no contaminated seepages discharge into Confederation Lake.

In Section 2 of this report, the historic data of the Mud Lake drainage basin are summarized, and contaminant loadings from the basin are estimated. In Section 3, the seepage pathways are defined through preliminary geophysical surveys and test drilling. In Section **4,** the various approaches to achieving the overall objective are outlined to provide a framework for selecting the implementation steps for the decommissioning approach. The rationale for the decommissioning approach will be complete upon, first, review of these approaches; second, selection of the final approach; third, development of an action plan for the steps towards implementation.

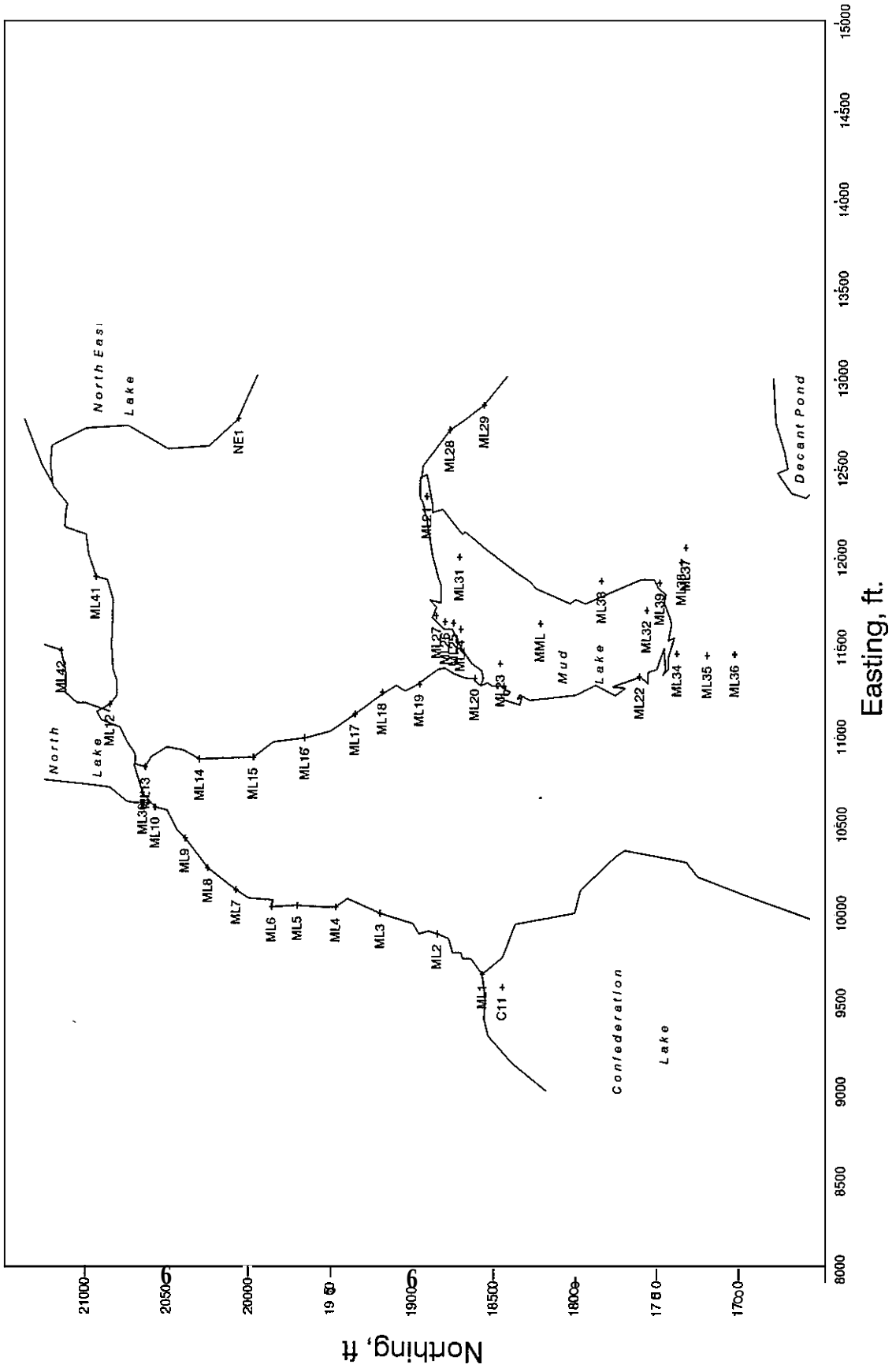
2.0 MUD LAKE DRAINAGE BASIN WATER CHEMISTRY

In Table 1, the water quality parameters of regulatory concern are summarized. The sampling stations in and around Mud Lake are given in Map **1.**

Table 1: Mud Lake-Water Chemistry, 1986-1994

)cation	Sample date	Zn mg/L	pH	Acidity mg/L	SO4 mg/L	Fe mg/L	Cond. uS/cm	Em mV
ML18	08-Apr-88	0.01	5.70	nd	42	0.1	350	
	16-Oct-89	0.31	7.15	11	11	0.6	41	
	12-May-91	0.13	6.17	40	26	0.4	197	
	24-Mar-92	<1	6.58	180	336	56	432	
	30-Mar-94	0.20	5.47	353	621	86	1050	65
	26-Apt-94	0.31	4.78	48	85	6.4	246	169
	13-Jun-94	6.79	2.76	218	666	30	1436	693
	11-Jul-94	6.84	2.88	188	585	23	1085	455
	27-Aug-94	6.68	2.77	148	627	20	780	457
ML21	05-Apr-86	0.06	6.10	nd	42	0.5	130	
	17-Jun-86	0.05	6.28	nd	36	0.2	150	
	25-Jul-86	<0.005	6.60	nd	180	0.3	480	
	08-Apr-88	0.01	nd	nd	144	0.2	nd	
	10-Jul-94	0.16	5.77	28	15	1.2	***64***	152
	27-Aug-94		6.08	14			175	109
MML	17-Jun-86	0.02	7.56	nd	160	0.1	430	
	25-Jul-86	0.03	6.20	nd	183	0.4	475	
ɔttom	30-Mar-94	11.80	5.33	600	1143	218	2200	333
	30-Mar-94	9.78	3.16	304	834	79	1423	393
ɔttom	27-Apr-94	7.99	5.09	379	954	168	1430	121
	27-Apr-94	1.72	4.17	79	188	19	406	272
	15-Jun-94	8.08	2.81	290	681	55	1450	660
ɔttom	15-Jun-94	8.06	2.79	280	690	55	1455	662
	28-Aug-94	7.85	2.74	171	494	27	700	384
ɔttom	28-Aug-94		5.63	281			1790	377
ML22	05-Apr-86	0.22	6.10	nd	28	0.6	130	
	17-Jun-86	0.04	7.26	nd	154	0.1	435	
	25-Jul-86	0.12	6.15	nd	132	0.6	480	
	19-Jul-87	<0.005	6.20	nd	51	6.9	200	
	14-Aug-87	<0.005	6.22	nd	27	1.0	240	
	16-Apr-91	0.67	6.32	nd	109	0.1	418	
ɔttom	27-Apr-94	6.95	3.80	500	1164	269	1670	264
	15-Jun-94	7.49	2.81	263	660	48	1440	668
	28-Aug-94		2.60	164			700	408
ɔttom	28-Aug-94		4.02	161			640	408

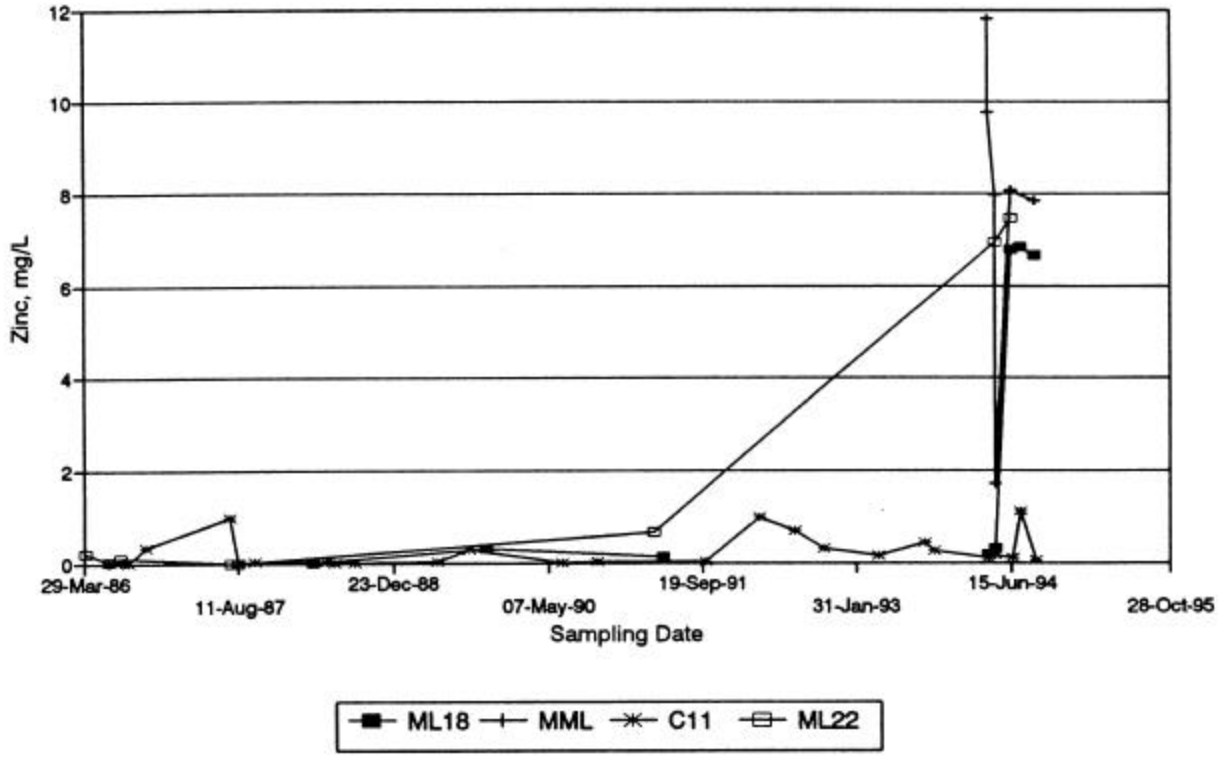
Map 1: Mud Lake Area
Sampling Locations



Between 1988 and 1994, station ML18 at Mud Lake outflow was the location where samples have been taken with any regularity. In March 1992, station ML18 water was pH 6.58 and contained < 1 $mg.L^{-1}$ zinc, similar to samples taken in 1988. The water quality characteristics of the March, 1992, ML18 water resembled that of the June, 1986 sample collected at the centre of the lake (station MML).

In Figure 1, zinc concentrations are plotted for sampling stations at the south end (ML22), the middle (MML) and the outflow (ML18) of Mud Lake and compared to those at station C11, located where the combined outflows of Mud Lake, Northeast Lake and Northwest Lake join Confederation Lake. Although zinc concentrations slightly peaked in late 1992 at C11, a similar peak occurred in 1987 when Mud Lake zinc concentrations were at background levels.

Fig. 1: Mud Lake 1994
Zinc Concentrations ML18,MML,C11,ML22



Variation in zinc concentrations at station C11 cannot be immediately attributed to the deterioration in Mud Lake water quality. This is not surprising, as Mud Lake is the smallest of three water bodies discharging to C11.

In Table **2,** the concentrations of the major water quality parameters determined for August 1994 are presented for water samples collected from Mud Lake (ML29, ML26, ML27, M18), Decant Pond Outflow (DRO), Northeast Lake (ML41), Northwest Lake (ML42) and the joint outflow of the three lakes to Confederation Lake (ML1).

Table 2: Mud Lake Area Water Chemistry and Flows, August 29, 1994.

	Decant Pond Outflow DRO	Fresh Inflow Stream ML29	Ground Water Inflow ML26 Bot	Ground Water Inflow ML27Bot	Mud Lake Outflow ML18	NE Lake Outflow Stream ML41	NW Lake Shore ML42	NE,NW, Mud Lake Outflow MLI
L/s	3.11	0.658			14.55			51.3
pH	5.72	6.08	5.3	5.7	2.77	5.98	6.03	5.49
Cond	450	175	3520	4120	780	32	148	163
TDS,mg/L	252	156	10200	12900	774	39	135	129
Na,mg/L	1.23	0.4	14.9	14.7	2.46	0.04	0.04	0.04
Cl,mg/L	0.25	1.61	19.9	23.1	2.22	1.43	1.84	0.89
S,mg/L	39	29	2553	3400	209	0.64	29	29
Zn,mg/L	1.1	0.05	184	184	6.68	0.029	0.246	0.2
Al,mg/L	0.025	0.025	0.191	0.025	0.168	0.042	0.025	0.025
Fe,mg/L	0.116	0.211	1610	1790	19.7	0.294	0.242	0.142
K,mg/L	5.6	4.4	19.6	22.9	2.3	5.1	4.5	0.4
Ca,mg/L	86.8	38	502	508	90.9	8.06	29	28.5

During 1994, the highest concentrations of contaminants were measured in bottom water samples collected at stations ML26 and ML27, located 5 m from the north shore of Mud Lake. During the preliminary drilling program in August, 1994, standpipes were installed at these locations. Upon installation, a small groundwater pressure head was observed in the standpipes.

In addition, measurable groundwater flow was detected at station ML24 using a seepage flow meter. These observations of pressure heads, combined with massive iron hydroxide precipitation on local vegetation, indicate that groundwater discharge from the lake bottom is occurring in this area of Mud Lake.

Fresh water was also sampled in the vicinity of Mud Lake. The freshwater inflow stream to Mud Lake at ML29, and the outflow of Northeast Lake (ML41) and the shore of Northwest Lake (ML42) were sampled. The concentrations of contaminants in these samples were, as expected, at background levels (Table 2).

The flow and water quality at these stations will be used to estimate loadings within the Mud Lake drainage basin and evaluate the contribution of flow of, and contaminants in, groundwater to surface water leaving the Mud Lake drainage basin.

2.1 Estimated Contaminant Loadings

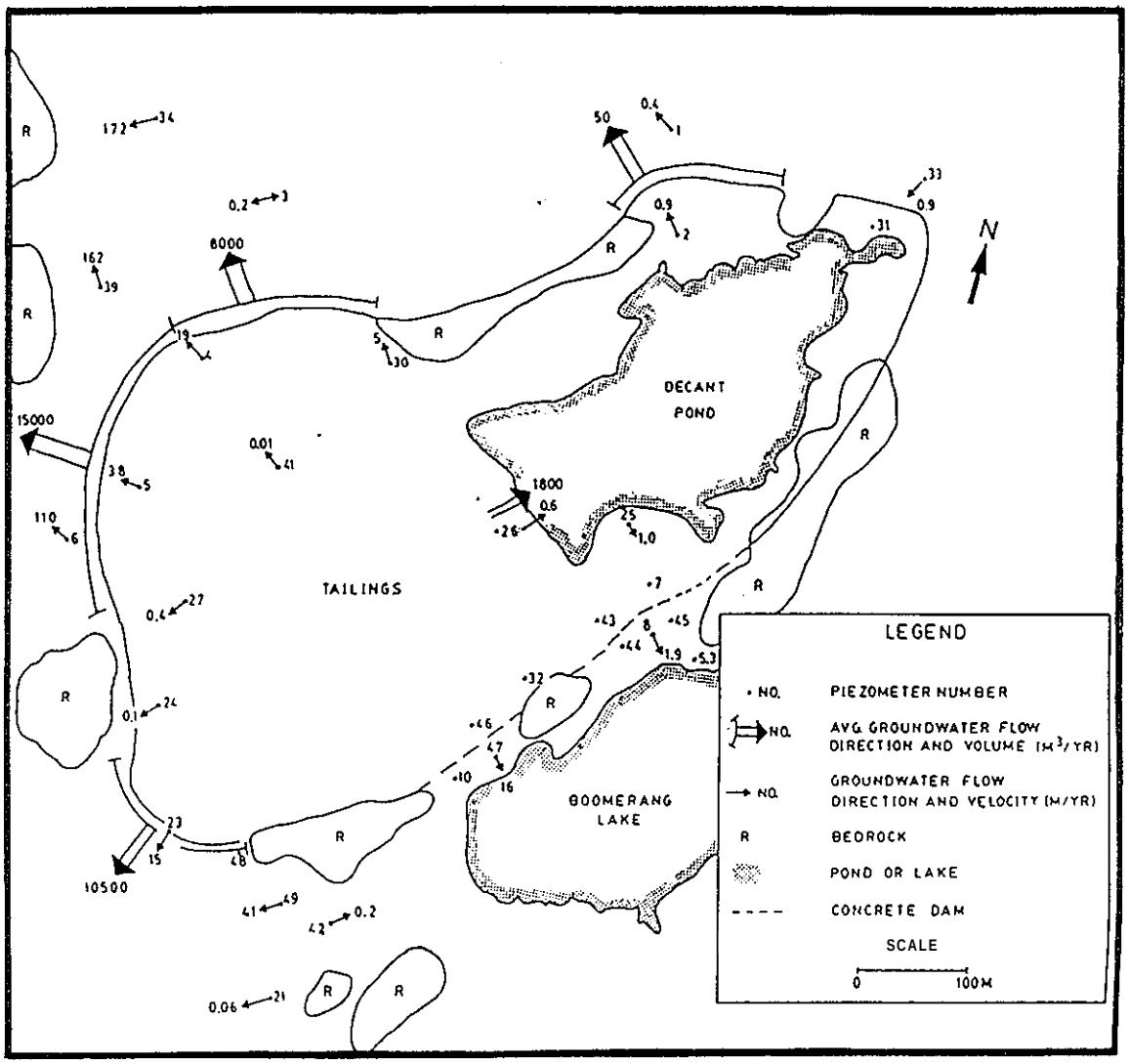
The Mud Lake drainage basin is approximately 185 ha in area (177 ha of land area and 8 ha of Mud Lake area). The total net precipitation per year is estimated at ~~485,513~~ $m^3.yr^{-1}$, equivalent to a flow of 15.9 $L.s^{-1}$ (Table 3). These dimensions of the drainage basin were derived from the Airquest aerial survey (February, 1987) and reported in Hydrological and Geochemical Aspects; South Bay Mine (R.O. van Everdingen, 1988).

In Map 2, estimates of the groundwater movements from the tailings into various directions are given, previously presented in the 1989 South Bay Report (Kalin, 1989).

Table 3: Mud Lake Drainage Basin

PARAMETER			
Area of Mud Lake drainage basin, ha	Total	185	ROVE, 1988
Area of Mud Lake, ha	Lake	8.35	ROVE, 1988
Land run-off, m3/yr (275 mm)	Land	485,513	ROVE, 1988
Lake run-off, m3/yr (175 mm)	Lake	14,612	ROVE, 1988
Total net run-off, m3/yr	Total	500,125	
Total net run-off, L/s	Total	15.9	
Groundwater flow from tailings, m3/yr			
N + NW + W flows		21,870	ROVE, 1988
If all to Mud Lake, GW flow, m3/s		0.0007	

Map 2: Hydrology of Tailings Area.



Some calculations have been completed in order to arrive at some first approximations of volume of tailings groundwater which could be reporting to Mud Lake. If it is assumed that all tailings groundwater flow (R.O. van Everdingen, 1989) moving to the north (55 $m^3.yr^{-1}$), northwest (7,437 $m^3.yr^{-1}$) and west (14,378 $m^3.yr^{-1}$) of the tailings are following a path to Mud Lake, then a total of 21,870 $m^3.yr^{-1}$ of groundwater could be entering Mud Lake (Table 3). This flow is equivalent to groundwater inflow to Mud Lake of 0.0007 $m^3.s^{-1}$, or 0.7 $L.s^{-1}$. This tailings groundwater inflow is relatively small compared to the estimate of the annual average run-off from the Mud Lake drainage basin of 15.9 $L.s^{-1}$ (Table 3).

On August 29, 1994 water samples were collected and flows recorded for the Mud Lake drainage basin. On this date, the measured flow at Mud Lake discharge (ML18 in Table 2) was 14.55 $L.s^{-1}$, a value very similar to the flow estimated for the drainage basin, 15.9 $L.s^{-1}$, derived from land (275 mm) and lake (175 mm) run-off coefficients and the areas of land and open water in the drainage basin (Table 3). Of this total flow leaving Mud Lake, 3.11 $L.s^{-1}$ were entering from Decant Pond to Mud Lake on this date (Table 2). It is therefore reasonable to assume that the remaining 11.44 $L.s^{-1}$ leaving Mud Lake was a combination of freshwater run-off (e.g. ML29) and contaminated groundwater (e.g. ML27 bottom; Table 2).

Assuming that this 'snapshop' of the flows entering and leaving Mud Lake on August 29, 1994 is somewhat representative of the existing conditions, mass balance calculations for the Mud Lake drainage basin can be performed.

Loadings of elements leaving Mud Lake at ML18 are the sum of loadings from Decant Pond Oufflow, freshwater run-off and groundwater inflow. In Table 4, the loadings, in mg per second ($mg.s^{-1}$) of major ions at Mud Lake Oufflow and Decant Pond Oufflow (DRO) were calculated by multiplying the concentrations by the flow. The loading contributions from freshwater run-off and groundwater inflow cannot be directly calculated, as flow rates for each component are not available.

Table 4: Mud Lake Area Contaminant Loadings, August 29, 1994, adjusted to balanced chloride mass.

Percent fresh water set at		94.7%	of Mud Lake outflow minus DRO flow, = 11.44 l/s			
		5.3%	of Mud Lake outflow minus RO flow			
	DRO Loadings mg/s	Freshwater Loading ML29 mg/s @ 10.83 l/s	Groundwater Loading ML27 Bottom	DRO+FW +GW	M.L. Outflow, ML18 Loading mg/s	% Diff. ('-'=loss)
TDS	784	1690	7822	10295	11262	9%
Na	4	4	9	17	36	110%
Cl	1	17	14	32	32	0%
S	120	317	2061	2499	3041	22%
Zn	3	1	112	116	97	-16%
Al	0	0	0	0	2	572%
Fe	0	2	1085	1088	287	-74%
K	17	48	14	79	33	-58%
			308	990	1323	34%

On August 29, 1994, the combined flow of these two components is the difference between DRO and ML18 (11.44 $L.s^{-1}$). The question remains, how much of this 11.44 $L.s^{-1}$ is freshwater run-off component, and how much is groundwater inflow.

Apportioning a fraction of the flow (11.44 $L.s^{-1}$) to freshwater run-off and the remaining fraction to groundwater discharge can be done by using the most chemically conservative element measured (i.e. soluble and not participating in precipitation processes) to complete a mass balance.

Chloride might be considered the most chemically conservative element, when moving through the ground in a dissolved form. On August 29, 1994, 1 $mg.s^{-1}$ of Cl was entering Mud Lake from DRO, while 32 $mg.s^{-1}$ was leaving Mud Lake (Table 4). This leaves 32 $mg.s^{-1}$ Cl from freshwater run-off and contaminated groundwater. The contaminated groundwater discharging into Mud Lake contained 23.1 $mg.L^{-1}$ Cl (ML27 bottom; Table 2), while freshwater run-off contained only 1.61 $mg.L^{-1}$ Cl (ML29; Table 2).

The extra Cl loading, 32 $mg.s^{-1}$, at Mud Lake oufflow can only be provided at a flow rate of freshwater run-off of 10.8 $L.s^{-1}$ (94.7 % of 11.4 $L.s^{-1}$) and a contaminated groundwater inflow of 0.6 $L.s^{-1}$ (5.3 % of 11.4 $L.s^{-1}$; Table 4).

The mass balance of other elements is now evaluated using the flows of groundwater and freshwater inflows. These calculations (Table 4) were made after the mass of chloride was balanced for the system (loadings in = loadings out). Assuming these flow proportions for freshwater and groundwater, an additional source/sink of elements can be identified, namely Mud Lake sediments. As Mud Lake acidified in 1993/1994, it can be expected that some elements in the sediments will be released, while during iron cycling, elements will be co-precipitated.

It appears that Mud Lake sediments contribute Na (an additional 110 %), S (22 %), Al (572 %), and Ca (34 %) in addition to freshwater, contaminated groundwater and DRO water.

The overall mass balance suggests that 19 % of the zinc, 75 % of the iron and 58 % of the potassium entering Mud Lake is not discharged and is deposited as precipitates. Visual observations confirm the massive precipitation of ferric hydroxide. Co-precipitation of zinc is occurring in the water body, as indicated from high zinc concentrations in Mud Lake sediment samples collected in 1994, compared to sediment samples collected in 1986 (Table 5).

The concentration of zinc in Mud Lake sediments in 1994 is 14 times higher than in 1986. Sulphur concentrations are only 2 times higher, and iron concentrations are 6 times higher than in 1986. Aluminum concentrations in sediments have declined in one-third 1986 concentrations. Aluminum and iron are both elements which, through their hydrolysis, contribute to hydrogen ion generation (pH decrease). Through microbial iron reduction which takes place in the sediments, pH decreases are counteracted.

Table 5: Comparison of 1986 and 1994 Mud Lake Sediment Composition.

Date Sampled	25-Jul-86	25-Jul-86	25-Jul-86	25-Jul-86	25-Jul-86	25-Jul-86		27-Apr-94	27-Apr-94	27-Apr-94	27-Apr-94	27-Apr-94	
Assayer No.							1986	4981	4982	4983	4984	4985	1994
Station	ML22	ML22	MML	MML	ML21	ML21	Average	ML23	ML31	MML	ML22	ML32	Average
Ag	< 10	< 10	< 10	< 10	< 10	< 10	10	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	1
Al	19000	17000	17000	16000	14000	14000	16167	5200	6140	4340	5310	6220	5442
B	< 10	< 10	60	20	20	20	23	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	1
Ba	300	300	300	300	200	200	267	81.5	94.5	61.4	66	71.9	75
Be	< 10	< 10	< 10	< 10	< 10	< 10	10	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	1
Bi	< 10	< 10	< 10	< 10	< 10	< 10	10	< 2.5	< 2.5	< 2.5	< 2.5	< 2.5	3
Cd	< 10	< 10	< 10	< 10	< 10	< 10	10	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	1
Co	< 10	< 10	< 10	< 10	< 10	< 10	10	16.7	7.8	33	11	8.7	15
Cr	30	30	40	40	40	40	37	23.4	17.9	101	27.3	405	115
Cu	30	30	20	20	40	20	27	11.6	12.6	13	16.1	29.9	17
Fe	10000	9800	13000	14000	13000	12000	11967	81200	30700	133000	55000	53100	70600
Mn	200	300	700	800	500	400	483	714	598	726	640	738	683
Mo	< 10	< 10	< 10	< 10	< 10	< 10	10	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	1
Ni	10	10	10	10	10	10	10	9.2	12.3	9.3	14.4	14.8	12
Pb	40	50	40	50	60	50	48	8.3	< 1	10.8	< 1	21.6	9
S	10000	11000	15000	15000	18000	16000	14167	27500	21400	42000	28700	39300	31780
Sn	10	10	10	10	10	10	10	< 2.5	< 2.5	2.8	< 2.5	< 2.5	3
V	20	20	20	20	20	20	20	19.7	16.6	16.9	15.2	17	17
Zn	200	200	200	200	400	400	267	2830	387	10300	2380	2450	3669
L.O.I.	58.82	59.97	54.26	54.43	59.64	58.63	58	46.86	48.53	44.05	49.25	47.55	47

Thus, the sediment is a key buffering medium for a water body. Clearly, the hydrolysis of iron and aluminum exceeded the buffering capacity of the Mud Lake sediments, as the pH had decreased to 2.7 by the end of August, 1994.

Sediment samples were collected at South Bay on July 10, 1994 in South Bay from two locations in Confederation Lake (CS13a, CS13b) and four locations in Mud Lake (MML, ML24, ML27, ML28). These samples were homogenized in the lab, then allowed to settle in 2 litre jars for two hours. Following this period, 100 mL of sediment from each sample were placed in a 250 mL Erlenmeyer flask, then 150 mL of each sediment's supernatant was added to the respective sediment sample in the Erlenmeyer flask. The pH, Em, conductivity, acidity and alkalinity of each sediment supernatant were then determined.

Using aquarium pumps, the sediment samples in Erlenmeyers were aerated for 143 hours over a 264 hour period. During aeration, the pH, Em and conductivity were periodically measured. The acidity and alkalinity of the supernatant in each flask was determined with a Brinkman autotitrator at the beginning and the end of the aeration period.

In Figure 2, the pH values obtained during the oxidation experiment are plotted for the duration of the experiment. The pH of the six sediment slurries did not appreciably decrease during aeration for 143 hours over the 264 hour period of the experiment.

Comparing the acidity of the supernatants, where available, before and after aeration (Table 6), only the acidity of ML27 sediment increased. This sample was collected from an experimental area amended with potato waste to stimulate microbial activity. During aeration, the conductivity also increased, a result of decomposition of organics.

Fig. 2: Sediment Oxidation Exp't
South Bay Samples: pH

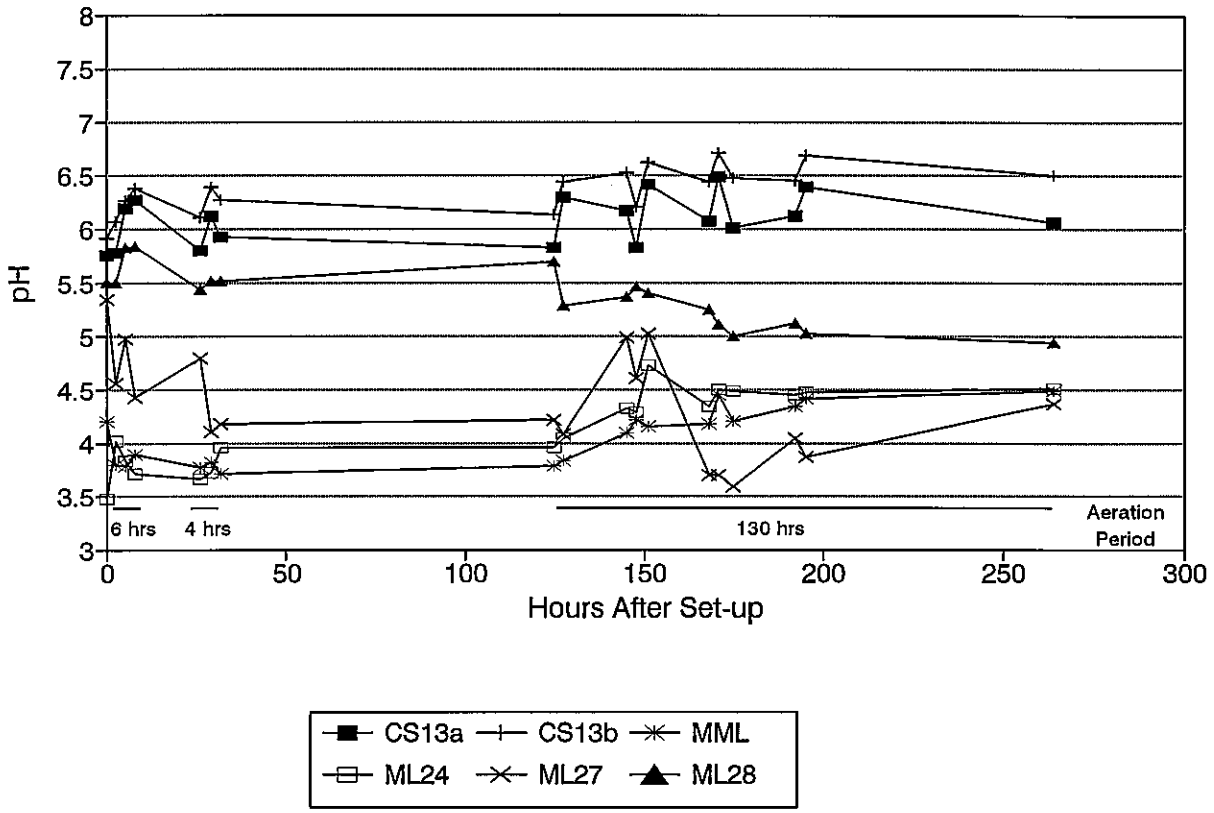


Table 6: Sediment aeration experiment. Initial and final chemistry following 143 hours of aeration.

	CS13a	CS13b	MML	ML24	ML27	ML28
Initial pH	5.75	5.92	4.2	3.48	5.34	5.51
Final pH	6.06	6.5	4.49	4.51	4.37	4.94
Initial Em (mV)	192	191	219	319	-74	15
Final Em (mV)	169	160	230	215	332	220
Initial Cond (uS/cm)	997	1396	1968	2160	2800	474
Final Cond (uS/cm)	1100	1460	2350	2270	4740	880
Initial Acidity (mg/l)	199	231	1223	776	2323	28
Final Acidity (mg/l)	165	84	519	334	4253	21
Initial Alkalinity (mg/l)	27	8	Nil	Nil	21	6
Final Alkalinity (mg/l)	8	39	Nil	Nil	Nil	4

The results of the vigorous aeration of the iron-enriched sediments suggest that, if the sediments were exposed to air, they would not represent an immediate source of hydrogen ions. Given the high concentrations of dissolved iron in, and low Eh of, contaminated groundwater, the pH decline in Mud Lake is due to groundwater ferrous iron oxidation and hydrolysis, and not due to oxidation of sediment pore water.

3.0 THE SEEPAGE PATHWAY

The water quality considerations presented in the previous section suggest that groundwater seepages, rather then the inflow from Decant Pond or other surface water connections to Mud Lake, are the cause of Mud Lake water quality deterioration. The hydrological calculations for of the drainage basin generally concur with the measured flows. The existing piezometers between the tailings and Mud Lake were re-sampled in 1993 (Map 3). The water quality data did not indicate that contaminated water was moving away from the tailings (Table 7). As the tailings have a maximum depth of about 5 m, and the piezometers between the tailings and Mud Lake were generally drilled to a depth of 4 m, it was suspected that the seepage path might either be deeper, and/or a diffuse seepage might be passing through the Mud Lake sediment.

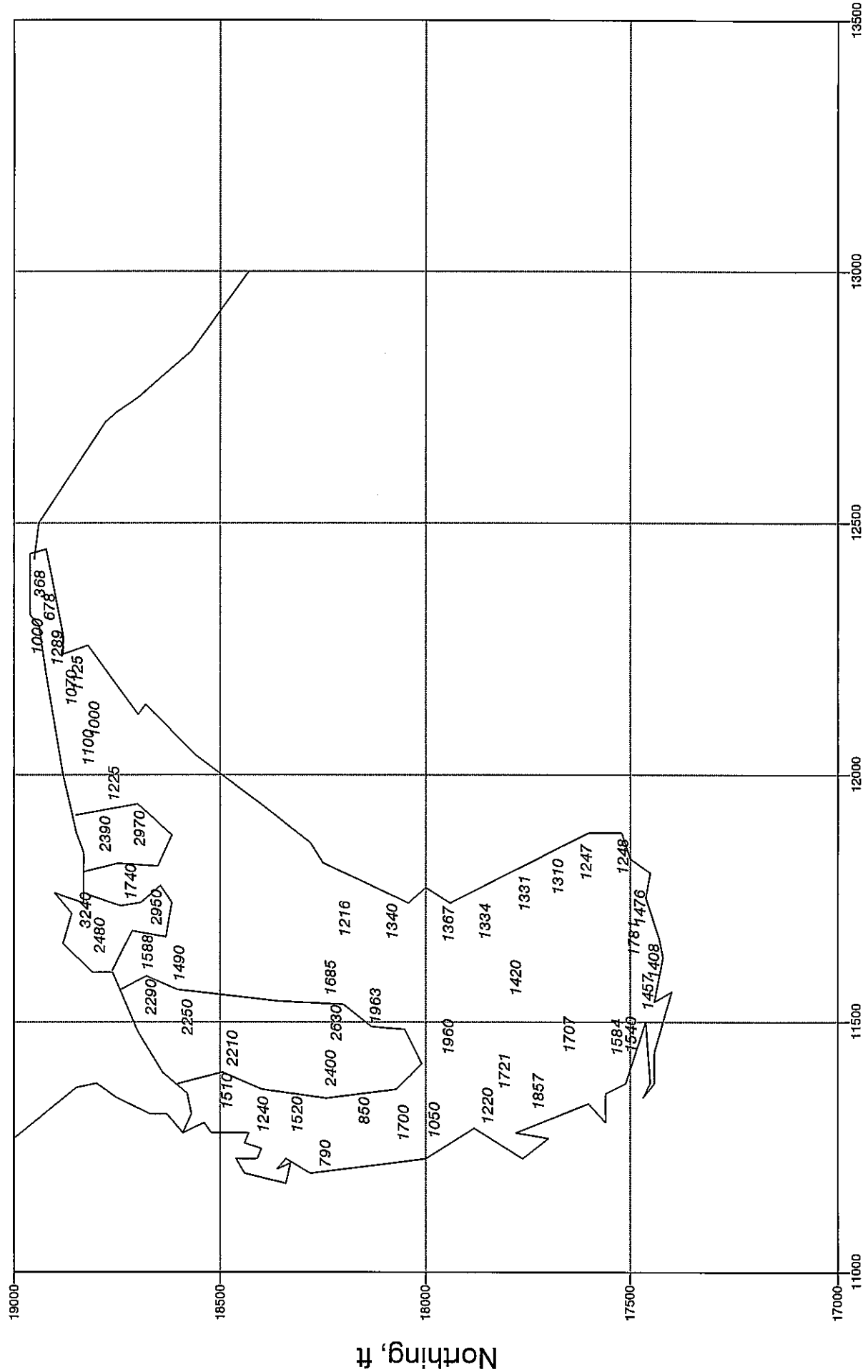
In Figure 3, the electrical conductivity of the Mud Lake sediments is plotted, based on a survey carried out in July, 1994. Distinct regions of elevated conductivity are noted in the north end of the lake. Electromagnetic surveys were carried out in June and July, 1994, using an EM34-3 to determine anomalies and their approximate depth. The results are presented in Maps A1 to A5 (in colour) and interpolation of probable depth is given in a drawing in Appendix 1. The most anomalous zone extends in the south to north direction in the gravel pit. A layer of relatively high conductivity, possibly contaminated groundwater, is predicted at an approximate depth of 7 to 12 m below the surface. Detailed evaluation of the Em survey was made by J. Pawlowski of Geomar (Appendix 1).

These anomalies revealed by the EM survey were further explored during a preliminary drilling program in September, 1994, by J.A Vonhof Consulting Ltd with Kenora Soil and Drilling. This program's objective was to confirm the existence of deeper contaminated seepages. The stratigraphy and bedrock topography were elucidated to a conceptual level with the results obtained during the drilling program between the tailings and Mud Lake.

Table 7: Historical Water Quality in Piezometers Between Tailings and Mud Lake.

Piezo Number	Date Sampled	pH	Cond,uS/c uS/cm	Eh, mV mV	Acidity mg/L	Alkalinity mg/L	Al mg/L	Fe mg/L	S mg/L	Zn mg/L
M1	06-Nov-86	3.4	600		96.5		0.24	15	114	2.4
M1	12-Apr-88	6.79	600						162	14
M1	23-May-88						0.02	0.03	152	5.1
M1	10-Apr-93	6.48	813	-46	41.8	116.3		0.708		0.012
M1	26-Apr-94	6.35	806	168	41.5	109.1		0.147	148	0.546
M1	14-Jun-94	6.58	591	256	20.7	93.9		0.801	63.6	0.132
M1	02-Sep-94	6.14	380	-54	9.7	32.2	<0.025	0.1	82.7	0.13
M2	06-Nov-86	6.4	440		77.2		0.6	19	51	1
M2	12-Apr-88	6.34	500				0.5	2.8	109	1
M3	06-Nov-86	7.2	130		11.5		0.44	1	8	0.24
M3	23-Jun-88						0.1		9.3	0.08
M3	14-Jun-94	6.98	133	219	2.9	41.5		0.158	5.87	0.016
M3	02-Sep-94	6.63	98	-78	5	52.4	10.1	3	8.2	0.32
M4	06-Nov-86	5.8	2850		3958		1.7	1009	1233	60
M4	12-Apr-88	4.68	2200				5	644	1249	45
M4	11-Oct-90	4.54	6000	150				40	205	1.1
M4	11-Oct-90	4.76	6000	78			0.9	37	204	1.8
M4	14-Jun-94	4.17	4470	414	2319.3		7.17	1760	1440	76.7
M4	02-Sep-94	4.59	2690	106	3870		15.3	257	3123	144
M30	06-Nov-86	6.6	115		13.5		0.44	0.36	12	0.33
M30	12-Apr-88	6.61	160				0.3	21	56	2.7
M30	11-Oct-90	5.87	300	13				0.3	21	0.2
M30	11-Oct-90	6.08	300	59				0.02	20	0.09
M30	26-Apr-94	6.28	329	65	56.6	7.7	0.064	13.6	49.5	1.21
M30	14-Jun-94	5.58	423	305	57.6	4	0.158	44.1	74.9	2.22
M31	06-Nov-86	6.75	70		11.5		0.46	0.15	3.7	0.06
M31	12-Apr-88	7	50				0.2		4	0.06
M31	10-Apr-93	6.4	116	136	4.7	19.7		0.006		0.078
M31	30-Mar-94	6.17	121	71	12.5	21.3	0.034	0.196	3.46	0.052
M33	06-Nov-86	6.8	90		11.6		0.5	1.5	5.3	0.43
M33	12-Apr-88	7.35	70				0.2		5	0.2
M33	10-Apr-93	6.54	134	138	4.5	26.2		0.102		0.059
M33	30-Mar-94	6.6	86	58	9.6	28.7	0.14	0.169	2.34	0.028
M33	02-Sep-94	6.12	400	79	293	169.5	3.99	5.9	2.6	0.02
M34	08-Nov-86	6.7	190				0.49	0.27	13	0.42
M34	23-Jun-88						0.09	0.3	6.6	
M34	08-Sep-93	5.57	287	-58	37.4	83.1		6.36		0.115
M34	26-Apr-94	6.54	165	62	25	85.4		0.094	8.82	0.05
M34	14-Jun-94	6.18	219	307	9	83.3		0.281	12.4	0.042
M39	06-Nov-86	6.6	400		88.8		0.47	18	84	7.4
M39	19-Jun-88						0.2	0.5	3.3	0.03
M39	08-Sep-93	5.38	784	-36	137.7	70.8		35.4		9.65
M39	26-Apr-94	6.71	125	56	1.9	12.1		0.094	9.34	0.485
M39	14-Jun-94	6.34	131	366	15.4	29.7		0.585	10.6	0.745
M39	02-Sep-94	5.98	360	-4	117.8	59.6	<0.025	7.5	80	7.52

Fig. 3: South Bay, Mud Lake Area
Bottom Conductivity, July 1994

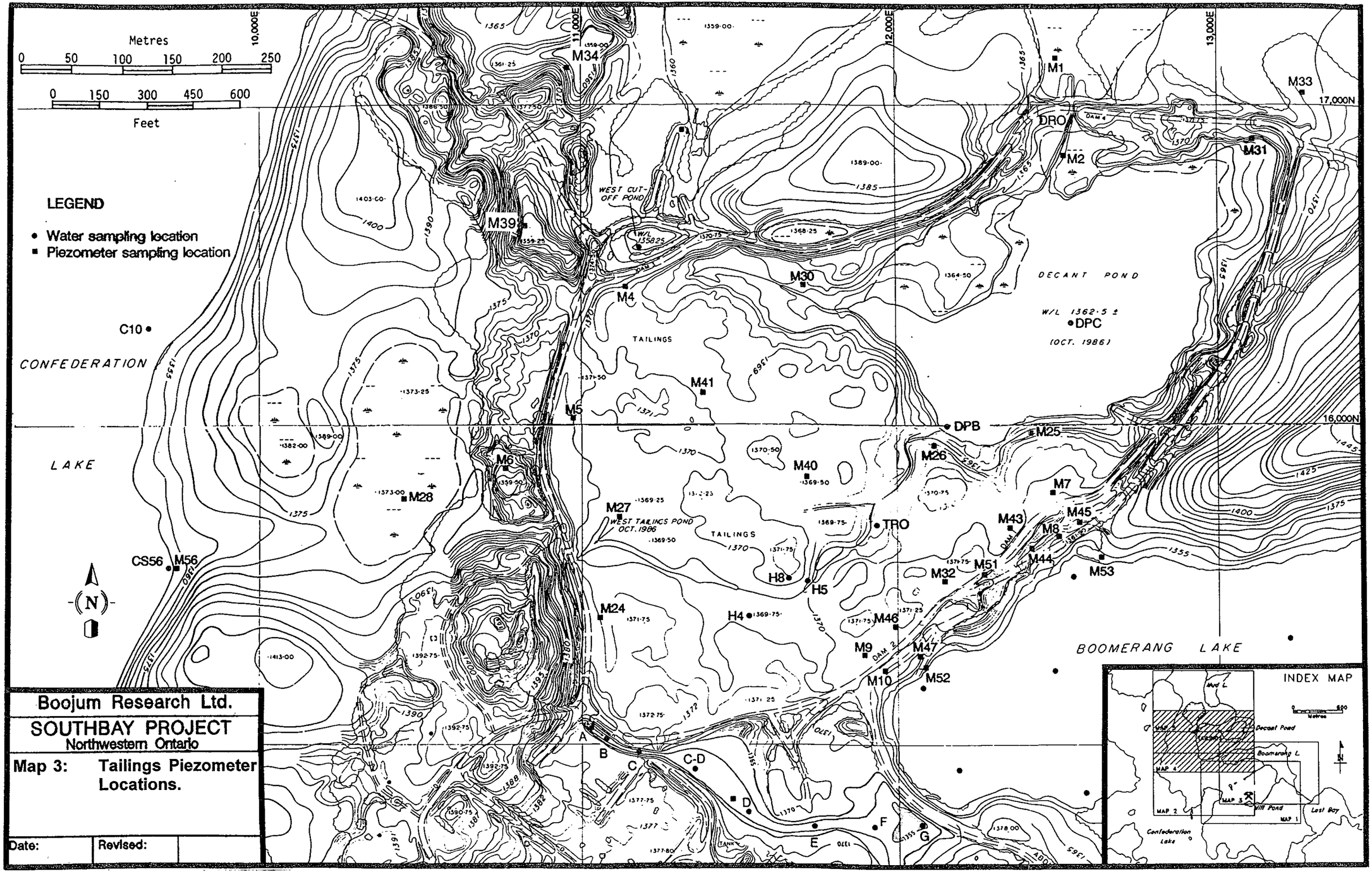


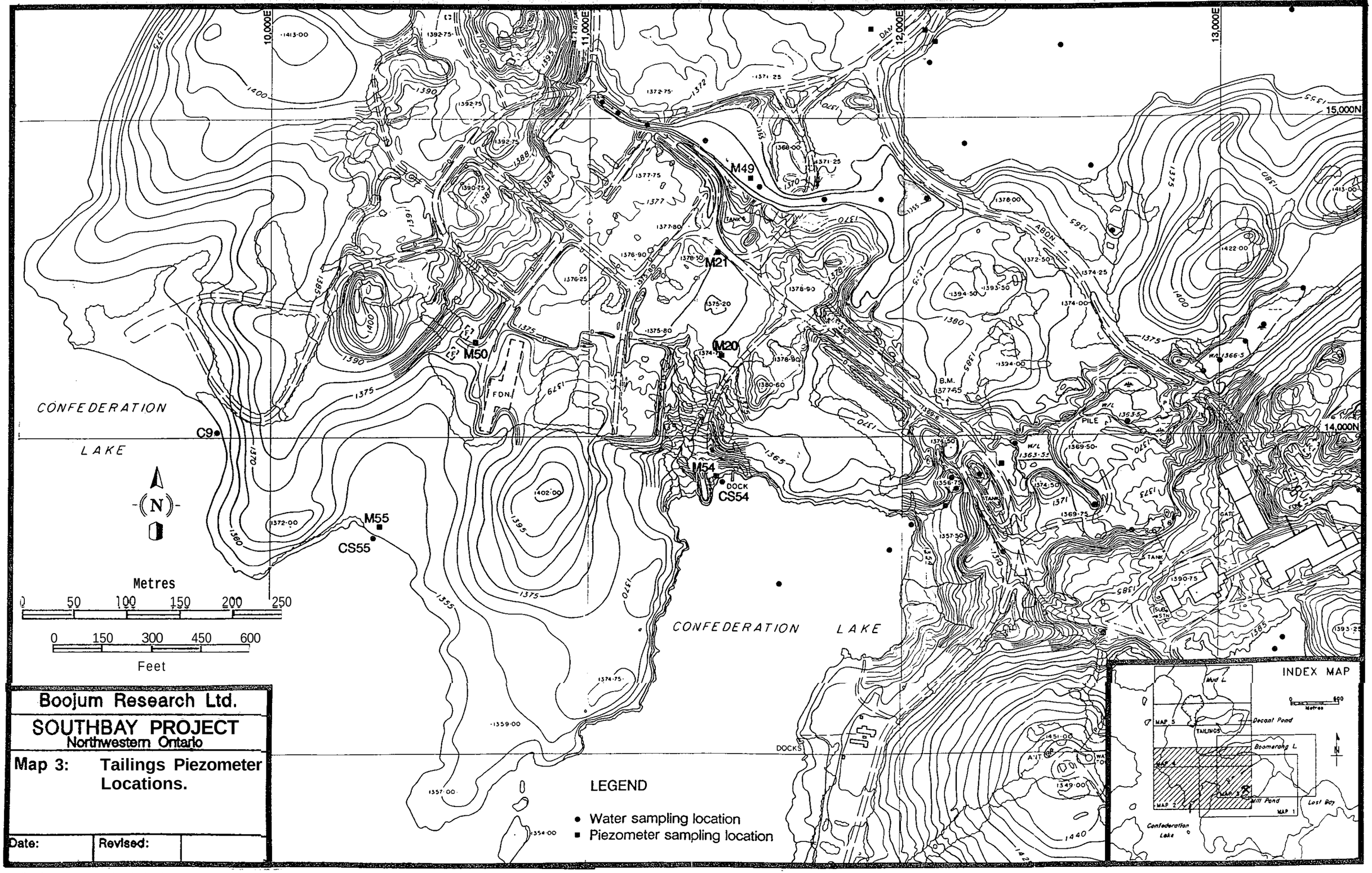
Several new piezometers were installed and groundwater samples were collected to provide groundwater quality data for geochemical simulations. A detailed report of the drilling program and interpretation of the hydrological data are presented in Appendix 2.

Prior to the drilling program mobilization, the existing piezometer water quality was re-evaluated to determine possible long-term trends in the tailings porewater quality. This geochemical evaluation was carried out by R.O. van Everdingen. The major trends are outlined below.

Available Records: Available analytical records for the piezometers at South Bay for the period 1986-1994 are assembled. Similarly, available records for sampling points other than the piezometers for the period 1992-1994 were summarized. These data can be made available on floppy, as the data sets are too large to print. The period prior to the last two field trips in 1994 is covered.

Graphs derived from the spreadsheet of the analytical records for individual sampling points were used to examine the trends in concentrations of elements in pore water. They show significant seasonal variations in elemental concentrations. It is, however, virtually impossible to discern long-term trends with any degree of confidence because, in most instances, samples for analysis were collected at different times of the year in different years. For some samples, the concentrations of only selected elements were determined. Piezometer locations are given in Map 3. Keeping the limitations of the data in mind, the following observations can be made.


Metres
0 50 100 150 200 250
0 150 300 450 600
Feet
10,000E
11,000E
12,000E
13,000E
17,000N
16,000N
LEGEND
• Water sampling location
▪ Piezometer sampling location
C10 •
CONFEDERATION
LAKE
M34
M1
M33
DRO
M2
M31
M39
WEST CUT-OFF POND
W/L 1358.25
M30
M4
DECANT POND
W/L 1362.5 ±
•DPC
(OCT. 1986)
TAILINGS
M41
M5
DPB
M25
M6
M40
M26
M7
M28
M27
WEST TAILINGS POND
OCT. 1986
TRO
M43
M45
M8
M44
M53
CS56
M56
H8
H5
M51
M32
M24
H4
M46
M9
M47
M10
M52
BOOMERANG LAKE
N
A
B
C
C-D
D
E
F
G
INDEX MAP
Decant Pond
Boomerang L.
Mill Pond
Last Bay
Confederation Lake
MAP 1
MAP 2
MAP 3
MAP 4
Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
Map 3: Tailings Piezometer Locations.
Date:
Revised:



Boojum Research Ltd.

SOUTHBAY PROJECT
Northwestern Ontario

Map 3: Tailings Piezometer Locations.

Date:	Revised:	

The **Mud** Lake - Confederation Lake Data

a) Concentrations in samples from piezometers M54, M55, and M56 increased between July 1992 and July 1994, while concentrations in the adjacent shoreline samples, C54, C55, and C56, decreased. It may well be that there is a time lag of several months between seasonal concentration peaks in the piezometers and in the lake. Sampling frequency has been insufficient to determine this.

b) Concentrations in samples from Decant Pond oufflow (DRO) appear to show seasonal variations only.

c) Concentrations in samples from piezometers M31, M2, M30, M4, M34, and M39 do not appear to show a long-term trend, whereas those in samples from piezometers M33, M1, and M3 appear to reflect a trend of decreasing concentrations.

Recommendations - **Mud** Lake / Confederation Lake.

1) Water samples should be collected as frequently as possible from:

- ML22, MLC, ML20, MLO, and C11;
- M56, C56, M55, C55, M54, and C54;
- M31, M33, M2, M1, M30, M4, M34, M39, M41, and M5;
- and from any new piezometers.

2) Complete analvses, for use in PHREEQE and NETPATH calculations, should be made on the samples from Mud Lake; from M2/M1, M30, M4/M34/M39; and from all new piezometers.

These water samples were collected, as recommended, during the September, 1994, field trip at the same time as the drilling program. In Table 8, the water chemistry is summarized. These results confirm that very contaminated water is found at greater depths. For instance, in piezometer M39A in the gravel pit, at 13.5 m the zinc concentration was 168 $mg.L^{-1}$, while at a depth of 4.7 m in M39, groundwater contained only 7.5 $mg.L^{-1}$ Zn. Water collected at a depth of 16.4 m from piezometer M60A contained 106 $mg.L^{-1}$ Zn, but piezometer M60B, drilled adjacent to M60A but only to a depth of 8.4 m, contained only 0.05 $mg.L^{-1}$ Zn.

In Table 8, the characteristics of emergent seepage water (west of M5) which is infiltrating the ground can be compared to emerging seepages at the north end of Mud Lake (at ML27 and piezometer M62). If it is assumed that these locations are on the same groundwater path, it appears that zinc and sulphate concentrations are attenuated along this path. However, acidity, an indicator of the sum of the dissolved metals and pH, cannot be compared in such a simple manner. Metals can either precipitate (e.g. iron) or dissolve (e.g. aluminum) upon transfer of the contaminated water from one medium to another, for example emergence from the ground to the lake bottom.

Geochemical simulations should be carried out in order to determine the source of contaminant groundwater (tailings or mine site) and the possible mixing ratios of freshwater with a particular contaminated groundwater type to achieve the characteristics of a given water sample. Analyses of water samples from (a) the tailings, (b) below the tailings, (c) the mine site, (d) new piezometers at different levels between the tailings basin and Mud Lake, and (e) Mud Lake, should be performed to determine the path of metal-contaminated water to Mud Lake, and the changes the water undergoes during its migration. This geochemical simulation approach has proven to be very useful in characterizing the mine site conditions, where a diversion ditch was dug to prevent seepages from entering Confederation Lake.

Table 8: Piezometer, Tailings Seepage, and Mud Lake Groundwater Inflow Water Quality, 1994.

	IN TAILINGS		TAILINGS SEEPAGE	PIEZOMETERS NEAR TAILINGS						PIEZOMETERS IN MUD LAKE AREA						IN MUD LAKE	MUD LAKE BOTTOM WATER
SAMPLE DATE	02-Sep-94	02-Sep-94	31-Aug-94	01-Sep-94	01-Sep-94	01-Sep-94	01-Sep-94	01-Sep-94	29-Aug-94	01-Sep-94	30-Aug-94	31-Aug-94	01-Sep-94	01-Sep-94	03-Sep-94	03-Sep-94	28-Aug-94
ASSAYERS CODE	5228	5230	5274	5224	5226	5232	5234	5238	5240	5236	5242	5244	5246	5248	5250	5252	5262
	M-4	M-5A	M-5 seep	M-1	M-3	M-28	M-33	M-39	M-39 A	M-34	M-58	M-59	M-60 A	M-60 B	M-61	M-62	ML-27
	Piezo	Piezo	Surface	Piezo	Piezo	Piezo	Piezo	Piezo	Piezo	Piezo	Piezo	Piezo	Piezo	Piezo	Piezo	Piezo	Bottom
Screen, m below surface	5.13	10.78		4.21	6.31	17.22	3.36	4.75	13.53	4.79	13.09	7.26	16.4	8.43	4.50	2.14	
Temp. (C)	15	17	13.9	14.9	13.6	13	10	13.8	15.2	15	15.9	6	6.5	8	7.2	6.5	9.1
pH	4.59	5.41	2.79	6.14	6.63	6.85	6.12	5.98	5.65	6.71	6.59	5.96	5.79	6.26	6.37	5.85	5.7
Cond. (umhos/cm)	2690	2690	4820	380	98	460	400	360	3600	170	185	440	2410	365	353	3160	4120
Eh (mV)	106	-15	396	-54	-78	71	79	-4	-115	-62	101	-32	-71	-50	-59	-52	-109
Acidity (mg/l)	3870	2714.6	5115	9.7	5	37	293	117.8	2753.2	16.2	3	56.8	1765.7	13.1	74.1	2462.9	3155.4
Alkalinity (mg/l)		8.8		32.2	52.4	243.8	169.5	59.6	29.8	81.6	81.2	99.8	156	151.6	68.5	121.9	105.6
ELEMENTS,mg/L: Al	15.3	1.82	88	< 0.025	10.1	< 0.025	3.99	< 0.025	0.043	< 0.025	0.473	< 0.025	< 0.025	0.043	0.164	< 0.025	< 0.025
Ca	377	224	230	90.5	30.8	123	13.8	87.8	354	37	33.1	118	458	99.8	98.2	503	508
Co	0.912	1.52	2.29	< 0.005	< 0.005	< 0.005	< 0.005	0.082	0.88	< 0.005	< 0.005	< 0.005	0.574	< 0.005	< 0.005	0.618	0.775
Cu	0.98	0.038	3.81	< 0.003	0.014	< 0.003	0.016	< 0.003	< 0.003	< 0.003	0.005	< 0.003	< 0.003	0.004	0.008	< 0.003	< 0.003
Fe	257	1240	750	0.1	8.66	0.152	3.73	0.143	1560	0.128	0.491	0.354	897	0.116	0.953	1380	1790
K	15.6	15.8	8.4	4.7	3	6.1	5.9	7.5	13.2	5.1	6.1	6	19.3	7.5	2.6	15.2	22.9
Mg	163	101	85.5	11.9	2.91	8.54	3.54	13.5	110	3.53	3.16	12.1	95	7.57	12.9	119	137
Mn	69	49.8	56	0.078	0.154	0.229	0.045	6.1	45.3	1.44	0.248	1.45	44.1	0.718	0.377	50.9	56.1
Na	5.59	6.34	3.61	1.01	0.83	4.16	8.32	2.35	10.2	1.34	0.85	8.5	11.6	6.77	2.66	13.9	14.7
Ni	0.09	0.17	0.29	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.06	< 0.01	< 0.01	0.01	0.02	< 0.01	< 0.01	< 0.01	0.08
P	0.43	< 0.06	< 0.05	< 0.05	0.14	< 0.06	< 0.06	< 0.05	< 0.05	< 0.06	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
S	3123	2077	3567	83	8.2	47	2.6	80	1567	13	5.6	89	1190	38	75	1623	3400
Zn	144	316	416	0.13	0.32	0.101	0.02	7.52	168	0.152	0.019	0.013	106	0.055	0.012	132	184
Chloride	11.2	11.3	4.53	0.22	0.31	1.71	0.22	0.86	7.76	0.46	3.64	6.65	10.8	20.9	1.87	16.6	23.1
Nitrate	< 0.03	< 0.03	< 0.03	0.09	0.33	0.19	< 0.03	0.52	< 0.03	0.06	0.32	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Fluoride	0.38	6.54	5.07	0.49	0.1	0.42	0.1	0.3	< 0.02	0.13	0.1	0.14	< 0.02	0.17	< 0.02	< 0.02	< 0.02
Bromide	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Nitrite (as N)	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.1	< 0.03	< 0.03	< 0.03
Alkalinity(as CaCO3)	< 1	< 1	< 1	29	47	248	27	53	< 1	82	83	104	< 1	154	81	< 1	< 1
Anion Sum	196	131	223	5.79	1.49	7.99	0.72	6.36	98.1	2.46	2.14	7.82	74.7	6.09	6.34	102	213
Bicarbonate	< 0.1	< 0.1	< 0.1	29	48.8	248	27	63	< 0.1	81.9	82.9	104	< 0.1	153	80.9	< 0.1	< 0.1
Carbonate	< 0.1	< 0.1	< 0.1	< 0.1	0.2	1.8	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	1.1	< 0.1	< 0.1	< 0.1
Cation Sum	40.1	31.8	34.1	5.7	1.9	7.23	1.24	6.26	34.5	2.39	2.12	7.47	36.7	6.12	6.18	42	45.8
Hardness (as CaCO3)	1620	974	925	276	89	343	49	275	1340	107	95	344	1530	280	298	1750	1830
Ion Balance	0.21	0.24	0.15	0.99	1.27	0.9	1.74	0.98	0.35	0.97	0.99	0.96	0.49	1.01	0.98	0.41	0.22
Langelier Index at 20C	-6.41	-6.51	-6.75	-1.49	-0.64	0.81	-1.92	-1.5	-5.75	-1.13	-0.91	-0.55	-5.51	0.5	-0.68	-5.81	-6.02
Langelier Index at 4C	-6.81	-6.91	-7.15	-1.89	-1.04	0.41	-2.32	-1.9	-6.15	-1.53	-1.31	-1.05	-5.91	0.1	-1.08	-6.21	6.42
Saturation pH at 20C	8.01	9.25	9.23	8.13	8.34	7.09	8.9	7.83	9.04	8.02	8.05	7.47	8.99	7.38	7.66	6.99	8.99
Saturation pH at 4C	9.41	9.65	9.63	8.53	8.74	7.49	9.3	8.23	9.44	8.42	8.45	7.87	9.39	7.78	8.06	9.39	9.39
Total Dissolved Solids	10400	8210	12300	387	131	535	59	433	6970	170	149	524	5210	413	425	7110	12900
Turbidity	2.1	< 0.5	0.5	< 0.5	32	9.6	144	2.4	1.7	2.5	22	1.8	0.5	22	21	1.7	1.2

3.1 Summary of Existing Conditions of Mud Lake

Seepage is discharging through a deep groundwater 'valley' (at least 16 m) to the north end of Mud Lake. Mud Lake pH has decreased due to groundwater iron oxidation and hydrolysis. The sediments are releasing aluminum, but zinc is co-precipitated with iron in the lake. By August, 1994, the monitoring station C11 cannot be considered to have been affected by the deterioration in the water quality of Mud Lake. The fresh water contribution to Mud Lake represent 95 % of the water leaving Mud Lake. Dilution from the drainage basin to the north of Mud Lake is evident in the outflow stream of Northwest Lake to C11.

These conditions raise some key questions which need to be resolved in order to determine the appropriate actions to address the overall objective. These are:

- What is the northern extent of the deep groundwater 'valley'?
- Is the deep groundwater 'valley' connected to Boomerang Lake?
- Is the deep groundwater 'valley' connected to the underground mine workings or major shear zones?
- Are there subsurface tributaries to the deep groundwater 'valley', and what is their relationship to the surface water bodies in the area?
- Is the deep groundwater 'valley' the only contaminated deep aquifer and is all of the contamination flowing to Mud Lake?
- What is the stratigraphy along the path of the deep groundwater 'valley'?
- What are the stratigraphic conditions that lead to groundwater discharge into the northern (western?) end of Mud Lake?
- What is the spatial definition of the contaminated seepage path?
- What is the stratigraphy under source (tailings area, Decant Pond, mine site)?
- Is there any contaminant retardation in the subsurface?
- Is there a groundwater divide in the tailings/mine site area?
- What conditions can lead to a change in directions and discharge characteristics of the seepage paths?

These questions need to be addressed as, otherwise, remedial actions may affect the conditions of the site with respect to the requirements of the decommissioning conditions. The future investigations should not be restricted to the Mud Lake drainage basin, as the origin of the deep valley seepage is not defined yet. The investigation should address the entire ground water regime on the peninsula and not be limited as the previous hydrology to the tailings alone. Ground water flow not only contributes to all the lakes in the vicinity of the mine and tailings site, but remedial measures taken in one area, may affect the whole site conditions.

4.0 DEFINITION OF THE SEEPAGE PATH

Three steps are proposed to address the questions put forth in Section 3.1 above

1. Use geochemical simulation on the water samples collected to determine the characteristics of the seepage as outlined in Section 3.

2. Carry out a geophysical survey.

3. Carry out test drilling and piezometer installations to better define the deep 'valley' where the contaminated groundwater is travelling. Details are presented in Section 4.2.

4.1 Geophysical Baseline Surveys

Boojum Research's field work in 1994 at the South Bay Mine clearly demonstrated that the combination of geophysical surveying and follow-up anomaly testing with piezometers is a very effective technique for "mapping out", or "seeing" plumes of contaminants in the groundwater.

Continued use of this technique is important for the following reasons:

(1) While the quality of surface waters in the vicinity of mine tailings is relatively easy to monitor using conventional methods of water, sediment and biota sampling, the quality of the groundwater is far more difficult to establish and monitor because sample locations are restricted to piezometer sites. Plumes of contamination may remain undetected in areas where piezometers are widely spaced, or in areas with multiple aquifers but without multiple piezometers.

The main problem is that we cannot easily "see" the quality of the groundwater to focus on a problem area and, as a result, are left with a wide choice of sampling sites and sampling depths. This handicap can, for the most part, be alleviated through the use of geophysical surveys, more specifically, through the use of electromagnetic techniques employing the EM 34-3 unit.

Areas of anomalously high conductivity become the target sites for piezometer installation, and an estimate of the depth of the plume can be determined from calculations of multiple directional surveys over those anomalies.

The result is that piezometers are installed at the most optimum sites for testing groundwater contamination.

(2) Geophysical survey results (readings) can normally be reproduced year after year, provided that the same unit/model is employed, and that the same background and instrument levels are set. The initial survey records the condition of the groundwater and location of plumes. The initial survey thus becomes a permanent record of the condition at that point in time and is referred to as a Baseline Survey.

Having a Baseline Survey is important for monitoring changes in the condition of the groundwater which result from (i) the migration of existing plumes, (ii) the appearance of new plumes, or (iii) the results of any remediation work, which can be measured by conducting subsequent surveys and comparing them to the Baseline Survey.

The Baseline Survey would involve the area surrounding the tailings site, focusing on mapping out the conductivity of the near subsurface strata to a maximum depth of 30 m. Profiles over the anomalies will help to establish the depth of the high conductivity.

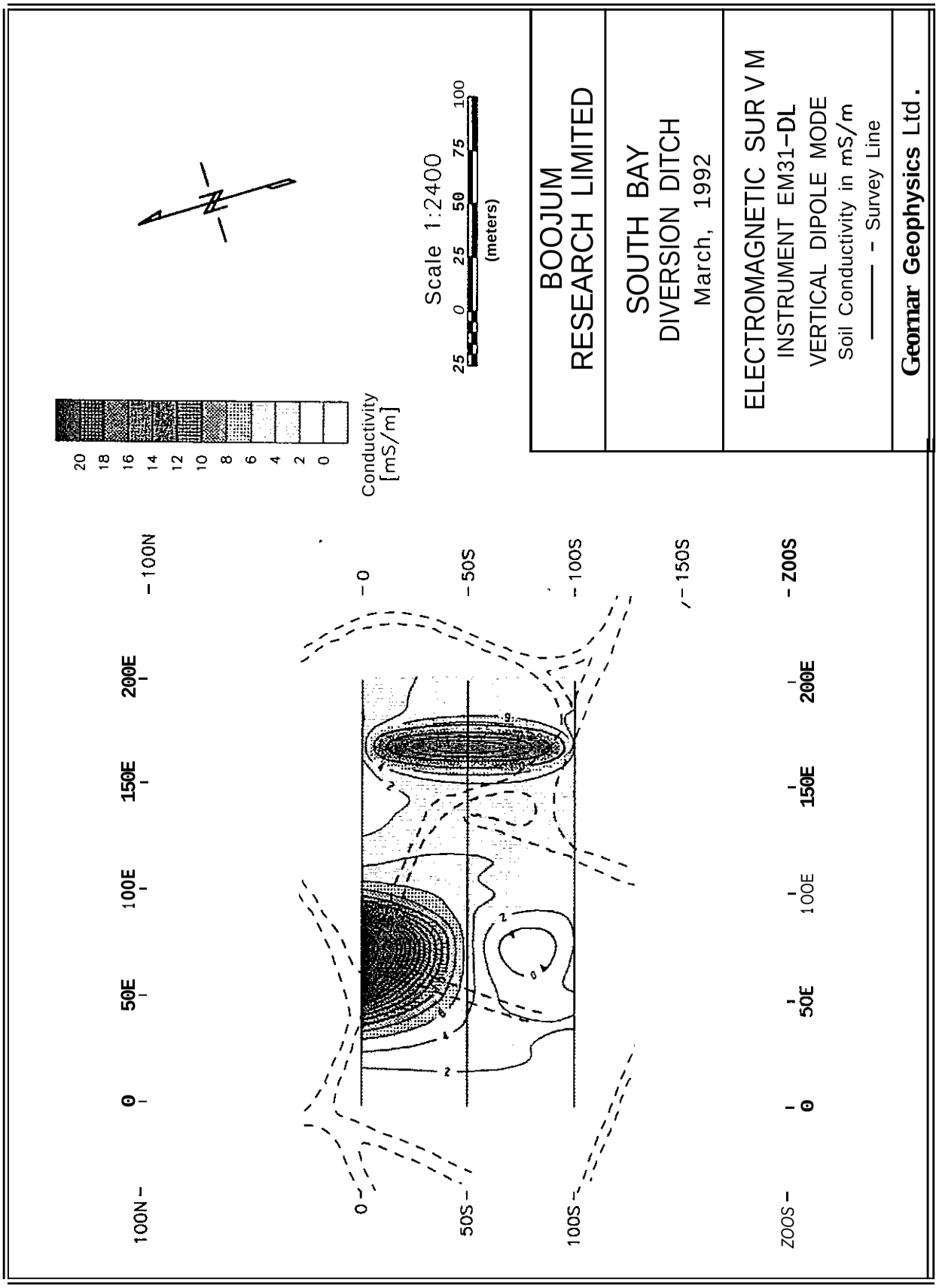
In fact, a very small Baseline Survey has already been implemented at South Bay in the Diversion Ditch area. Three lines were surveyed in March 1992 and again in September 1993 to determine whether the Diversion Ditch at the Mine site was effective. These survey data, shown in Maps 4 to 7 along with the data from two other surveys covering the Mine Site (Maps 8 to 11) and Tailings Dams 1 and 2 (Maps 12 to 14) will be incorporated in the overall data set. Baseline Surveys can be staged over several seasons, with the initial focus on areas with existing problems.

For South Bay, proposed programme for the winter of 1994-1995 is shown in Map 15. The coverage would depend on any number of factors and would be adjusted based on the findings in each line. A distance of 500 m out from the margin of the tailings dam may be adequate for the initial pass.

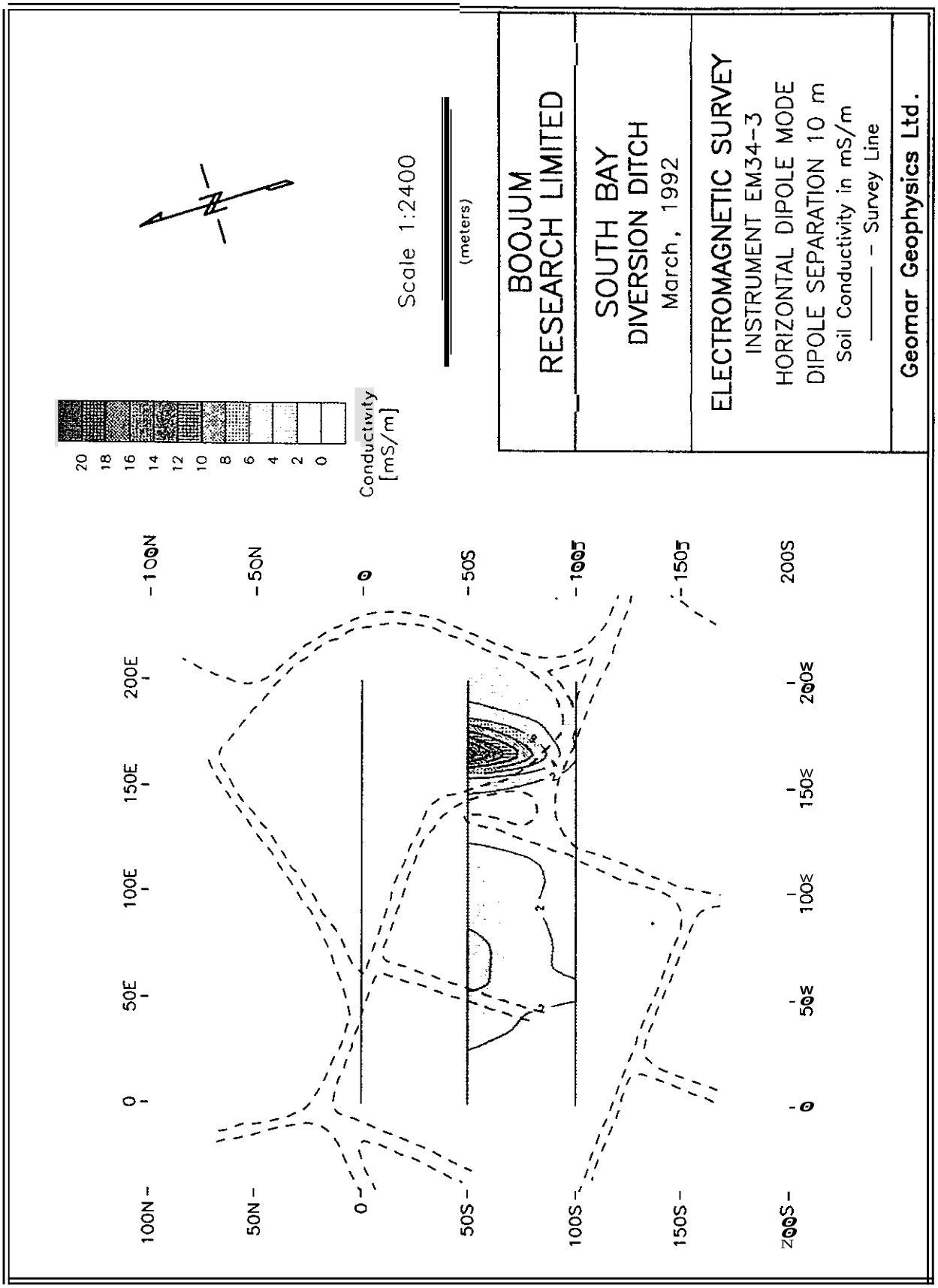
The geophysical anomalies would be screened to separate responses that are likely from conductive overburden, such as layers with clays, from those that potentially represent contaminated groundwater.

Anomalies would then be tested with piezometers as required. The total would not only depend on the number of anomalies, but also on the locations and depths of the existing piezometers.

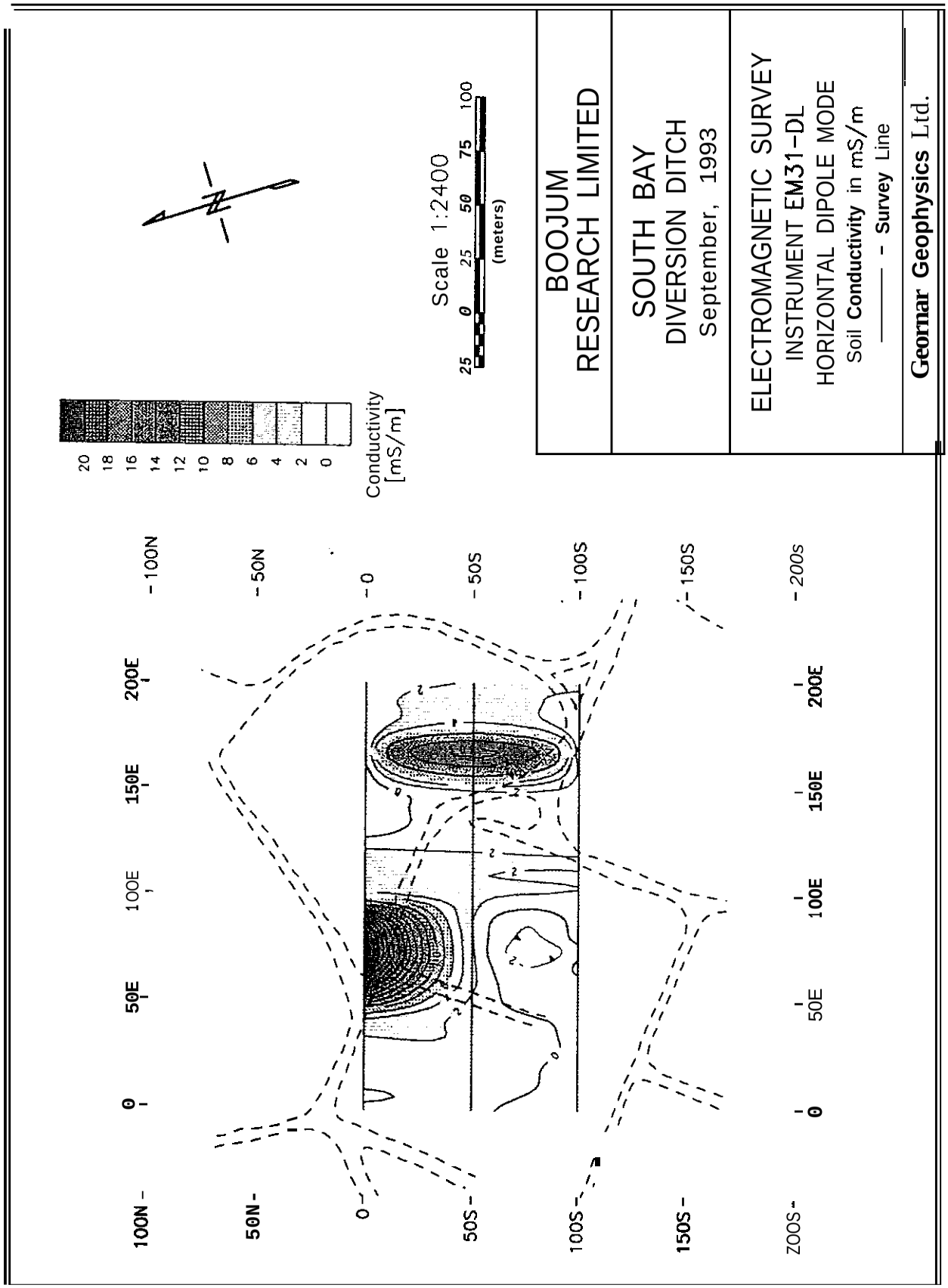
The results of the survey would be used to select the locations for the drilling program outlined in the following section.



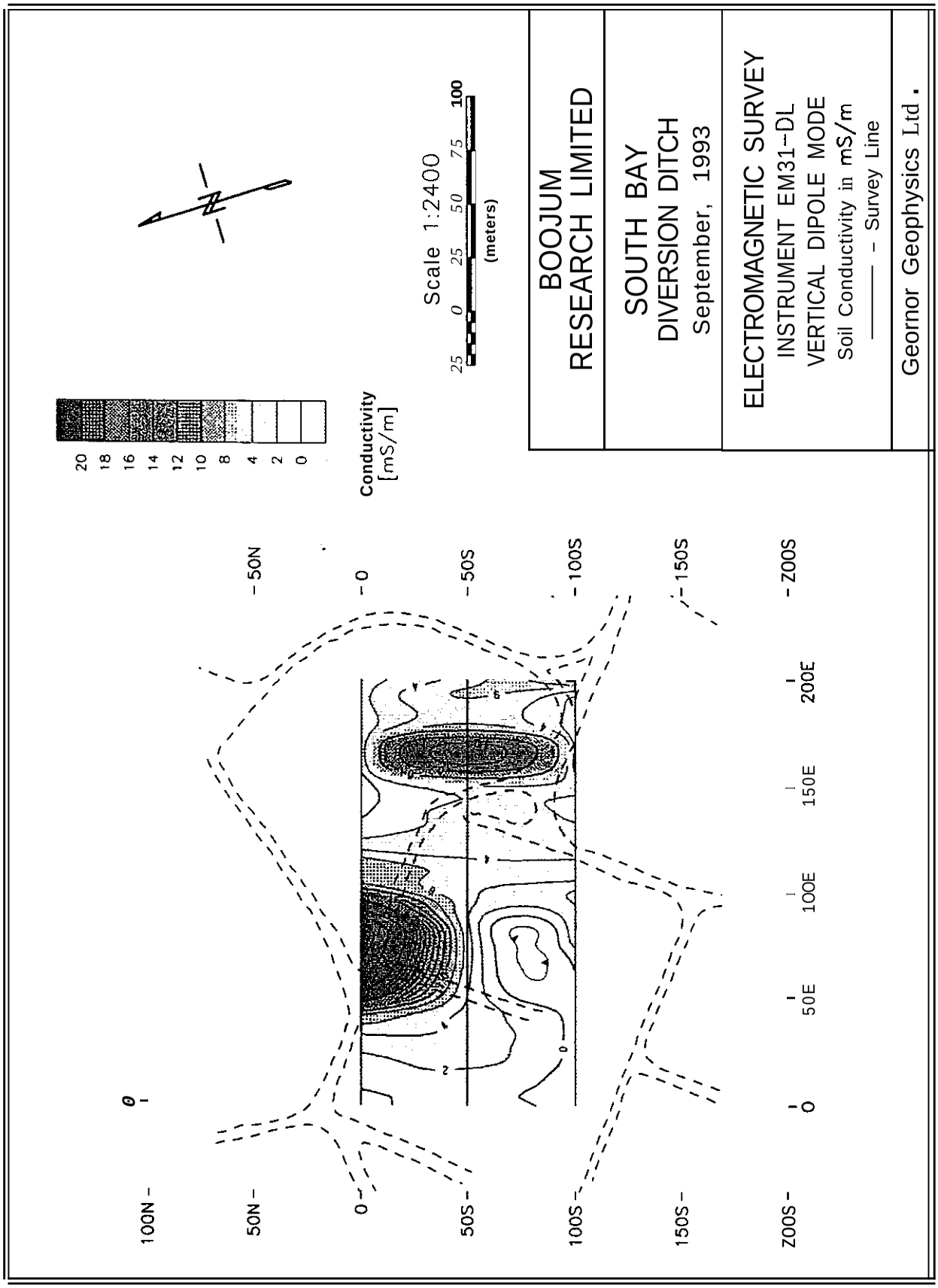
Map 4 Tailings Diversion Ditch, EM31 Survey Vertical Dipole Mode, March 1992.



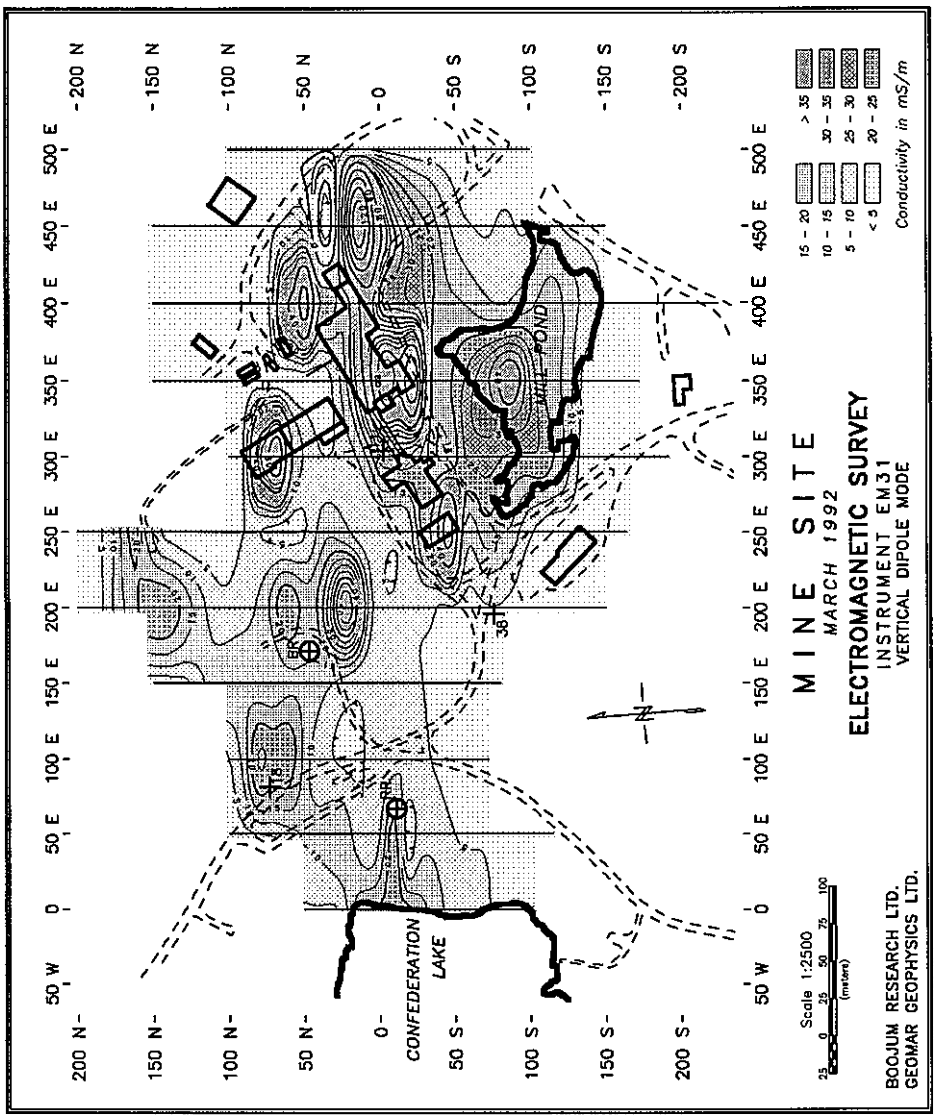
Map 5 Tailings Diversion Ditch, EM31 Survey Horizontal Dipole Mode, March 1992.



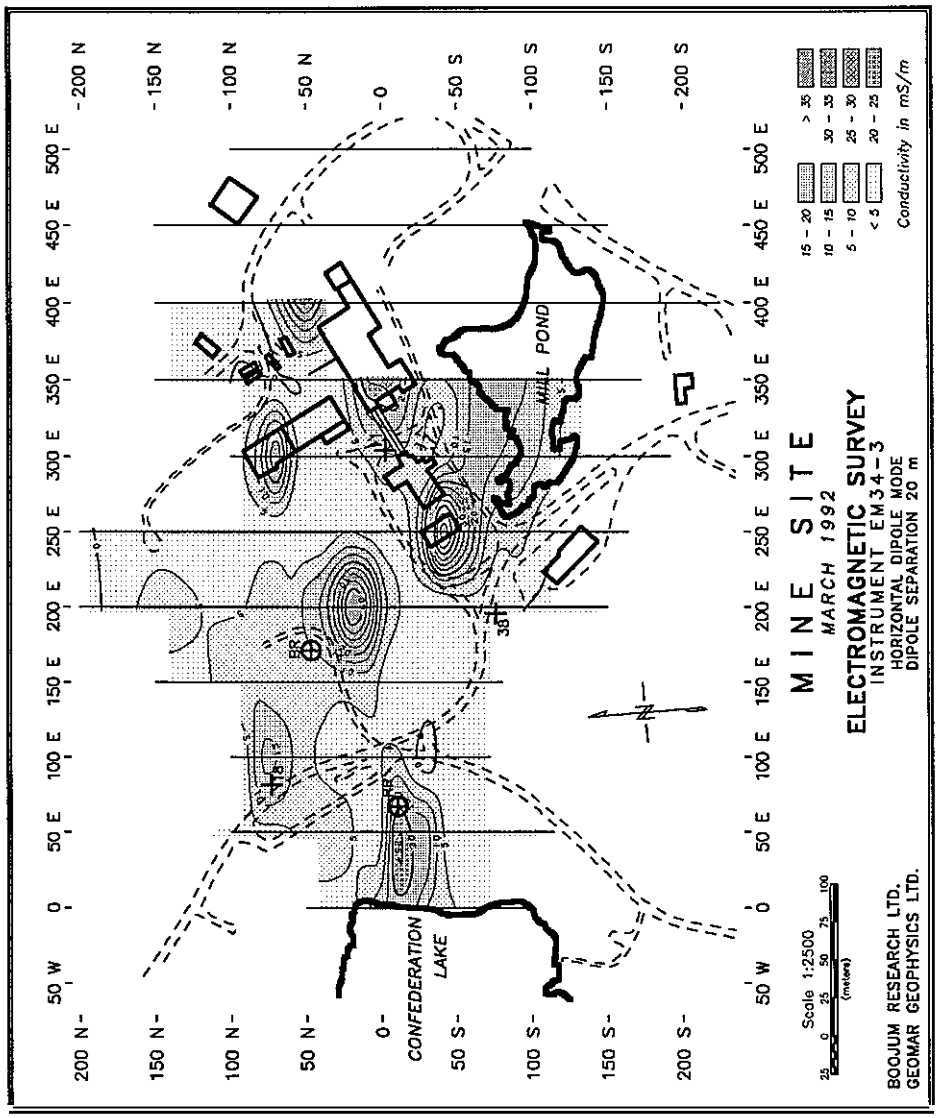
Map 6 Tailings Diversion Ditch, EM31 Survey Horizontal Dipole Mode, Sept 1993.



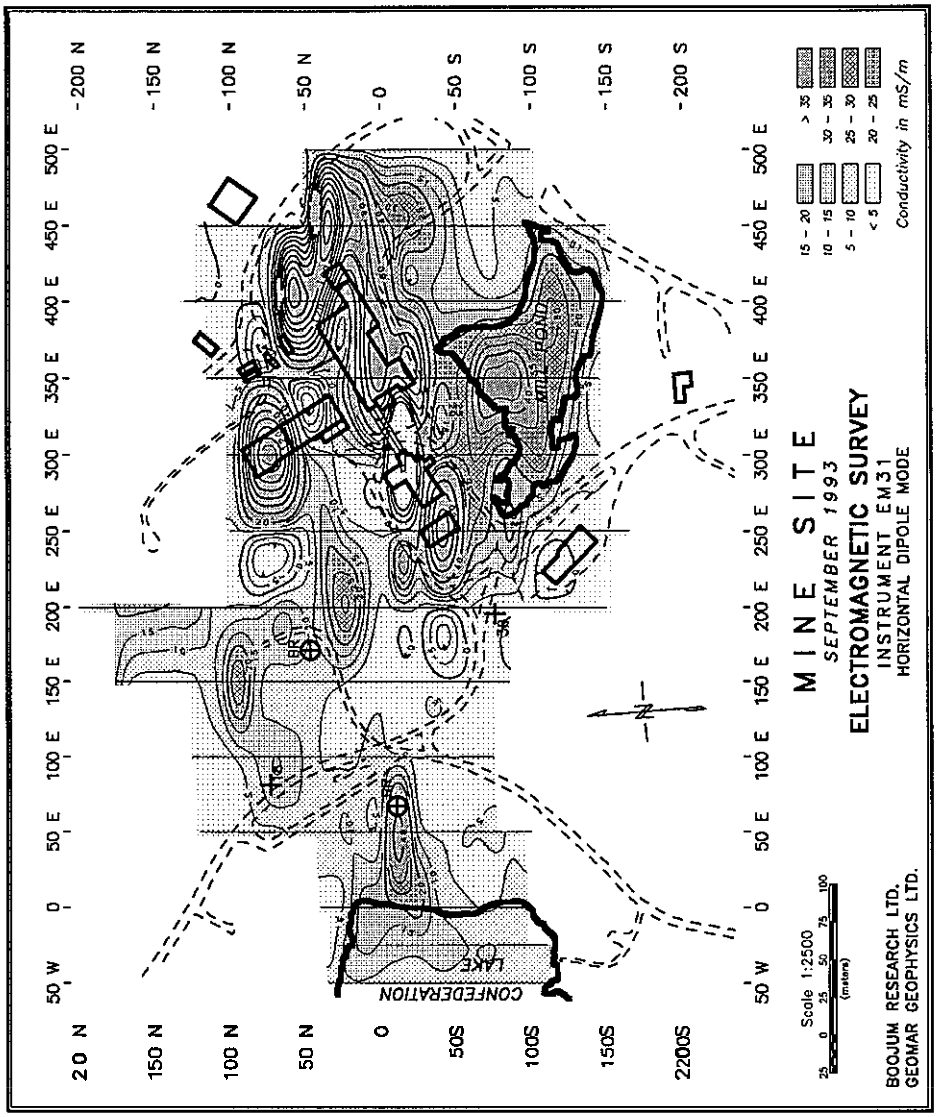
Map 7 Tailings Diversion Ditch, EM31 Survey, Vertical Dipole Mode, Sept 1993.



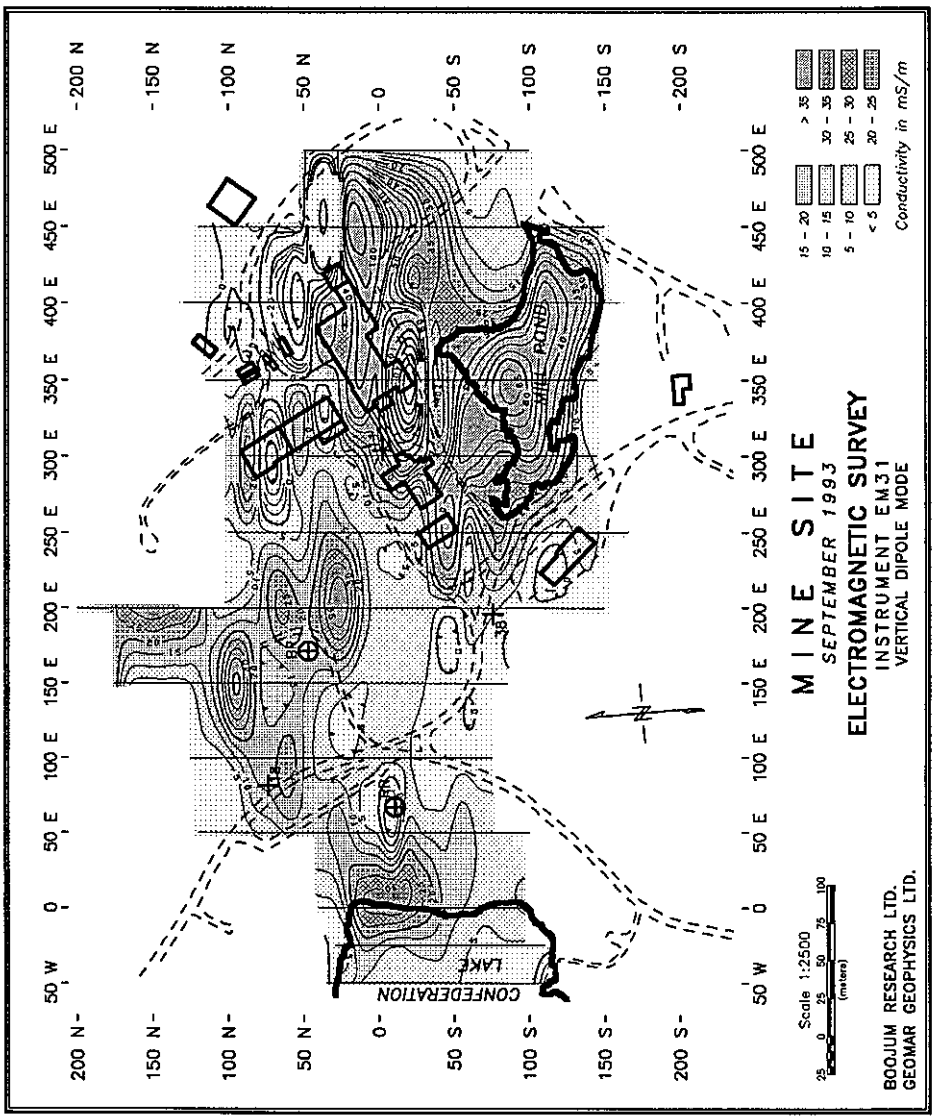
Map 8 Mine Site, EM31, Vertical Mode, March, 1992.



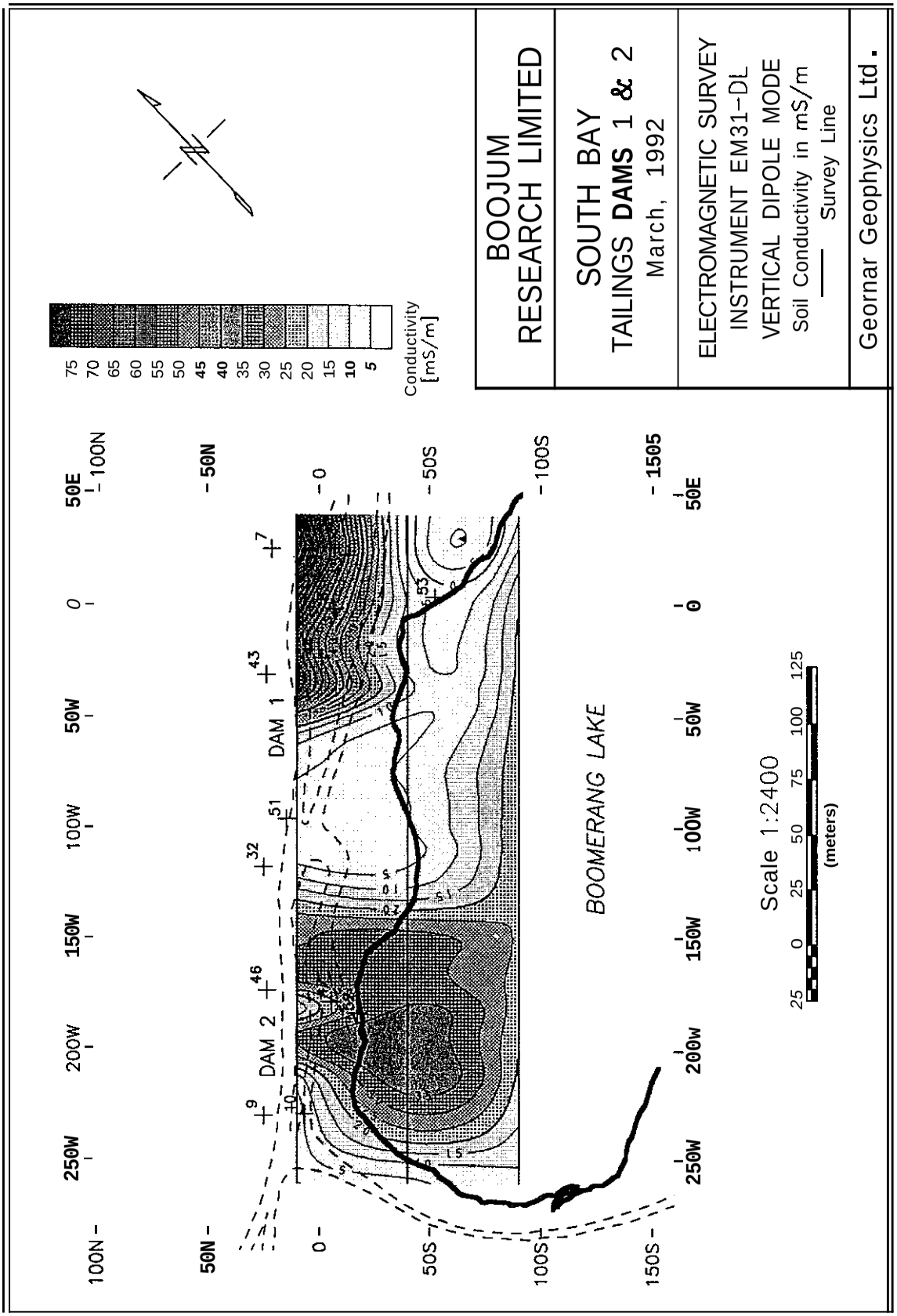
Map 9 Mine Site, EM34-3, Horizontal Mode, March, 1992.



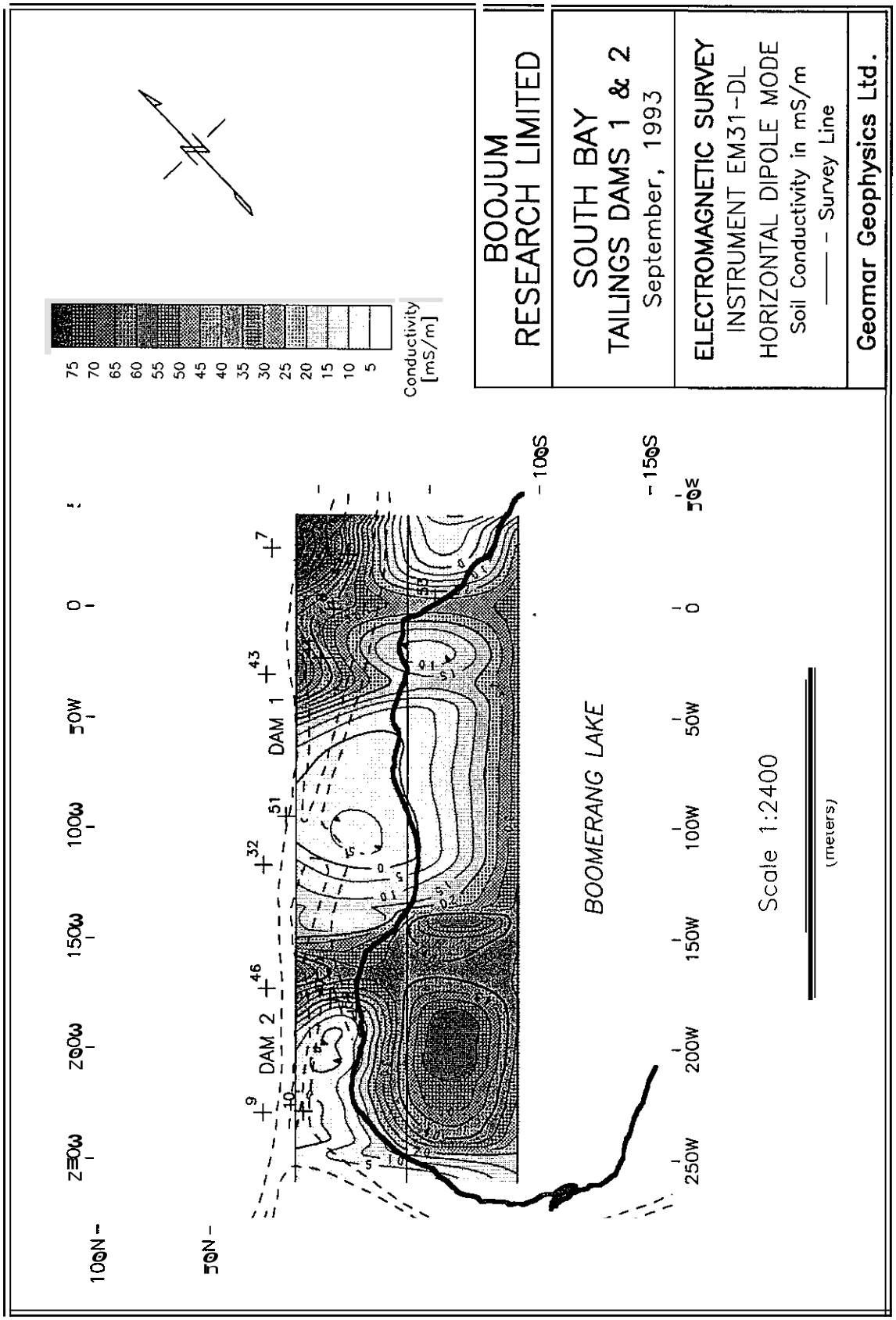
Map 10 Mine Site, EM31, Horizontal Mode, September 1993.



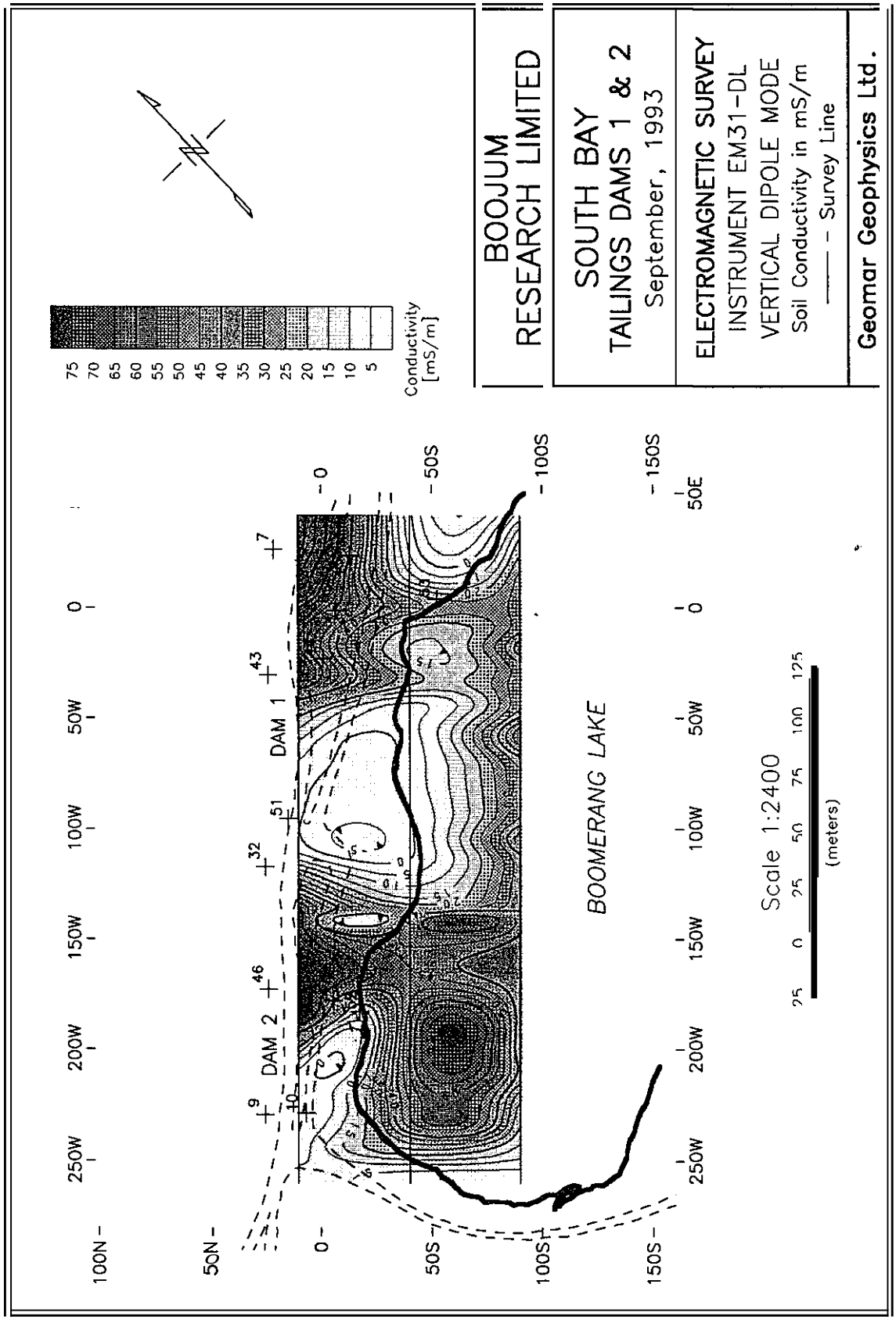
Map 11 Mine Site, EM31, Vertical Mode, September 1993.



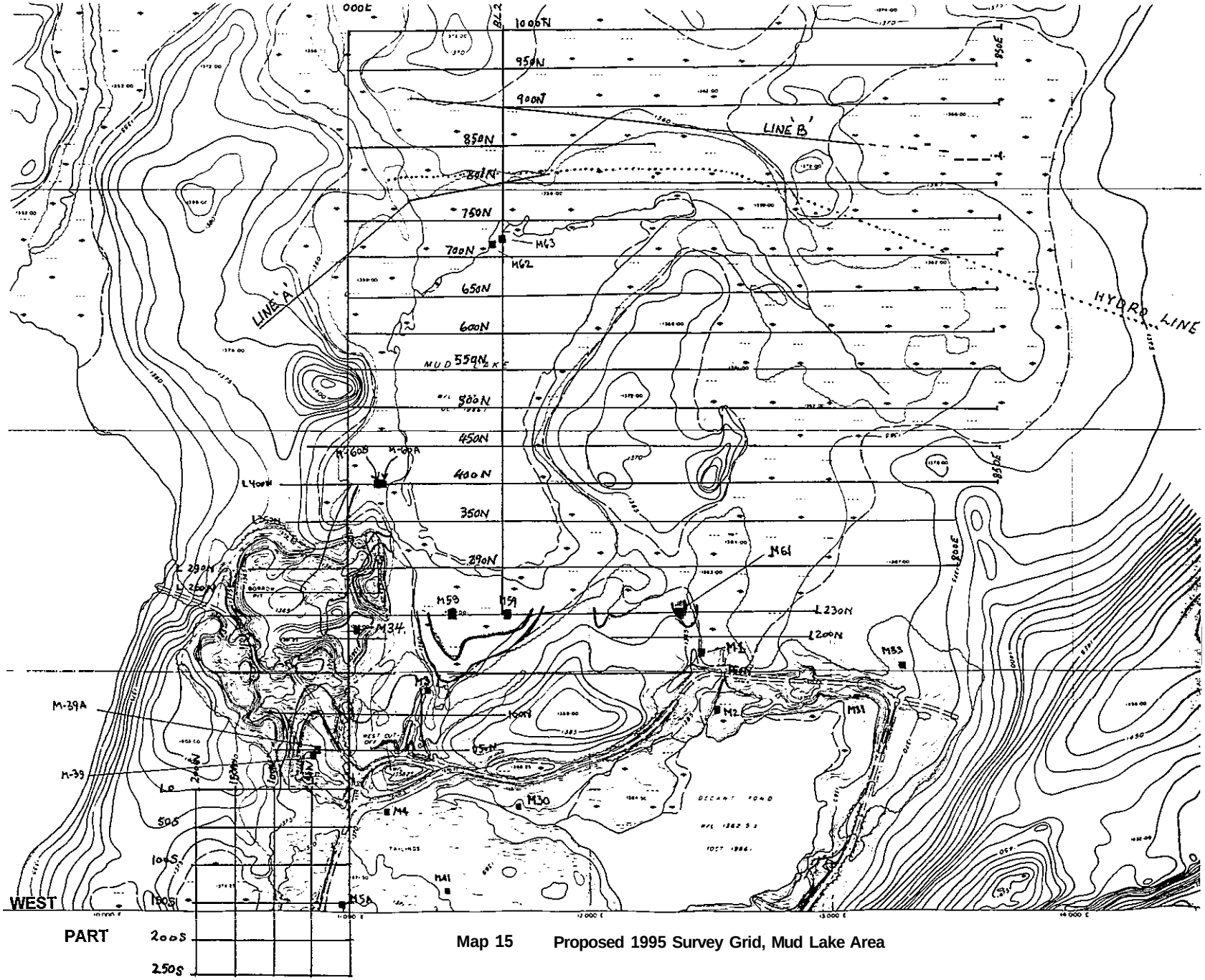
Map 12 Tailings Dams, EM31, Vertical Dipole Mode, March 1992.



Map 13 Tailings Dams, EM31, Horizontal Dipole Mode, September 1993.



Map 14 Tailings Dams, EM31, Vertical Dipole Mode, September 1993.



Map 15 Proposed 1995 Survey Grid, Mud Lake Area

NORTH PART

LINE	LENGTH (m)
1000N	850
950N	850
900N	600
850N	400
800N	850
750N	850
700N	850
650N	850
600N	850
550N	850
500N	850
450N	900
350N	800
290N	800
15 lines	12.000 m
+baseline	770 m
	12.77 km

WEST PART

LINE	LENGTH (m)
0	200
50S	200
100S	200
150S	200
200S	200
250S	200
BL	250
50W	250
100W	250
150W	250
200W	250
11 lines	2.45 km

4.2 Test Drilling and Piezometer Installations to Define the Bedrock Valley of The Seepage Path

Drilling should be conducted during late winter to ensure the least problems with mobilisation. Also, during late winter, sufficient daylight is available for an effective operation. The drilling rig should be capable of drilling into bedrock and should also have the capability to taking sediment cores in the unconsolidated sediments. Geophysical logs (Single Point Resistivity and SP and possibly Gamma Ray) should be run in the boreholes in order to obtain an independent and more detailed definition of the stratigraphy.

6.0 APPENDICES

Appendix 1 GEOMAR - EM SURVEY **COLOUR** MAPS A-2
Appendix 2 A. VONHOF DRILLING REPORT A-I0

GEOMAR Geophysics Ltd.
1585A Britannia Road East, Unit 7, Mississauga, Ontario, Canada L4W 2M4
Tel: (905) 564-3360
Fax: (905) 564-3393

August 17, 1994

Ms. Margarete Kalin
BOOJUM RESEARCH LIMITED
468 Queen St. East, Suite 400
Toronto
Ontario M5A 1T7

Dear Margarete,

Please find enclosed two sets of five maps and one drawing presenting results of a survey conducted in Mud Lake area in South Bay during July, 1994. Below I will describe shortly our findings.

EM34-3 Survey

The survey results are presented on 5 colour maps of soil conductivity and one drawing:

- Map 1 contains results of the survey conducted at 10 m coil separation (depth of investigation is approximately 0 to 7.5 m),
- Map 2 contains results of the survey conducted at 20 m coil separation (depth of investigation is approximately 0 to 15 m),
- Map 3 contains results of the survey conducted at 40 m coil separation (depth of investigation is approximately 0 to 30 m),
- Map 4 contains calculated results with reduced overburden response (depth of investigation approximately 6 to 15 m),
- Map 5 contains calculated results with reduced overburden response (depth of investigation approximately 12 to 30 m),
- Drawing presents modelled vertical geoelectric section along profile C (dotted line on maps).

The EM34-3 measurements show soil conductivity varying from 0 to over 10 mS/m in anomalous areas. The average low soil conductivity (0 to 3 mS/m) indicates presence of shallow bedrock and coarse grain sand. Elevated conductivity values may indicate presence of fine grain material and/or inorganic contamination of soil.

Several distinctive high conductivity areas (3 to 10 mS/m) can be observed on Maps 1 to 3.

The most substantial anomalous zone extended in S-N direction can be observed in the gravel pit area (approximately between 50N, 50W and 400N, 30E). The EM34-3 response along this zone is higher at 20 m coil spacing (Map 2 and 4) than at 10 m coil spacing (Map 1). Then measured conductivity is lower at deeper measurements at 40 m coil spacing (Map 3 and 5). This indicates that a layer of more conductive soil is located below the surface. It should be

noted that at the northern end of the anomaly, in swamp area, near surface conductive material can be observed (Maps 1 and 2). Five soundings (using 6 possible configurations of EM34-3) were performed in this area along profile C (dotted line on conductivity maps). Sounding data was used for modelling of subsurface layers using inversion method and the result is presented on the enclosed drawing. It shows two (top and bottom) layers of low conductivity and one layer of relatively high conductivity. The top layer can be associated with gravel material, the bottom may indicate bedrock, and the intermediate layer (approximately 3 m thick and 7 to 12 m deep below the surface) appears to represent contaminated material. It should be noted that conductivity in the conductive layer appears to be lower at the northern end of the section. The depth was calculated in relation to the surface level, and therefore the drawn section is not corrected for the terrain topography.

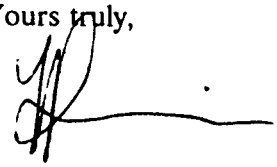
High conductivity zone located at the South end of Mud Lake (130 to 210E, and 150 to 230N) appears to indicate presence of shallow conductive material. This can be observed on Maps 1, 2, and 3. Since this anomaly is located in swampy area, it is possible that elevated conductivity is caused by very fine grain material and high contents of moisture in the soil. However inorganic contamination may be present in this area as well. Further analytical investigation would reveal real nature of soil in this zone.

There are two smaller high conductivity zones located at (350E, 200 to 230N) and (450E, 150 to 230N). These anomalies are located in swamp area and their nature appears to be similar to the anomaly described above.

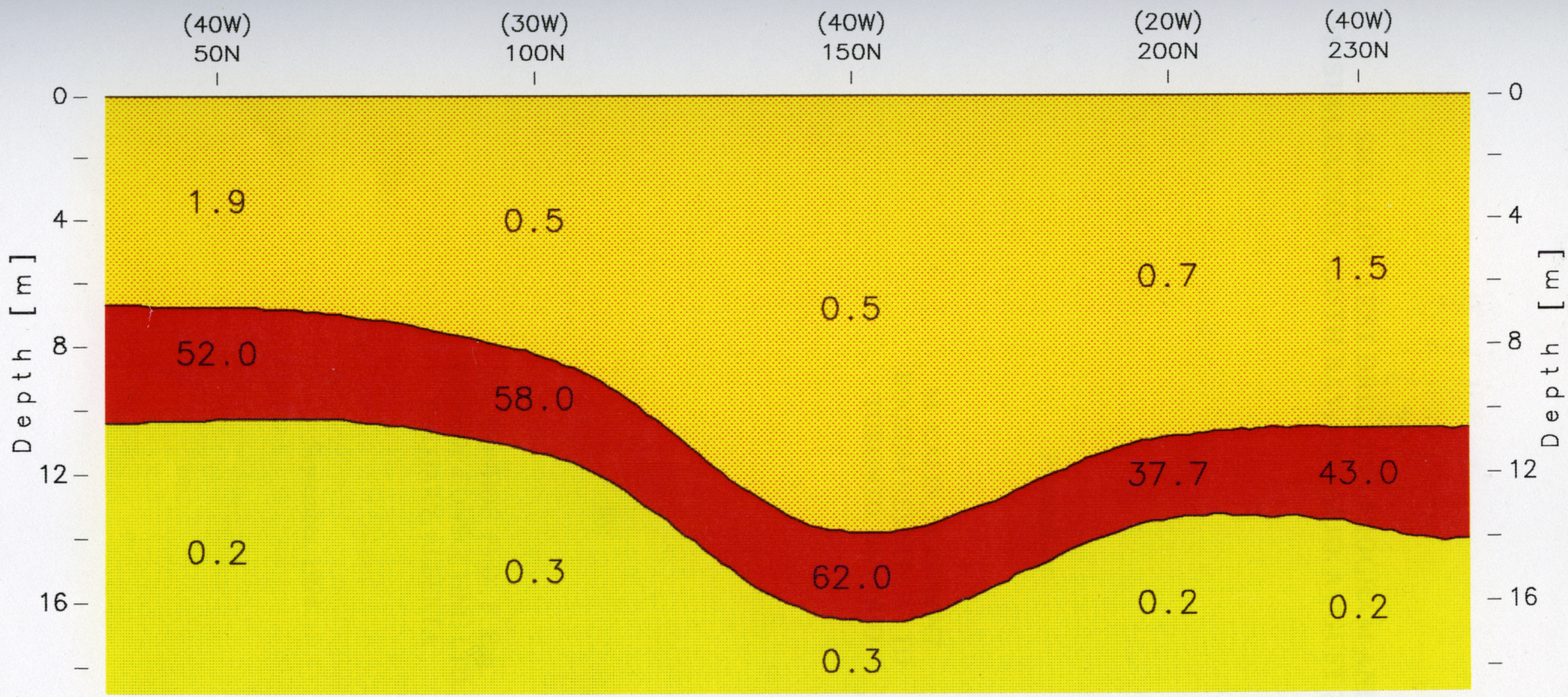
Four lines (AWest, AEast, BWest, and BEast) were surveyed North of Mud Lake. Higher readings can be observed along lines A in the area adjacent to a creek and in the swamp East of the creek. High conductivity zone at the East end of line AEast can be originated by a noise from nearby power line. Maps 1, 2, and 3 indicate shallow nature of conductive material in this area, and therefore elevated conductivity may be originated by fine grain (swamp) material and high contents of moisture at this location. However presence of inorganic contamination is still possible and further analytical sampling would be necessary to reveal its potential level.

In conclusion, the survey between tailing areas and Mud Lake revealed potential deeper (approximately 7 to 14 m below the surface) contaminant flow under gravel layer along the channel like area (50W, 50N) to (50E, 300-400N). Possible near surface contaminant transport to Mud Lake may occur in the area (50-90E, 50N) to swamp area (140E, 150-230N), and between (450E, 150N) to (440W, 230N). Geophysicaly detectable evidence of any flow from tailings area to Confederation Lake was not observed.

Yours truly,



Jerzy Pawlowski, M.Sc.
Geomar Geophysics Ltd.



TALISMAN ENERGY INC.

SOUTH BAY
MUD LAKE AREA

A6 CALCULATED VERTICAL GEOELECTRIC SECTION

Based on EM34-3 Soundings Along Profile C
Topography Correction Not Included

Soil Conductivity in mS/m

Plotted by Geomar Geophysics Ltd.

BOOJUM RESEARCH LIMITED

SHALLOW TEST DRILLING PROGRAM AND PIEZOMETER INSTALLATION, SOUTH BAY, ONTARIO, AUGUST 27- SEPTEMBER 3, 1994.

Prepared for:

M. KALIN, PRESIDENT
BOOJUM RESEARCH LTD
TORONTO, ONTARIO

By:

J.A. VONHOF, Ph.D., P. Eng.
VONHOF CONSULTING LTD
CALGARY, ALBERTA

September, 1994

TABLE OF CONTENTS

	page
SYNOPSIS	3
Introduction	4
Drilling Equipment and Method	4
Chronology of Drilling	5
Results of the Test Drilling and Piezometer Installation	10
Bedrock Topography and Stratigraphy	14
Hydraulic Conductivity	14
Water Level Measurements	15
SUMMARY	17
References	19
Appendix A: Construction details of piezometers	20
Appendix B: Stratigraphy of Testholes	21
Appendix C: Slugtest Data	26
FIGURES	28

SYNOPSIS

The results of the test drilling program and piezometer installation show that:

The bedrock surface under the southern part of Mud Lake is overlain, in ascending order, by sand and gravel deposits, silt and clay beds, and gyttja and muskeg deposits. Near the northwestern corner of the tailings area, the entire section, to a depth of 15.2 m., is composed of sand and gravel.

The unconsolidated sediments overly an irregular bedrock surface characterized by topographic depressions and bedrock high's.

A small buried valley appears to be present in the western part of the area under investigation. This valley emerges from the northwestern part of the tailings area and trends towards the southwestern part of Mud Lake.

The hydraulic conductivity of the sediments in which the piezometers are completed varies from $0.07 - 9.3 \times 10^{-2}$ cm/sec. The highest hydraulic conductivities were found in the sediments present in the deeper part of the buried valley (M39A & M60A).

Mud Lake is located in a groundwater discharge area with considerable upward flow gradients.

The horizontal gradient along the buried valley from M39A to M60A is 0.012 and relatively high.

Based on field measurements conducted on water samples collected from the newly installed piezometers it appears that contaminated groundwater is present at M39A, M60A and M62.

The geophysical anomalies are in part caused by the stratigraphy, i.e. the presence of relatively thick conductive clay beds in the section of unconsolidated sediments overlying the bedrock or by the presence of highly conductive (contaminated) groundwater within the unconsolidated sediments.

Introduction.

A geophysical survey (EM) conducted in South Bay during June/July 1994 in part of the area between the tailings deposits and the south end of Mud Lake showed a number of significant anomalies (Berezowsky, Sept. 8, 1994). The presence of these anomalies and the discovery of contaminated groundwater discharging into the northern part of Mud Lake warranted further investigation of the hydrogeological environment in this area.

A small drilling program was, therefore, initiated with the following objectives:

- To "ground truth" the geophysical anomalies.
- To obtain stratigraphic information on the sediments overlying the Pre-Cambrian bedrock surface.
- Install piezometers to obtain groundwater samples for chemical analysis and information on the hydraulic head distribution in the surficial sediments.

Drilling Equipment and Method.

The presence of significant areas with muskeg in the area of investigation and the time of the year during which the drilling was to be conducted, severely limited the choice of the drilling equipment.

A small "muskeg" rig, mounted on a widetrack Bombadier, was chosen by Boojum Research Ltd for this job and the rig was supplied by Kenora Soils and Drilling Ltd. from Kenora, Ontario. According to telephone conversations with the owner/operator, the equipment was capable of driving casing, rotary and diamond drilling, and splitspoon and shelby tube sampling and had been used on similar projects elsewhere. In addition, it was apparently the only equipment of this type present within a reasonable distance from South Bay. However, the drilling equipment was <u>not</u> inspected prior to the start of the job.

The general procedure of drilling the testholes and installing the piezometers was discussed with the driller and as follows:

5 ft (1.5 m) long sections of casing with an ID of 3 inches (7.5 cm) were to be driven into the ground using a 350 lb. (158 kg) hammer. The first section of casing was equipped with a 3 inches (7.5 cm) long hardened drive shoe.

After a section of casing had been driven into the ground, any sediment, which had accumulated inside the casing, was washed out using a plastic hose, an auxiliary pump and low conductivity water. Sediment samples were to be recovered during this procedure.

A splitspoon sampler, 30 inches (76 cm) long was then used to obtain sediment samples beyond the drive shoe of the casing, prior to driving the next section of casing.

If permeable saturated sediments were encountered, the casing could be pumped out (repeatedly, if necessary) and the conductivity of the recovered water measured.

If blockage of the drive shoe occurred and/or the penetration rate during driving of the casing became to slow due to coarse gravel or small boulders, an insert bit, with a diameter of 2 7/8 inches (7.3 cm), mounted at the end of drill rods could be used to drill out the casing and drill up the coarse rock fragments ahead of the casing.

Once refusal during the driving of the casing occurred, a diamond bit and core barrel could be used to confirm if refusal was the result of encountered bedrock or boulders.

Once bedrock was confirmed, a piezometer would be installed inside the casing. 10 feet (3.05 m) long sections of threaded, smooth jointed, Schedule 40 PVC pipe with a diameter of 2 inches (5.08 cm) would be used for the piezometer. Each piezometer has a 5 feet (1.52 m) long slotted section at the bottom with a glued-on end cap. The slot size opening would be 0.010 inches (0.254 mm). Once the piezometer was lowered to the bottom of the casing, the casing was hammered upward and out of the ground. The "plunger" action of the upward moving casing and the vibration of the hammering would ensure that the unconsolidated sediment would collapse around the slotted pipe section. This procedure would be continued until the drive shoe of the casing was at least 30 cm above the top of the slotted section. At this point bentonite pellets with a diameter of 6.3 mm would be placed in the annulus for a sufficient length to ensure that the slotted section was isolated from the rest of the hole. Subsequently, all the casing would be hammered out of the hole. The annulus at surface would then be backfilled with bentonite chips, powder or pellets.

Development of the piezometer would be achieved by pumping and air lifting. After development was complete, water samples for chemical analysis would be taken.

Chronology of Drilling.

August 27

10:00 Driller arrived with equipment, unload and rig up (M39A).

11:15 Start driving casing to 10 feet.

12:00 Lunch

12:30 Get load of water from Confederation Lake. Rig up water pump and hoses, wash out casing (no sample). Tried to take splitspoon sample, unsuccessful, rock on bottom, jammed drive shoe. Decide to pull casing. Move over 1 meter.

13:30 Restart driving casing from surface. Tried to take splitspoon sample @ 2.5 ft. No success (sediment too coarse grained). Hammer casing to 5 ft. Wash out casing

and drive shoe. Could not wash out shoe. Drive casing to 10 ft. Wash out casing and drive shoe. No success. Rig up to rotary drill. Drill drive shoe and short distance below. Sand locked bit and 3" casing rotating. Worked bit free. Trip out and drive casing to 15 ft.

15:00 Tried washing out casing. Washout hose hit refusal @ 10 ft. Suspect casing unscrewed. Tighten casing and pull casing. Recovered 10 ft of casing. Left bottom joint and drive shoe.

15:45 Move rig and start again. Drive casing 10 ft, wash out casing. Drive to 15 ft. Wash out casing, ran out of water. Get load of water. Make up diamond bit to clean out casing.

18:00 Shut down and drive back to lodge.

August 28

08:00 Start operation, wash out casing. Tried to take splitspoon sample, no success. Drive casing to 20 ft, wash out casing, tried to take splitspoon sample, no success (sediment too coarse).

09:30 Drive to 25 ft. Rig up diamond bit and drill out shoe, hit boulder. drill through and worked hole.

10:15 Drive to 30 ft., problems breaking off driving head. Wash out casing, and went for load of water.

11:15 Rig up to diamond bit, drill ahead 5 ft. Trip out diamond bit.

12:30 Drive casing to 40 ft and wash out casing.

13:00 Lunch.

13:30 Rig up diamond bit, drill ahead to 45 ft, rig out diamond bit.

14:15 Start driving casing to 45 ft. Get load of water.

15:30 Rig up diamond bit and drill ahead to 50 ft. Trip out with diamond bit.

16:40 Drive casing to 50 ft. Rig up wash pipe and run in hole, rotate and circulate.

17:30 Shut down and drive back to lodge.

August 29.

08:15 Get load of water. Bail casing to get water sample. Discover at least one leak in casing at 15 ft during bailing. (highly variable conductivity, see Figure 1). Decide to pull casing.

11:30 Run in with bit to clean shoe. Drill 1 ft below drive shoe, still in fine gravel. While drilling, casing rotated 6 inches out of ground. (NOTE: No drill rod centralizer for top of casing present on site. No possibility to adjust rotary head to angle of casing. As a result very high vibration in casing during high rpm drilling. Suspect that casing vibrated loose at joints). Pull out of hole with rods and bit. Decided to pull one length of casing to determine integrity of casing string in hole. Everything appeared OK.

13:00 Lunch

13:30 Decided to attempt to install piezometer at this depth. Discovered that driller did not have bentonite pellets on job (although specified !), but only 1/2 - 3/4 inch poor quality bentonite chips. Started breaking up chips. Occasional rain. Excersise in futility and stopped. Decide to rely on collapse of unconsolidated sediment during pulling out of the casing to provide seal in the annulus.

14:00 Make up slotted pipe and end cap, and lower piezometer pipe in casing. Hammer casing out of hole and discovered that bottom joint and drive shoe were left in hole. NOTE: all casing joints were loose.

15:45 Start bailing and pumping. Very fast recovery of water level. Piezometer cleaned up rapidly. Initial conductivity of water 2000 μmhos/cm which increased to 3280 @ 9 °C.

16:00 Rig out and move rig to new location in muskeg (M58).

18:00 Shut down and drive back to lodge.

August 30

08:30 Rig up.

09:00 Start driving casing. Almost free fall to 10 ft. took water sample. Drive to 15 ft, wash out casing, take splitspoon sample. Drive to 25 ft, wash out casing, take splitspoon sample. Drive to 40 ft, washing out casing after each length and collect sediment samples.

12:00 Lunch.

12:30 Pump casing and measure conductivity. Start driving casing to 45 ft, hit refusal at 43.5 ft. (Hammer bouncing on top of casing). Could not drill ahead, top casing to high with respect to rotary head (no adjustment possible !).

13:45 Install piezometer, hammer out casing, bail and pump piezometer, and take water sample.

15:30 Rig down and move rig to new location (M59).

17:00 Start driving casing, wash out casing, collect samples, take splitspoon samples to a depth of 15 ft.

18:15 Shut down and drive back to lodge.

August 31

08:30 Drive casing to 20 ft, wash out casing, collect samples, take splitspoon sample. Pump out casing and take water sample.

09:15 Start driving casing to 25 ft., hit refusal @ 24 ft. Wash out casing.

10:00 Rig up to and start coring. Core barrel jammed (no water). Appears inner barrel too long or lost landing ring (No replacement parts on site !). Drill/core without inner barrel.

11:30 Screw in rotary head broke (fatal breakdown, no replacement parts, further rotating during rest of drilling program impossible).

12:30 Recover core barrel. Install piezometer. After installation, piezometer flowing. Hammer casing out of hole.

13:00 Lunch.

13:30 Start pumping and developing piezometer. pumping steady @ 8 l/min., take water sample.

14:15 Rig down and move rig to new location (M60A).

15:00 Rig up, start driving casing, wash out casing, collect sediment samples, take splitspoon samples, reached a depth of 35 ft.

18:00 Shut down and drive back to lodge.

September 1

08:00 Hole flowing, measure water conductivity (362 µmhos/cm, 8 °C). Drive casing to 40 ft., tried washing out casing, only partial successful. Drive next 5 ft to 45 ft deep. Wash out casing, sediment jammed in core barrel, 2.5 ft of fill left. Tried lowering water level to induce flow into casing and break up jammed sediment, hand rotate drill rods.

10:30 Put different wash head on rods and start cleaning to bottom, use 140 lb. hammer to break up sediment in casing. Only partially successful, start driving casing down. Pull out of hole, lay down wash down tools.

11:00 Drive casing to 50 ft, wash out casing. Start driving casing to 55 ft.

12:00 Lunch.

12:30 Finish driving casing to 55 ft (FINAL DEPTH. no more sections of casing left on site).

13:00 Wash out casing and drive shoe and prepare for piezometer installation.

14:00 Install piezometer, recover casing, and develop and pump piezometer at 25 l/min. with only 5 cm of drawdown. Take water sample.

15:30 Move rig 15 ft west (M60B). Drive casing to 29.5 ft. Install piezometer, recover casing, develop and pump piezometer.

18:00 Shut down for the day and drive back to lodge.

September 2

08:00 Pump piezometer, take water sample.

09:15 Rig down and move to M61.

10:15 Start driving to 15 ft, wash out casing, collect samples, take split spoon sample.

11:30 Start driving to 20 ft, hit refusal @ 16.5 ft. Clean out casing and install piezometer, recover casing, start pumping.

12:45 Lunch.

13:15 Take water sample. Rig down and drive to staging area. Demobilize.

It is apparent from the foregoing that, contrary to the assurances of the drilling company prior to the commencement of the job, the equipment had a number of inadequacies which affected the flexibility of the actual drilling operation. In addition, mechanical breakdown and lack of replacement parts during the drilling operation placed further and progressively greater limitations on the collection of subsurface data. Consequently, there are a number of uncertainties in the data base inherent to the drilling operation. These are:

1. Poor stratigraphic control and
2. Definition of the bedrock surface.

ad. 1: The lack of stratigraphic control is the result of poor sample recovery while driving casing. Splitspoon sampling, on the other hand, generally provided good sample recovery if the sediment was finer than medium grained. However, due to the constraints of the drilling equipment, splitspoon samples could only be taken when the casing was low to the ground.

ad. 2: M39A. The loss of integrity of the casing string during drilling prevented further deepening of this hole and consequently the position of the bedrock surface was not determined.

M58. When refusal was hit during driving of the casing, the position of the top of the casing with respect to the rotary head on the rig made it impossible to switch to diamond drilling and confirmation of the presence of the bedrock surface by diamond drilling and coring was therefore not possible.

M59. After refusal was hit during driving of the casing, the "fatal" breakdown of the feed screw in the rotary head made it impossible to conduct any type of rotary drilling operation in this hole or any of the subsequent holes to confirm if refusal during the driving of the casing was caused by the bedrock surface or boulders.

M60. This hole was terminated at a depth of 16.8 m. (55'), because the driller ran out of useable casing for driving.

Notwithstanding the above, the widetrack mounted drilling equipment did allow for access in muskeg areas, which otherwise would not have been possible at this time of the year. As a result, significant information for the "ground truthing" of the geophysical anomalies present in these areas was obtained.

Results of the Test Drilling and Piezometer Installation.

The six boreholes drilled in the area between the tailing deposits and the southern part of Mud Lake tested portions of three EM 34 anomalies. The location of the actual borehole was focused on peaks within broader conductivity trends (Figs. 2 and 3).
Piezometers were installed in all the boreholes. The screened interval was placed in the deepest part of the borehole, immediately above the zone of refusal encountered during

drilling or the greatest depth reached during drilling (See Appendix. A for completion details).

M 39A

The borehole at this location tested an EM 34 anomaly with a conductivity peak of 7 μ S/m at 20 m. coil separation. The borehole was terminated at a depth of 15.2 m. The stratigraphy shows the presence of sand and gravel from surface to total depth. The hole did not reach bedrock. A piezometer was installed in this borehole and the screen was placed from 12.1 - 13.5 m below ground surface.
Field measurements on a water sample obtained from this piezometer showed the following results:

pH: 5.65 units
Eh: -115 mv
Conductivity: 3280 μS/cm @ 9 ^{0}C (4750 μS/cm @ 25 ^{0}C)

The source of the EM 34 anomaly is attributed to the high conductivity in the groundwater. which in turn represents, in all likelihood, contaminated groundwater derived from the mine tailings, located less than 100 m. to the southeast.

M 58

The borehole, drilled to a depth of 13.3 m, tested an EM 34 anomaly with peak readings of approximately 10 μS/m at 10 m coil separation and 7 μS/m at 20 m. coil separation. The stratigraphy of this borehole shows the presence of muskeg and gyttja to a depth of 4.3 m., soft, plastic grey clay (varved and silty in part) from 4. 3 m to a depth of 8.2 m, and sand and gravel from 8.2 m to 13.3 m. A piezometer was installed in this borehole and the screen was placed from 11.6 - 13.0 m below ground surface.
Field measurements on a water sample obtained from this piezometer showed the following results:

pH: 6.36 units
Eh: + 11 mv
Conductivity: 133 μS/cm @ 6 ^{0}C (177 μS/cm @ 25 ^{0}C)

If the refusal encountered during drilling at a depth of 13.3 m represents bedrock than the EM 34 anomaly may be entirely due to the presence of the relatively thick conductive clays. However, if the hole did not reach bedrock, than the possibility of high conductivity water in the lower portion of the aquifer still exists and the anomaly would be the result of the combined effect of conductive clays and water of high conductivity.

M 59

This borehole is located approximately 75 m. east of M 58 and it was drilled in a second anomaly peak within the same broad anomalous zone tested by M 58. The hole was drilled to a depth of 7.3 m at which point refusal was encountered. The stratigraphy of this borehole shows the presence of muskeg and gyttja to a depth of 3.4 m., soft, plastic grey clay (varved and silty in part) from 3.4 m to a depth of 5.8 m, and sand and gravel from 5.8 m to 7.3 m. A piezometer was installed in this borehole and the screen was placed from 5.8 - 7.3 m below ground surface.
Field measurements on a water sample obtained from this piezometer showed the following results:

pH: 6.50 units
Eh: - 32 mv
Conductivity: 440 µS/cm @ 6 ^{0}C (690 µS/cm @ 25 ^{0}C)

The source of the anomaly is most likely the conductive clays. However, if the refusal does not represent the bedrock surface, than, as pointed out above for M 58, a conductive aquifer at greater depth remains a possibility.

M 60A

The borehole at this location, drilled to a depth of 16.4 m., tested the north end of the N-S trending anomaly previously tested by borehole M 39A. The stratigraphy of this borehole shows the presence of muskeg and gyttja to a depth of 3.5 m., soft, plastic grey clay (varved and silty in part) from 3.5 m - 7.0 m, and sand and gravel from 7.0 m to 16.6 m. A piezometer was installed in this borehole and the screen was placed from 14.9 - 16.4 m below ground surface.
Field measurements on a water sample obtained from this piezometer showed the following results:

pH: 5.79 units
Eh: - 71 mv
Conductivity: 2410 µS/cm @ 6.5 ^{0}C (3733 µS/cm @ 25 ^{0}C)

Although bedrock was not reached in this borehole, high conductivity groundwater was encountered. The source of the EM 34 anomaly can, in all likelihood, be attributed in part to the conductive clays and in part to this high conductive groundwater.

M 60B

This borehole, drilled to a depth of 8.5 m, is located 5 m. west of borehole M 60A and a piezometer was installed to test the water in the upper part of the aquifer initially encountered in M 60A.

Field measurements on a water sample obtained from this piezometer showed the following results:

pH: 6.26 units
Eh: - 60 mv
Conductivity: 365 µS/cm @ 8.0 ^{0}C (543 µS/cm @ 25 ^{0}C)

The results for the water in the upper part of the aquifer show a significantly lower conductivity than in the deeper part of the aquifer (M 60A).

M 61

The borehole at this locality tested an EM 34 anomaly that is the weakest of those tested. Peaks were 5-6 µS/m at 10 m. coil separation, and 4-5 µS/m at 20 m. coil separation. The N-S trending anomaly lies directly north of Decant Pond. The hole reached bedrock at a depth of 4.7 m. The stratigraphy of this borehole shows the presence of muskeg and very clayey gyttja to a depth of 2.1 m., soft, plastic grey clay (silty in part) from 2.1 m - 3.2 m, and sand from 3.2 m - 4.7 m. A piezometer was installed in this borehole and the screen was placed from 3.0 - 4.5 m below ground surface.
Field measurements on a water sample obtained from this piezometer showed the following results:

pH: 6.37 units
Eh: - 59 mv
Conductivity: 365 µS/cm @ 8.0 ^{0}C (543 µS/cm @ 25 ^{0}C)

The source of the weak EM 34 anomaly appears to be the conductive clay.

In addition to the six piezometers installed in the boreholes, two additional piezometers, M 62 and M 63, were emplaced by hand into so-called "Black Holes" at the north end of Mud Lake. Previous work in this area suggested that the "Black Holes" are discharge points of contaminated groundwater into Mud Lake (M. Berezowsky, memo July 18, 1994).

M 62 was inserted to a depth of 2.2 m. The screened portion is at a depth of 1.6 - 2,1 m. below lake level. After installation the piezometer was bailed and allowed to recover overnight.
Field measurements on a water sample obtained from this piezometer the next day showed the following results:

pH: 5.85 units
Eh: - 52 mv
Conductivity: 3160 µS/cm @ 6.5 ^{0}C (4895 µS/cm @ 25 ^{0}C)

The conductivity of the groundwater entering this piezometer is considerably higher than the 850 µS/cm (@ 25 ^{0}C) of the bulk of the water of Mud Lake. In addition, the magnitude of the conductivity of the groundwater in this piezometer falls within the same range as measured in M 39A and M 60A. Furthermore, the waterlevel in this piezometer is 6.5 cm above lake level, which indicates that upward groundwater flow conditions do exist at this locality. It is therefore reasonable to assume that the "Black Holes" represent conduits for the discharge of contaminated groundwater into Mud Lake.

M 63

Piezometer M 63, located about 10 m. northeast of M 62, also was inserted in a "Black Hole", but at a greater depth (3.0 m.) than M 62. This piezometer was also bailed after installation. However, 24 hours after bailing the waterlevel in the piezometer had not recovered. It is suspected that the screened interval (2.4-2.9 m below lake level) was probably plugged during installation or that the screened interval was placed in very clayey sediments. As a result, no water sample was taken for chemical analysis.

Bedrock Topography and Stratigraphy.

The stratigraphy of the testholes (Appendix B) shows that the bedrock surface is overlain, in ascending order, by a fining upward sequence of sand and gravel deposits, varved silt and clay beds, gyttja deposits and muskeg at surface, except for testhole M39A. This testhole shows the presence of sand and gravel over its entire length.

Based on the location of outcrops, the information obtained from the testholes and the results of the EM surveys the following tentative conclusions can be drawn with respect to the bedrock surface:

- The area between the southern part of Mud Lake and the tailing dam shows a number of north-south trending depressions flanked by bedrock high's (Fig. 4 , A,B & C).
- Depression A appears to be the deepest and is most likely part of a small bedrock valley. This valley appears to emerge from the tailings area near piezometer nest M5A/B.
- Depression A appears to be in part separated from Depression B by a subsurface bedrock ridge. The northern extent of this ridge is not known.
- Depression B is separated from Depression C by a bedrock high in the vicinity of the tailings dam, whereas towards Mud Lake the depressions seem to merge.

Hydraulic Conductivity.

Hydrodynamic response tests were conducted on all piezometers to determine the hydraulic conductivity of the sediment in the completion zone, except M 63. The waterlevel in the piezometers was raised (or lowered) by the sudden addition (or removal) of a known volume and the subsequent rate of change of the waterlevel was measured manually (Appendix C). It soon became very apparent from the tests, that the response

time of the piezometers was so rapid that electronic measuring equipment would be required to obtain accurate results. In other words: the hydraulic conductivity of the sediments in the screened interval is high. Except for piezometer M 60B, which was completed in silty sand, the hydraulic conductivities obtained from the manual measurements in the other piezometers are a first approximation only and the magnitude, in all likelihood, is conservative. The data was interpreted according to Cooper et al, 1967. The results are listed below

Piezometer	Hydraulic Conductivity (cm/sec)
M 39A	5.0×10^{-2}
M 58	9.0×10^{-3}
M 59	1.4×10^{-2}
M 60A	9.3×10^{-2}
M 60B	7.0×10^{-4}
M 61	9.0×10^{-3}
M 62	5.0×10^{-3}

The magnitude of the hydraulic conductivity corroborates the type of sediment in the screened interval of the piezometers.

Water Level Measurements.

Water levels were measured in the newly installed piezometers. The survey level equipment available on site was only suitable for operation on dry land and measurements of distant points could not be obtained. As a result only the elevation of piezometer 39A was established. The top of this piezometer has an elevation of 418.74 m.

M39/M39A. The water levels in this piezometer pair, measured on September 1, 1994, are at an elevation of 418.068 m. in piezometer M39 and 418.105 m. in piezometer M39A. This indicates that a slight upward gradient is present at this locality in the aquifer. Contaminated groundwater with a conductivity of 4750 µS/cm @ 25 ^{0}C, present at a depth of 12 m. in M39A, will, therefore, move upward. The conductivity of the water in piezometer M39, completed to a depth of 4.8 m., is 462 µS/cm @ 25 ^{0}C. It appears, therefore, that significant volumes of upward moving contaminated groundwater have not reached the depth of the shallow piezometer. However, piezometer M39 appears to be completed with slotted pipe over its entire length, even the part above the ground surface is slotted and a depression is present in the ground surface immediately surrounding the piezometer pipe. Both factors readily contribute to the entry of surface runoff into this piezometer. As a consequence, depending on the sampling protocol, analytical results obtained on the water from this piezometer may not reflect the true composition of the groundwater at this depth.

Mud Lake Piezometers: M58, M59, M60A, M60B and M62. The elevation of the top of these piezometers could not be established at this time due to reasons outlined above. The

results of the water level measurements in the piezometers are therefore discussed with respect to the relative surface water level in the muskeg at the time of measurement. It is assumed that this surface water level is not only the same for all piezometer locations but also reflects the water level of Mud Lake. The following results were obtained:

Piezometer	Date	Water level with respect to Mud Lake Level. (cm)
M58	94-09-03	+ 44.5
M59	94-09-03	+ 36.8
M60A	94-09-03	+ 33.6
M60B	94-09-03	+ 34.2
M62	94-09-03	+ 06.5

It is obvious from these results that Mud Lake is situated in a groundwater discharge area and relatively strong upward gradients are present between the aquifer and Mud Lake.

The water levels in piezometer pair M60A and M60B, both completed in the same aquifer, indicate upward groundwater flow with respect to Mud Lake. However, the elevation of the water level in the shallow piezometer (M60B) is slightly higher than in the deep piezometer, which, in all likelihood, is due to the difference in hydraulic conductivity between the top and bottom part of the aquifer (2 orders of magnitude) or could indicate the presence of more significant vertical permeability discontinuities i.e. thin clay beds within the vertical interval between the completion zones of the piezometers.

The most recent measurement of the elevation of Mud Lake was made in October 1986. At that time the elevation of Mud Lake was 413.6 m. (1357 ft) amsl. According to Boojum Research this elevation has remained more or less constant over the years. If this contention is true, than the elevation of the water level in piezometer M60A is 413.936 m., which is 4.17 m. lower than the water level in piezometer M39A (418.105 m.). The distance between piezometer M39A and M60A is 350 m. and the horizontal gradient within the aquifer is, therefore, 0.012. This horizontal gradient is relatively high.
The stratigraphy of the area shows that no confining clay beds are present at M39A, while at M60A the aquifer is overlain by a 3.5 m. thick clay bed. The stratigraphy in conjunction with the relatively high horizontal gradient indicates:

- continuity of the aquifer to the north, i.e. no major lateral facies change, and/or
- significant changes in vertical permeability, in other words, significant discontinuities in the low permeable sediments (silts, clays) overlying the aquifer north of piezometer M60A resulting in more or less unimpeded upward flow.

The latter scenario would explain the discharge of contaminated water into the northern end of Mud Lake.

SUMMARY

The test drilling and piezometer installation program was primarily conducted to ground test the geophysical anomalies found during previous fieldwork in the area. The results obtained show that the EM 34 geophysical survey is an effective tool for identifying areas with potential contamination. Although, it is not possible to distinguish the source of the anomaly (natural or man-made in origin), it is an invaluable tool for delineating drill targets for further investigation and locations for piezometer installation, especially in areas where access is severely limited due to adverse terrain conditions. In addition, geophysical surveys provide a much greater degree of continuity than could ever be achieved with drilling alone. Furthermore, the use of different coil spacings also provides valuable information on the relative position of the bedrock.

The current investigation was focused only on the southern and southwestern part of the Mud Lake basin, i.e. the area with geophysical EM 34 coverage, which is only a small portion of the total Mud Lake basin. The results of this investigation have shown beyond doubt that groundwater contamination is occurring in this area and that contaminated groundwater has already traveled a considerable distance from its source.

Based on the available information, it appears that for the southwestern part of the Mud Lake basin the main path of contaminated groundwater movement is a narrow buried valley which emerges from the northwestern part of the tailings area and enters the Mud Lake area in its southwestern part.
However, the hydrogeological environment of most of the Mud Lake basin has not been defined. There is no information on the bedrock topography and the position of the buried valley, stratigraphy, etc. There is no areal geophysical survey coverage (north of M60A, geophysical surveys were conducted along two isolated lines only). Also, terrain conditions at this time were such, that boreholes could not be drilled north of M60A, because even the so-called "muskeg" drilling equipment could not be moved into the northern part of the Mud Lake area.
All that has been established for the northern part of the Mud Lake basin, is the fact that contaminated groundwater is discharging into the northern part of Mud Lake (M62). However, no relationship has been established between the contaminated water in the buried valley at M60A and the contaminated groundwater discharging at M62. Also, the physical parameters which cause the discharge of contaminated water in this area are unknown. Furthermore, the true northern extent of groundwater contamination is also not known.

Although part of one potential pathway has been established, this does not preclude the presence of other pathways, for example, immediately south of Mud Lake. Especially, if the hydrogeological setting of piezometer M4 is considered. This piezometer, located south of M58 and within the tailings basin, is completed in a sand underlying the tailings and shows the presence of contaminated groundwater. Based on water levels in the piezometers, the horizontal hydraulic gradient between M4 and M58 appears to be greater than between M39A and M60A. Furthermore, a geophysical anomaly (not ground tested)

is present north of the dam in the vicinity of M4. However, based on the field measurements, no contamination was found in M58. The question therefore arises: does the geophysical anomaly represents contamination or does it reflect significant changes in stratigraphy ? If the anomaly is caused by contaminated groundwater, what is retarding the rate of groundwater flow ? Does the refusal encountered during drilling of testholes M58 and M59 represents the bedrock surface or does the possibility of a deeper pathway still exist ? Unfortunately, as a result of breakdowns of the drilling equipment, lack of spare parts and inflexibility during the drilling operation, it was impossible to establish, beyond doubt, the cause of the refusal encountered in these boreholes.

It is obvious from the results obtained from this preliminary investigation, that groundwater movement in the shallow subsurface environment plays an active role in contaminant transport away from the source areas and that considerably more work has to be undertaken in order to define the pathways , rates and areal extent of the contaminant movement. These future investigations should not be restricted to the Mud Lake basin only, but should completely envelop the tailings disposal and the waste rock area, because groundwater flow contributes to all the lakes in the vicinity of the mine site. Without a properly defined hydrogeological environment, design of remedial measures, predictive modeling, etc. becomes a theoretical exersice and cause and effect relationships of specific measures undertaken in selected areas cannot be predicted or evaluated.

References

Berezowsky, M, 1994a. Memo July 18, 1994 (internal Boojum Report)

Berezowsky, M, 1994b. Memo September 8, 1994 (internal Boojum Report)

Cooper, H.H., Jr., Bredehoeft, J.D. and Papadapoulos, I.S., 1967. Response of a finite-diameter well to an instantaneous charge of water. Water Resources Res., V3, pp. 263-269.

FIGURE 1. CHANGE IN CONDUCTIVITY DURING PUMPING OF CASING IN 39A FROM A DEPTH OF 50' (15.2 m)

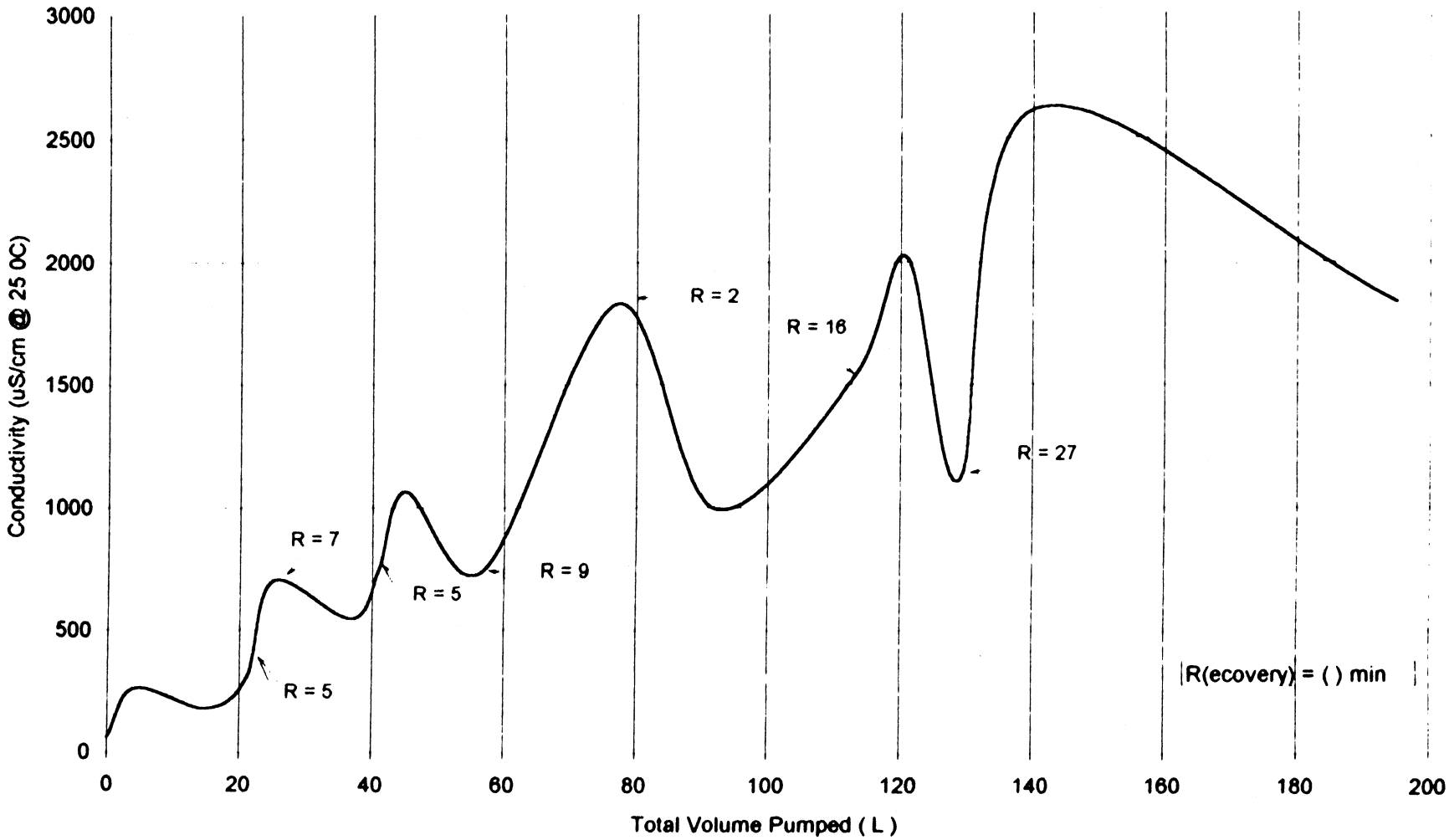


FIGURE 2: PIEZOMETER LOCATIONS AND EM 34 ANOMALIES

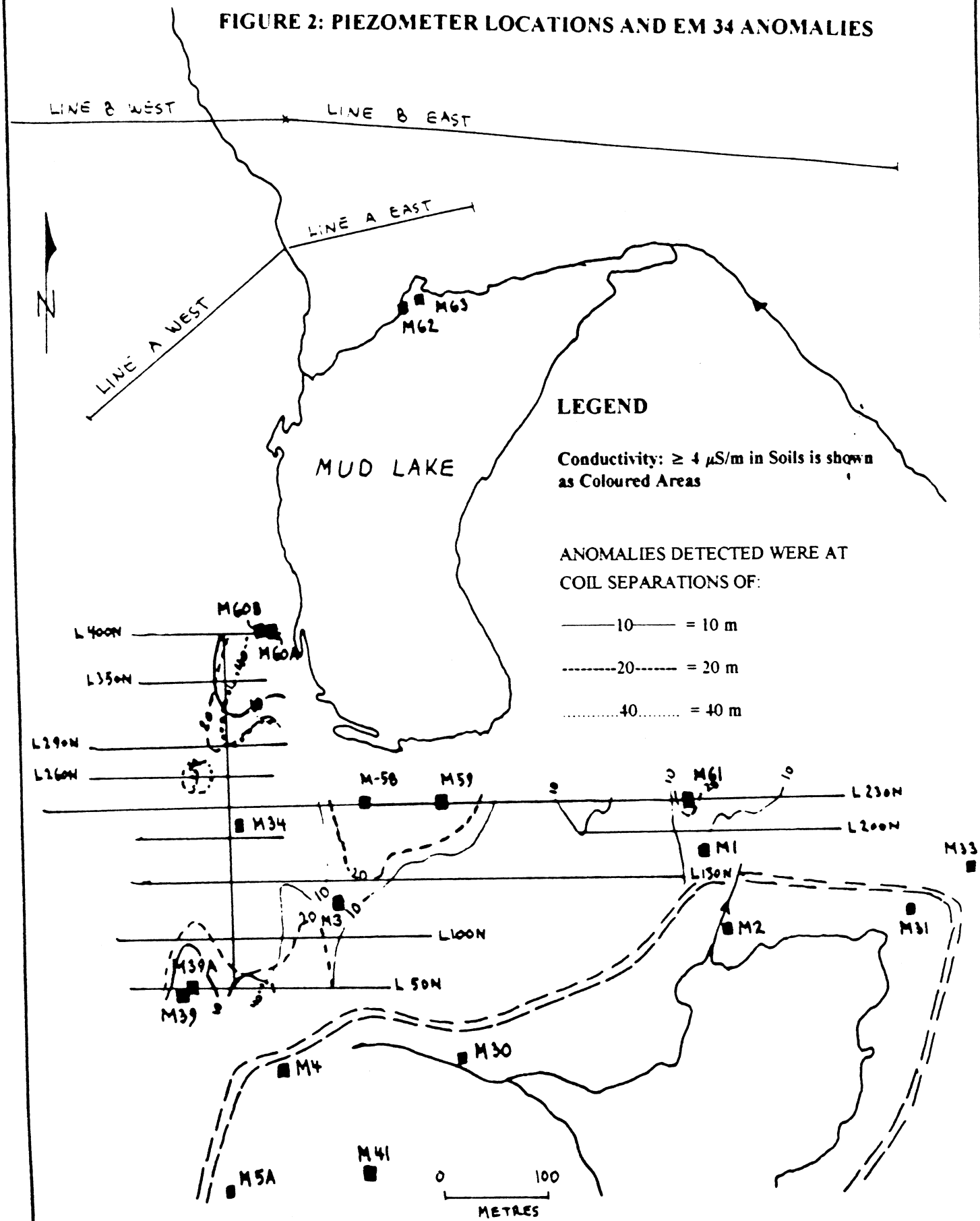


FIGURE 3: PIEZOMETER LOCATIONS AND EM 34 ANOMALIES (ANOMALIES SHOWN HAVE REDUCED OVERBURDEN RESPONSE)

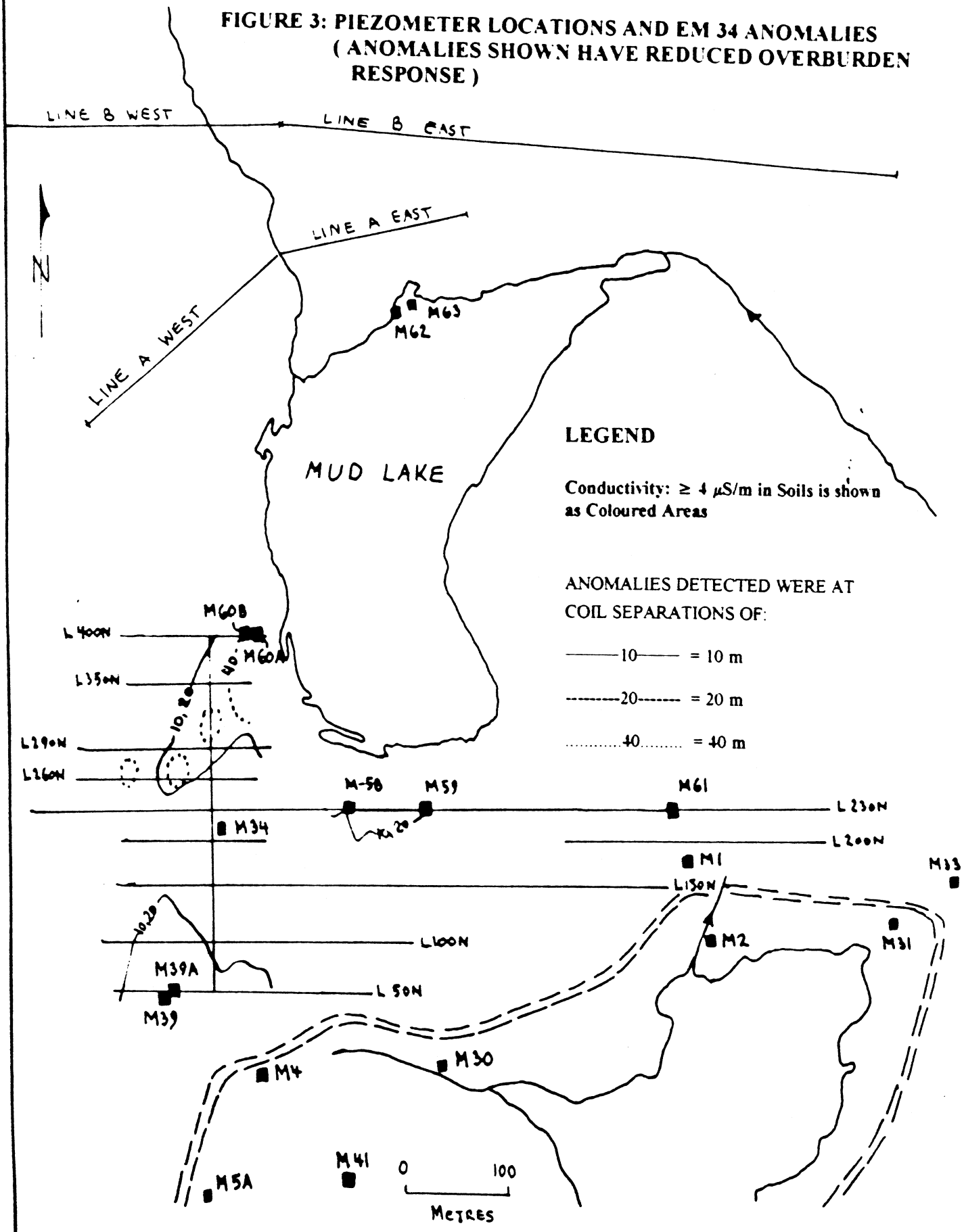
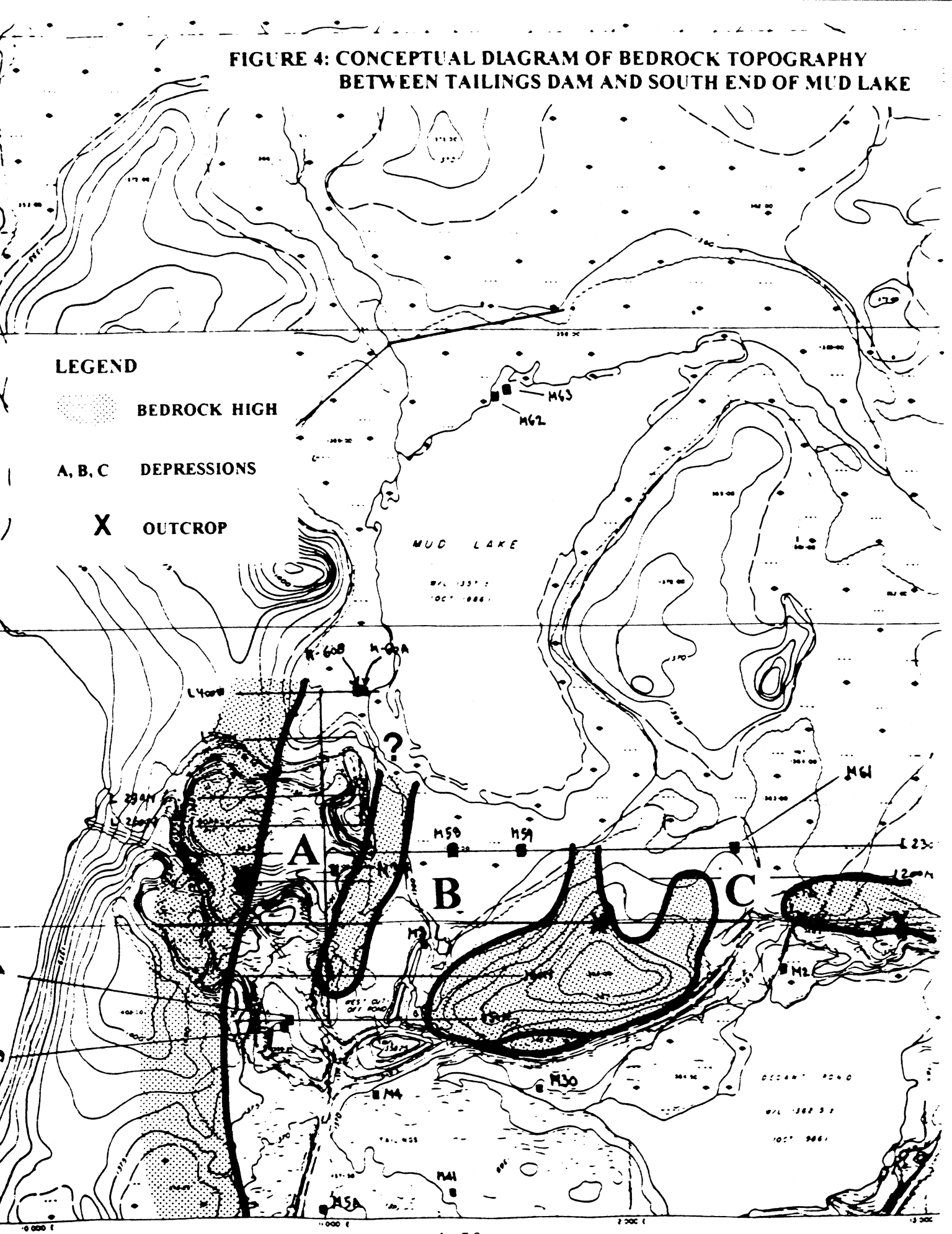


FIGURE 4: CONCEPTUAL DIAGRAM OF BEDROCK TOPOGRAPHY BETWEEN TAILINGS DAM AND SOUTH END OF MUD LAKE



APPENDIX A: CONSTRUCTION DETAILS PIEZOMETERS

	M39A (m)	M58 (m)	M59 (m)	M60A (m)
Top Stick-up	+ 0.154	+ 0.595	+0.924	+ 0.336
Ground level	0.000	0.000	0.000	0.000
Top Screen	-12.046	-11.605	- 5.776	-14.904
Bottom Screen	-13.531	-13.090	- 7.261	-16.399
Tip Piezometer	-13.576	-13.135	- 7.306	-16.434
Total Length	13.730	13.730	8.230	16.770

	M60B (m)	M61 (m)	M62 (m)	M63 (m)
Top Stick-up	+0.372	+0.643	+0.115	+0.220
Ground level	0.000	0.000	0.000	0.000
Top Screen	- 6.948	- 3.017	- 1.575	- 2.450
Bottom Screen	- 8.433	- 4.502	- 2.140	- 2.943
Tip Piezometer	- 8.478	- 4.547	- 2.185	- 2.988
Total Length	8.850	5.190	2.300	3.208

APPENDIX B: STRATIGRAPHY OF TESTHOLES

M39A

Depth (m)

0.00 - 0.30	Gravel, coarse, > 5cm, angular- subangular, with a fine-coarse grained sand matrix.
0.30 - 0.76	Sand, black-dark grey, very coarse grained to granules, angular.
0.76 - 1.52	Gravel, fine, < 2cm, angular-subangular, granules and sand as above.
1.52 - 3.05	Gravel, as above, with Sand, black-dark grey, medium-very coarse grained, angular-subangular, moderately sorted; trace Silt.
3.05 - 4.57	Sand, black-dark grey, medium-very coarse grained, pebbly, subangular-angular, sorted; trace grey Silt and Clay.
4.57 - 5.18	Sand, as above, predominantly medium-coarse grained.
5.18 - 7.62	As above, occasionally thin coarse gravel beds.
7.62 - 9.14	Sand, medium-coarse grained, as above with coarse gravel beds.
9.14 - 10.67	As above.
10.67 - 12.19	Sand, medium-coarse grained, as above with more coarse gravel (difficult to drive casing).
12.19 - 13.72	As above, more gravelly.
13.72 - 14.17	Gravel, fine-coarse and Sand, medium-very coarse grained.
14.17 - 15.24	Sand, greenish grey, very fine grained, subangular, pebbly; grey Silt & Boulders.

M58

Depth (m)

0.00 - 1.22	Muskeg.
1.22 - 4.27	Gyttja, dark brown, clayey, progressively more clayey with depth.
4.27 - 4.57	Clay, light brown grey, organic, occasionally Gastropod and Mollusk fragments, soft, spongy.
4.57 - 5.33	Clay, grey, slightly calcareous, very soft, plastic, silty, with depth grading to Silt, grey, clayey, slightly calcareous. Varved in part.
5.33 - 7.62	Clay and Silt, as above.
7.62 - 8.23	Clay, grey, silty, more silty with depth, grading to Sand, grey-greenish grey, silt size-very fine grained, quartzose, subangular-subrounded, clayey in part.
8.23 - 8.53	Sand, as above, more silty.
8.53 - 9.14	Sand, grey, very fine-fine, fine & medium grained, quartz, feldspar, mafic grains, angular-subrounded, well sorted, coarser with depth.
9.14 - 11.58	Sand, grey, as above, predominantly fine-medium & medium grained.
11.58 - 12.19	Sand, black-dark grey, medium & medium-coarse grained, quartz, feldspar, mafic grains, angular-subrounded, well sorted, coarser with depth.
12.19 - 13.26	Sand, black, coarse-very coarse grained with granules, quartz, igneous rock fragments, mafic grains and fragments, angular-subangular, moderate-well sorted, pebbly. REFUSAL.

M59

Depth (m)

0.00 - 2.44 Muskeg.

2.44 - 3.35 Gyttja.

3.35 - 4.57 Clay, light grey, slightly calcareous, soft, very plastic, silty interbeds, organic fragments and debris in places.

4.57 - 5.79 Clay, as above, generally more silty and stiffer, varved.

5.79 - 7.31 Sand, black, dark grey, very fine-medium grained, quartz, feldspar & mafic grains, angular-subrounded, well sorted, coarser with depth. Near base minor coarse-very coarse grained Sand with occasionally granules and coarse pebbles. REFUSAL

M60A

Depth (m)

0.00 - 1.22 Muskeg.

1.22 - 3.50 Gyttja.

3.50 - 6.10 Clay, light-dark grey, organic in places, soft-stiff, trace-common calcareous, varved, progressively more silty with depth.

3.50 - 7.31 Clay, light grey, very silty, calcareous, interbedded with Silt, grey, clayey; with depth progressively coarser and grading to Sand, grey, silt size-very fine grained, quartzose, subangular-subrounded, well sorted, calcareous, occasionally clay interbeds.

7.31 - 9.14 Sand, grey, very fine grained, quartz, trace feldspar & mafic grains, subangular-subrounded, well sorted, slightly calcareous, with Silt and Clay interbeds & lenses in places; grading to Sand, grey - salt & pepper, fine grained with medium grained component, quartz, trace feldspar, common mafic grains, angular-subrounded, well sorted, progressively more coarse with depth.

9.14 - 10.67 Sand, dark grey, black, medium-coarse grained with minor very coarse grained component, mafic grains, quartz & feldspar, angular-subrounded, well sorted, with depth predominantly coarse grained.

10.67 - 12.19 Sand, black, coarse-very coarse, very coarse grained and granules, predominantly mafic grains and fragments, angular-subangular, well sorted; occasionally grey Clay lens or interbed; occasionally small pebbles.

12.19 - 13.72 Sand, black, as above, predominantly medium-coarse grained.

13.72 - 15.24 Interbedded sequence of medium, medium-coarse, coarse & very coarse grained Sand, with occasionally grey Clay stringers.

15.24 - 16.61 Sand, black, coarse-very coarse grained, pebbly, mafic grains & fragments, angular-subangular, well sorted.

NOTE: The stratigraphy of M60B is similar and due to its close proximity is not further described.

M61

Depth (m)

0.00 - 0.60	Muskeg
0.60 - 2.13	Gyttja, clayey and silty.
2.13 - 2.74	Clay, light grey-grey, silty, organic fragments, slightly calcareous.
2.74 - 3.20	Silt, grey. clayey, interbedded with Clay, as above.
3.20 - 3.75	Sand, grey-grey brown, silt size-very fine grained, quartz, sub angular-subrounded, well sorted, with interbeds of Clay, as above; grading to Sand, dark grey, very fine -fine grained, quartzose and as above. At base, Sand, black, coarse-very coarse grained with granules and small pebbles, predominantly mafic grains & fragments, subangular-angular, moderately sorted.
3.75 - 4.57	Sand, coarse-very coarse grained, as above.
4.75 - 4.63	Sand, brown grey, fine-medium grained with minor coarse grained fraction, quartz, feldspar & mafic grains, angular-subrounded, poor-moderately sorted; occasionally interbeds and lenses of Clay, brown grey, organic, plastic.
4.63 - 4.75	Sand, grey-brown grey, fine-medium & medium grained, quartz, feldspar & mafic grains, angular-subrounded, well sorted. REFUSAL.

APPENDIX C: SLUG TEST DATA.

Maximum instantaneous displacement: H_0 = 0.405 cm

M39A

Time (sec)	h (cm)
1.68	0.236
2.45	0.186
3.14	0.136
3.95	0.086
5.39	0.036

M58

Time (sec)	h (cm)
1.55	0.332
6.10	0.282
6.50	0.242
7.8	0.232
10.3	0.182
12.7	0.162
14.1	0.152
14.9	0.142
16.7	0.132
17	0.122
20	0.102
28	0.082
31	0.062
34.75	0.053
38.25	0.042
42.8	0.032
49	0.022
60.5	0.012
82.5	0.002

M59

Time (sec)	h (cm)
5	0.176
7	0.126
11	0.116
12.1	0.086
12.4	0.086
17.7	0.056
20.1	0.056
22.1	0.046
23.8	0.036
28	0.036
36	0.016
39	0.026
56	0.016
61	0.006
65	0.006

M60A

Time (sec)	h (cm)
1.045	0.224
3.8	0.174
4.58	0.124
4.98	0.074
5.17	0.024

M62

Time (sec)	h (cm)
7.0	0.250
7.88	0.200
12.6	0.150
19.0	0.100
35.6	0.060
40.8	0.050
49.8	0.040
61	0.030

M60B

Time (sec)	h (cm)
5.8	0.400
17	0.370
26	0.350
31	0.340
37	0.330
43	0.320
47	0.310
54	0.300
60	0.290
67	0.280
74	0.270
88	0.250
121	0.210
139	0.190
162	0.170
186	0.150
216	0.130
251	0.110
292	0.090
351	0.070
411	0.050

M61

Time (sec)	h (cm)
2.4	0.323
6.3	0.193
8.3	0.163
10.1	0.143
14	0.083
20.9	0.073
22.8	0.063
25	0.053
27	0.043
34	0.033
39	0.023
54	0.009
57	0.003