GEOPHYSICAL ASSESSMENT OF WASTE DRILLING FLUID CONTAINMENT SITES IN THE MACKENZIE RIVER VALLEY REGION, NWT

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EXECUTIVE SUMMARY

Drilling waste containment in eight abandoned sumps in the Mackenzie Valley region was assessed using geophysical methods. The major objectives of the study were to assess the performance of abandoned sumps in the containment of waste drilling fluids and to suggest improvements to the current practice of total containment. The assessment was carried out as a reconnaissance survey over a range of permafrost conditions from sporatic to continuous. Geophysical electrical conductivity measurements were made at each sump, supplemented by surface soil analysis to assess any chemical expression of geophysically detected wastes. Notes were taken on site stability, signs of accelerated erosion, and the success of revegetation. Contour maps of apparent conductivity were prepared for depths of 3.5 m and 7 m and surface soil analyses were correlated with apparent conductivities at each site.

Evidence of waste fluid movement was assessed by evaluating apparent conductivity contours at each sump location. Because electrical conductivities are an indirect measurement of the salt concentration in the soil, evidence from other factors known to influence waste fluid containment and/or detectability were included in the assessment. These included the existence of permafrost, texture of subsurface materials, depth of water table, chemistry of the drilling fluids and surface contamination. Based on the collective evidence each sump was given an overall containment rating ranging from definite leakage to probable containment. On this basis six of the eight sumps were rated as having some likelihood of leakage. For two of the six,

apparent conductivity contours alone provided clear evidence of fluid migration away from the sump while for the others a combination of evidence was necessary to establish a classification. Two of the sites had significant stability problems related to site selection. At only three of the sites was revegetation considered adequate.

Recommendations were made concerning sump location criteria and the direction for future studies. A key question which needs to be addressed as a part of any future work is the potential environmental hazard of leaking sumps. It was recommended that this question be answered by utilizing all of the relevant evidence concerning environmental hazard available at abandoned sump sites (i.e. influence on water, soil and plant tissue chemistry). A recommended starting point is the creation of an environmentally related computer data base (sump register) utilizing industry and government file data from the more than 1500 abandoned sumps in the Territories. From this, representative sumps could be selected for field investigation and assessment of containment, environmental implications and appropriateness of current practices.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

The containment and ultimate disposal of waste drilling fluids in an environmentally acceptable and economically feasible manner is a concern of both the petroleum industry and government regulators. Because of the chemical complexity of drilling mud and the lack of adequate information concerning environmental hazards, current practice on Territorial lands requires that waste drilling fluids be totally contained upon well completion. The current industry approach to this requirement is to store waste drilling fluids and sediment in a sump which is filled and capped upon abandonment. Although this method of containment is generally well accepted by both industry and government, few studies have been undertaken to demonstrate that the contaminants do not leak into the surrounding environment over time.

This study reports the results of a field survey utilizing geophysical soil conductivity measurements coupled with near-surface soil chemistry analyses to determine if drilling wastes are migrating away from the boundaries of eight sumps abandoned over a range of permafrost conditions in the Mackenzie Valley region.

1.1 BACKGROUND

Sumps in all areas of the north are easiest to abandon during winter when the sump fluids are frozen. Since most drilling (approximately 95 percent) takes place during winter, this scenario is the norm. The frozen sump is backfilled with the excavated material from the pit to form a cap which is then reclaimed or left to revegetate naturally (Hardy BBT 1987).

The thickness of the cap approximates the depth of fluids in the sump and serves to counteract any thawing in the backfill and sump materials. Small depressions may develop in the cap but the surface tends to remain above the original ground surface. Since sumps in permafrost regions are excavated below the active layer, the frozen fluids are not expected to thaw. However, in some cases, a high salt concentration may depress the freezing point of the fluid and cause an unfrozen layer to persist within the frozen sump. Over time it is possible that these unfrozen fluids will migrate out of the sump. In areas south of the continuous permafrost zone fluids will not remain frozen and it is likely that seepage is taking place over time. There is good reason to believe that containment in sumps is not total. Therefore it is important to gather data on the performance of sumps under various terrain conditions to accurately assess this situation.

Standard Methods. One method of monitoring the persistence of fluid containment in a given sump is to collect soil samples at depth from within and around the sump to determine if there is subsurface migration of the drilling fluids away from the sump. A drawback to this approach is the high cost of collecting and analyzing the large number of samples required to accurately define the outline of the deposited fluid body and to detect the existance of a contaminants plume.

Geophysical Methods. Another approach, which is more cost-effective where the fluids or deposit is salt bearing, is the use of geophysical soil conductivity measurements. Although an indirect measurement and not highly quantifiable, it can rapidly and inexpensively detect a salt bearing body and provide a rational basis for selecting drill sites for further sampling.

Inductive geophysical techniques have been available for mapping soil conductivities for a number of years (McNeill, 1980; McNeill, 1986). The applications include agricultural studies (Cameron et al., 1981; Corwin and Rhoades, 1982; Rhoades and Corwin, 1981) where geophysical conductivity values were related to soil salinity and sump investigations (Nenniger, 1987), where a sump containing saline fluids in a permafrost region was monitored using geophysical conductivity measurements.

Most near surface rocks and soils contain water in their pores. Since the conductivity of the pore water is determined by the ion concentration, any change in that concentration will lead to a change in the electrical conductivity. Other factors that will influence soil conductivity measurements include moisture content and temperature. The range of influence that these factors can have over soil conductivity readings is documented in Hardy BBT Limited (1988) and Nenniger (1987).

These studies show that the soil moisture content can vary seasonally with a range of measured soil conductivity that would be generally less than 5 mS/m. Temperature changes can produce large variations in soil conductivy, with the observed changes occurring as a result of freezing or thawing of the active layer in permafrost zones. It is important to understand the effect of these seasonal variations when interpreting the soil conductivity data.

Since most drilling fluids, especially those used in permafrost regions, contain salt-bearing solutions, soil conductivity measurements using an inductive conductivity technique can provide a rapid means of detecting ion rich fluids within a sump and migrating away from a sump. This technique reduces the requirements for the number of soil samples and allows the optimal selection of soil sampling sites. It also provides a means of cost-effective long-term monitoring of a site, should it be necessary. The Geonics inductive conductivity meter (EM31) was developed to measure subsurface conductivities without the need of electrical contact with the ground. It is hand carried and can be operated in various modes in order to obtain different depths of investigation. The EM31, which has two coils mounted in a fixed boom, can be operated in a "side" position, with the coils in a vertical plane, or an "up" position, with the coils in a horizontal plane. In the side mode the measurement represents subsurface conductivities to a depth of approximately 3 m. In the up mode, an investigation depth of approximately 7 m is obtained. A more complete description of the principles of operation for this instrument is contained in Appendix A.

1.2 STUDY OBJECTIVES

The objectives of this study were:

1. To assess the performance of abandoned sumps in the containment of waste drilling fluids.

2. To suggest improvements to the current practice of total containment.

This assessment was to be carried out as a reconnaissance survey of a number of abandoned sumps over a range of permafrost conditions. Evidence of fluid movement was to be provided by geophysical conductivity readings supplemented by surface soil samples to assess any chemical expression of geophysical conductivity readings on the surface.

The study was designed as a rapid and relatively inexpensive general assessment of the success of waste drilling fluid containment; it was not expected to provide definitive evidence concerning the mobility of sump contents. The study included:

1. Field reconnaissance at selected abandoned drilling sumps to characterize the general natural conditions at the sites including the presence of permafrost.

2. Implement inductive conductivity survey for the sites with the Geonics EM31.

3. Take samples of soil materials or soils as may be necessary for chemical analysis, including seepage corridors, to document the local conditions.

4. Prepare sketches, drawings and/or photographs to document the locations of transects and sampling points.

5. Analyse the soil samples for pH, conductivity and soluble ions (K, Na, Mg, Cl and SO_4).

6. Prepare maps of distribution of apparent conductivity, contoured at appropriate intervals for each site surveyed to depths of about 3.5 and 7 metres.

7. Prepare interpretational maps for each site based on all factors surveyed. The intention of these maps will be to show areas of potential movements of contaminants from the sumps.

8. Discuss the methodology of survey, the data obtained and the conclusions and recommendations relevant for the objectives of the work.

2.0 METHODS

A candidate list of sixteen abandoned sump sites along the Mackenzie River Valley was provided by the Department of Indian Affairs and Northern Development (DIAND). These sites were deemed to represent average terrain conditions over a range of permafrost conditions from sporadic to continuous. Eight of these sites were selected by Hardy BBT for study. Selection was based primarily on logistic considerations as little information concerning the sites was available prior to the field survey. Information including sump dimensions, drilling fluid composition, sump completion date, and a description of sump fluid disposal or containment was provided by DIAND and Canada Oil and Gas Lands Administration (COGLA) personnel following the field program.

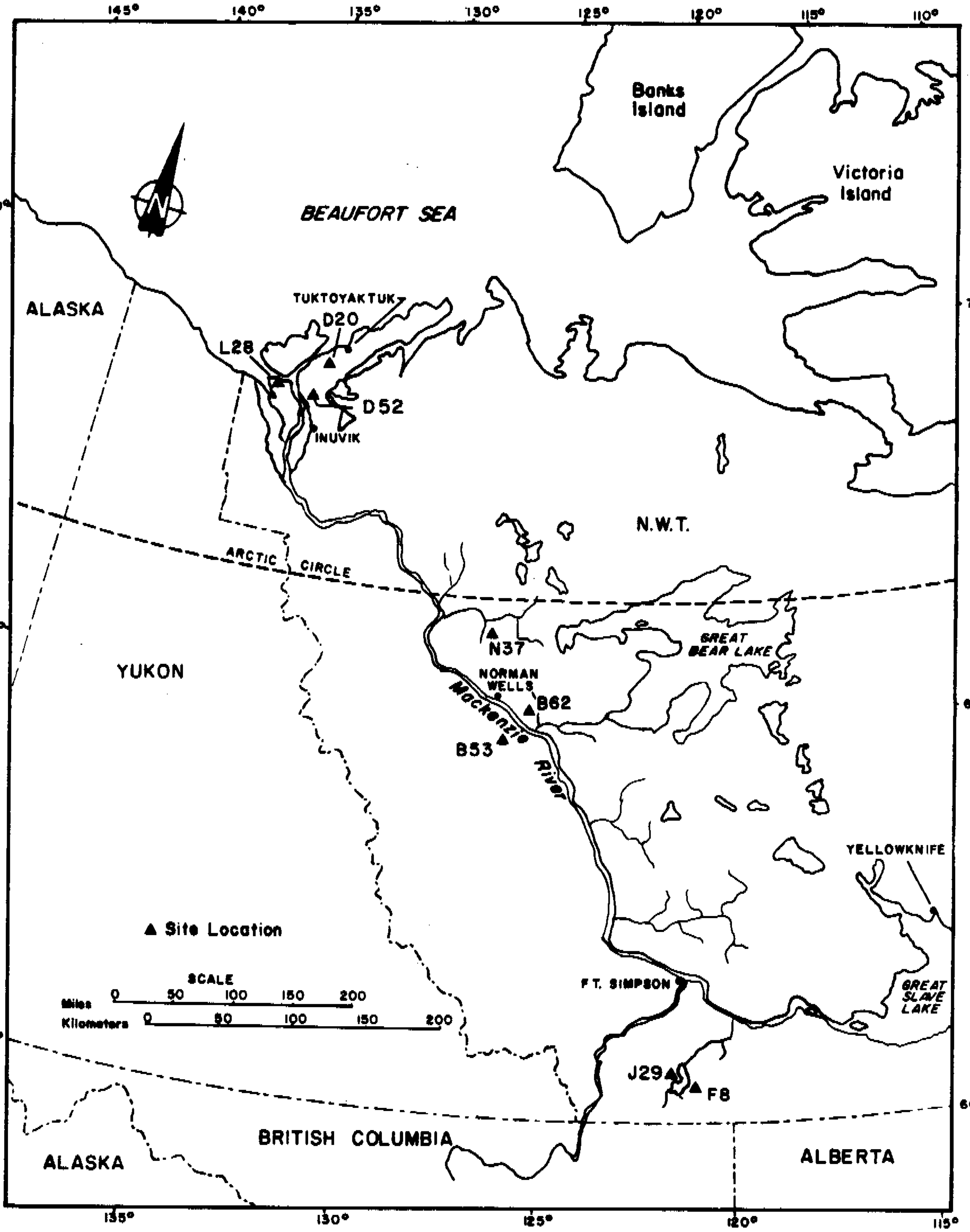
Chemical analyses of the fluids disposed in the sumps was not available. However COGLA provided a list of ingredients used in each drilling fluid (Appendix B). To estimate ion (salt) concentration, each fluid ingredient was assigned a solubility rating from 0-10 on the basis of known solubilities of the various chemical compounds in the ingredients. These ratings were multiplied by the amount of each ingredient and the products summed to provide an ion concentration rating. These ratings, though not based on actual analytical results, provided a means of rating the contents of each sump and of ranking the sumps in terms of expected detectability by EM31 equipment.

2.1 FIELD SURVEY

The field survey took place over a four day period in early August, 1987 and included sites near Fort Simpson, Norman Wells and Inuvik (Figure 1). Approximately five hours was required at each site including travel time from one of the above cited bases.

Apparent conductivities were measured using the EM31 on a grid established over the abandoned sumps. In all cases the grid was extended beyond the sump boundaries to provide background readings and to establish if ion-rich contaminants were migrating away from the sump. A 50-m tape and surveyors flags were used to mark out the grid on two sides of the sump. Station spacing and line spacing was 5 or 10 m with the total size of the grid varying with the size of the sump. The boundary coordinates of the sump were noted so that the sump outline could be accurately overlain on the final apparent conductivity contour map. At each grid point two readings were taken, one with the EM31 coils in the vertical plane measuring apparent conductivity down to 3.5 m and one with the coils in the horizontal position measuring apparent conductivity down to 7 m.

Soil samples were collected at each site from sampling locations selected on the basis of the EM31 readings. Several samples were collected in areas generally off the sump cap where EM31 readings were minimal or at background levels and several were collected on the sump cap where readings were the highest. Where EM31 readings suggested a movement of fluid away from the sump area, the EM31 grid was extended to map this area and soils were sampled in a transect across the



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ABANDONED SUMP LOCATIONS

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region of apparent movement. Soil samples were hand augered. Sampling depth varied from 30 to 100 cm with the deepest samples being taken close to the water or permafrost table whichever was encountered first. Photographs were taken of the surface condition of the sump cap as well as notes concerning the surface vegetation.

2.2 APPARENT CONDUCTIVITY MAPS

Grid point coordinates and apparent conductivities were entered into a HP9816 microcomputer and contour maps plotted for the two depths at each sump location. The 16 contour maps for the 8 sites are included in Appendix C. The sump cap outline was overlain on the 7-m depth contour map along with selected surface features from sketch-maps made in the field. These 8 composite maps are included in the main body of the text.

2.3 CHEMICAL ANALYSIS

Soil samples were air dried at room temperature, crushed to pass a 2-mm sieve and shipped to Hardy's analytical laboratory for analysis of pH, conductivity, soluble Na, K, Ca, SO_4, Mg, and Cl, and calculation of sodium adsorption ratio (McKeague, 1976).

Chemical analysis focused on soluble salts because they are (1) a common component of sump fluids, (2) the primary sump fluid component to which geophysical methods respond, and (3) inexpensive to analyse for. Soil conductivity analysis on a saturation paste is the accepted analytical method used to assess the concentration of soluble salts in a soil and provides general assessment of the suitability of the soils for plant growth (Richards, 1969). Measurement of the individual soluble ions and calculation of the sodium adsorption ratio (SAR) are a standard part of a soil salinity analysis and are presented in Appendix D. The SAR is used to express the relative activity of sodium ions in exchange reactions in the soil. Where the SAR is greater than 11 a soil is classified as alkali and depending on the amount of other soluble salts, may also have poor internal drainage. Correlation analysis was run between surface soil conductivity measurements and apparent conductivity readings at the 3.5 m depth at each of the sump sites.

3.0 RESULTS

The study collected data on eight abandoned sumps; two in the sporadic permafrost zone south of Fort Simpson, three in the discontinuous permafrost zone near Norman Wells and three in the continuous permafrost zone near Inuvik (Figure 1, Table 1). The sumps except one (D20, completed in 1977) were completed between 1985 and 1987. All were generally rectangular in shape, 20 to 70 m on a side and 3.5 to 5.5 m deep. All are located at sites with low topographic relief ranging from nearly level to gently sloping. As a result, surface erosion was minimal except on D52 where the sump cap was intercepting drainage which had eroded much of the cap perimeter.

The five sites in the sporadic and discontinuous permafrost zones were all in poorly to imperfectly drained portions of the boreal forest typified by black spruce and tamarak. In the continuous permafrost zone two sites were located in upland shrub heath tundra (D52 and D20) and one was in the wet sedge meadow vegetation of the outer delta of the Mackenzie River. While the two upland tundra sites are moderately well drained, the outer delta site is wet most of the growing season and is flooded annually during spring break-up.

Although all sites were seeded to assist in revegetation, plant cover on the sump caps was generally low, averaging less than 10 percent.

TABLE 1. CHARACTERISTICS OF THE ABANDONED SUMPS SELECTED FOR STUDY

Site[a]	Location	Permafrost Zone	Topography	Drainage	Sump Dimensions (m)	Completion Date	Ion[b] Concentration Rating of Drilling Fluid	Revegetation Cover (%)
J29 Trout Lake	60°38'N;121° 19'W	Sporadic	nearly level	poor	37x22x3.5	Mar./86	Very low (49)	<10
F8 North Trout Lake	60°37'N;121° 1'W	Sporadic	nearly level	poor	29x25x4	Feb./86	Very low (52)	30-40
B53 Windy Lake	64°52'N;121° 40'W	Discontinuous	nearly level	imperfect	31x29x3.5	Mar./85	Very low (58)	<10
B62 K'ALO	65°11'N;125° 27'W	Discontinuous	nearly level	imperfect	56x39x4.5	Mar./86	High (1090)	<10
N37 Tunago	66°07'N;126° 22'W	Discontinuous	gently sloping	imperfect	33x33x4	Apr./85	Low (218)	<1
D52 Onigat	68°41'N;133° 44'W	Continuous	gently sloping	moderately well	39x31x4	Feb./85	Low (279)	20-40
L28 Unak	68°47'N;135° 22'W	Continuous	nearly level	poor	73x24x5	Feb./87	Medium (430)	<1
D20 Parsons Lake	68°59'N;133° 34'W	Continuous	gently sloping	moderately well	58x53x5.5	Feb./77	Very High (2724)	20-40

[a] Complete site names are found in Appendix B.

[b] Ion concentration rating based on the sum of the products of the solubility rating (0-10) and weight (kg) of the ingredients used in each drilling fluid.

With respect to their potential ion concentration, five sump fluids were rated as low to very low, one as medium and two as high to very high (Table 1).

3.1 SPORADIC PERMAFROST ZONE - J29 AND F8

3.1.1 Soils/Vegetation

Soil conductivity data for both sumps in this zone indicate that there are only minor differences in salt content between the soils of the sump cap and those of the undisturbed area adjacent to the cap (Table 2). Control or background readings taken away from the cap range between 0.35 and 0.73 mS/cm while readings on or adjacent to the cap range between 0.34 and 0.77 mS/cm (Figures 2 and 3). A review of the individual ions (Appendix D) suggest some general surface contamination on and adjacent to the sump cap at J29, particularily by sodium, calcium and sulphate.

Revegetation efforts had been made at both sites. A relatively good grass cover (30 to 40%) exists at the F8 site dominated by timothy and creeping red fescue. The same two species are evident at J29, however cover here is less than 10%. A great deal of slash was pulled back over the sump at this site and may have limited revegetation success. At neither sump do the salt concentrations of the surface soils pose a limitation to the establishment of seeded grasses (Richards, 1969).

TABLE 2. NEAR SURFACE SOIL CONDUCTIVITY AND APPARENT CONDUCTIVITY (EM31) ON SELECTED DRILLING SUMP SITES IN THE SPORADIC PERMAFROST ZONE, MACKENZIE VALLEY N.W.T. AUGUST 1987

Site	Sample #	Soil[c] Conductivity (mS/cm)	Sample Depth (cm)	Permafrost (PF)/Water Table (WT) Depth (cm)	EM31 Apparent Conductivity[d] (mS/m) 3.5 m	7 m	Ion Concentration Rating of Drilling Fluid
J29	Cap 1[a]	0.52	30	30 WT	20	29	very low (49)
	DS[b] Cap 2	0.77	30		24	35	
	DS Cap 3	0.34	30		23	34	
	Control 4	0.35	30	30 WT	18	27	
F8	Cap 1	0.50	40	30 WT	24	28	very low (52)
	Control 2	0.73	40	30 WT	17	25	

a See figures for soil sample locations

b DS = Downslope of

c For complete chemical analysis see Appendix D

d For an explanation of conductivity units see Appendix A

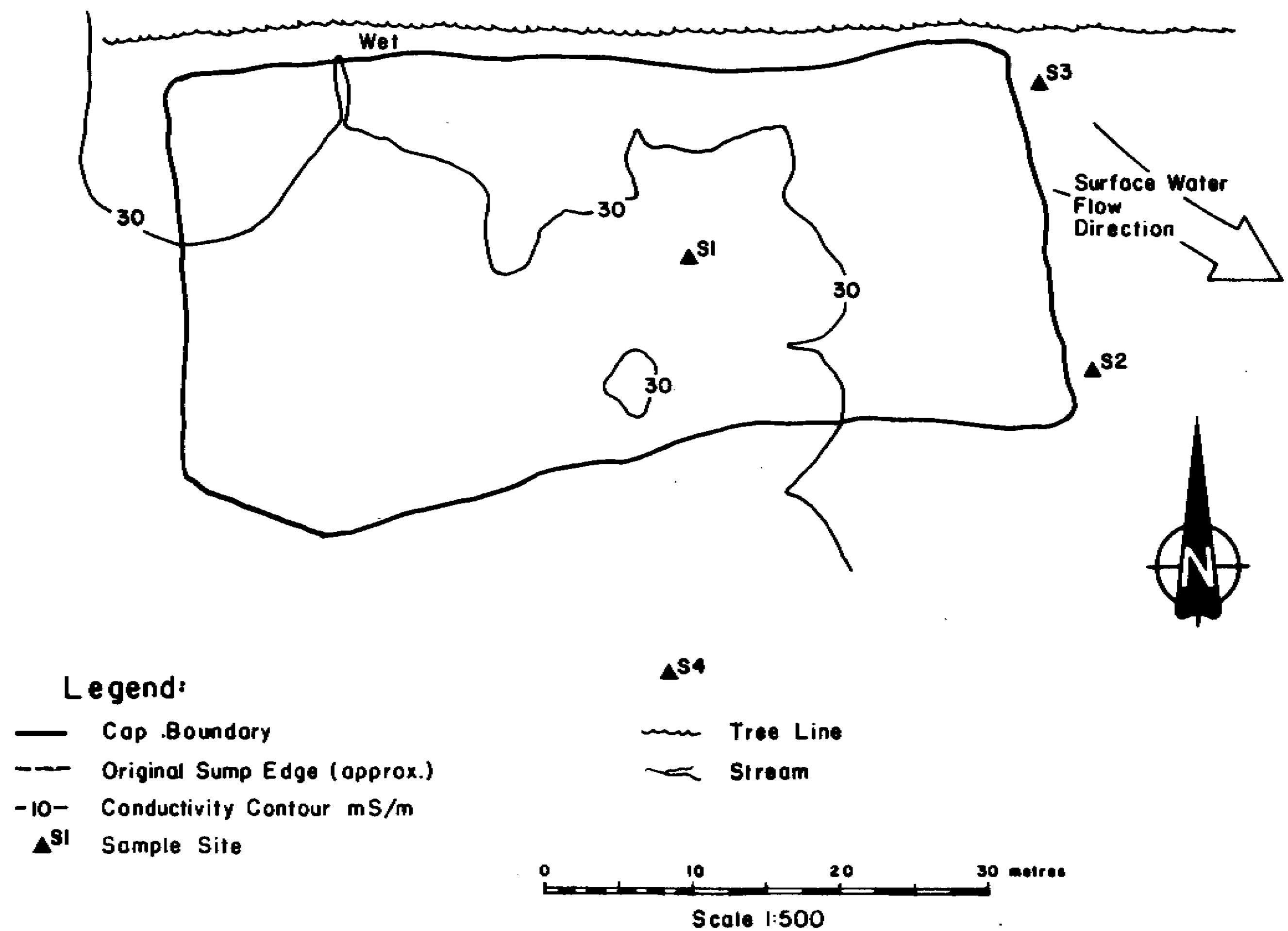

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Figure 2.
Apparent Conductivity Contour Map: J29
Depth of Investigation 7.0m
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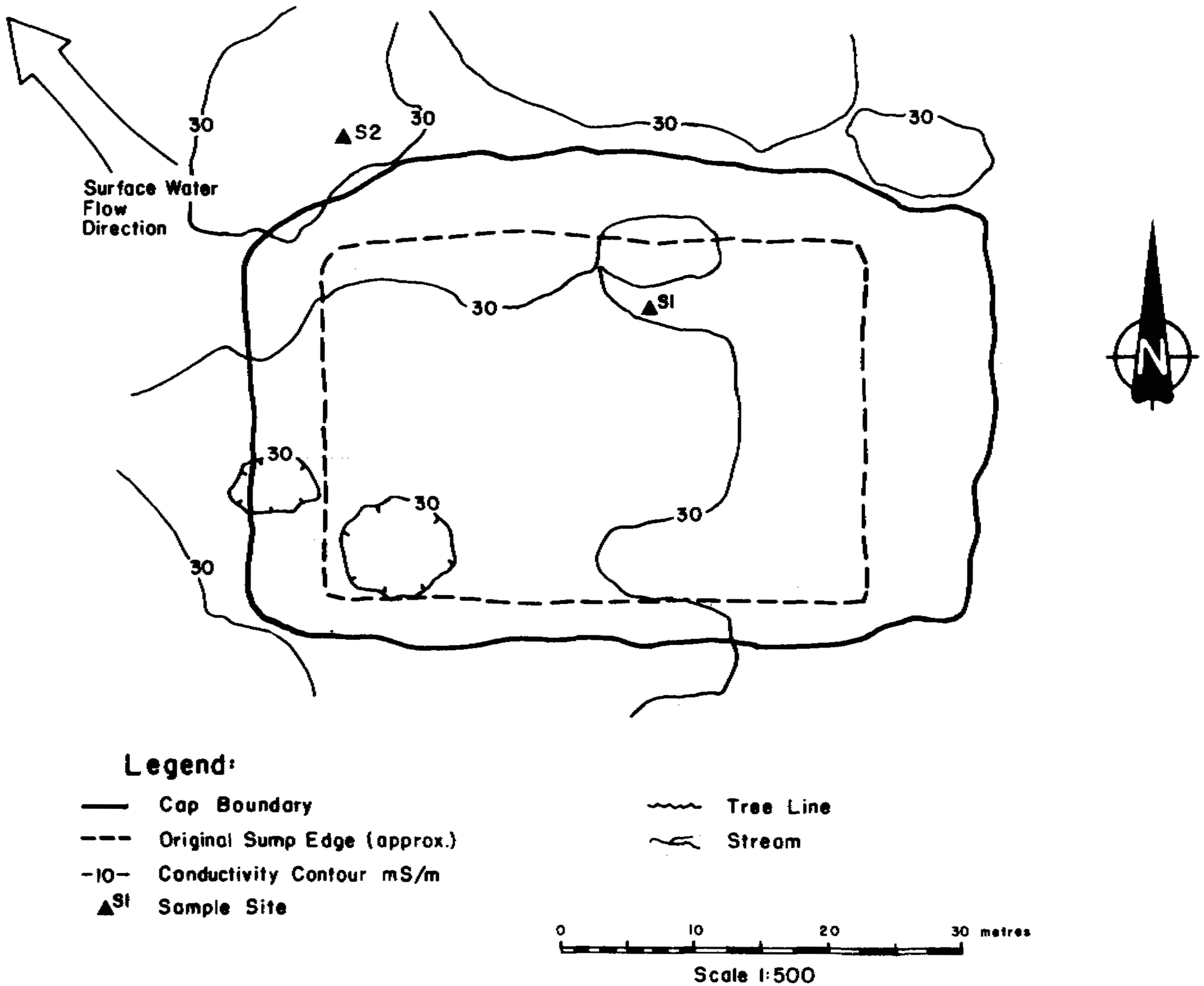

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Figure 3.
Apparent Conductivity Contour Map: F08
Depth of Investigation 7.0m
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3.1.2 EM31 Apparent Conductivities

The apparent conductivities measured on both sites (Figures 2 and 3) were consistent with the range of values expected for a wet, clay-rich unfrozen material (25 to 35 mS/m). There was no indication of ion-rich fluids either within the sumps or migrating away from the sumps. Because the ion concentration of the fluids at both sumps was very low (Table 2), the apparent conductivity readings are not conclusive evidence that the originally deposited fluids are absent. In addition, both sumps are in a clay rich till material (land use inspection reports) which generally has a low permeability. The lack of permafrost, the high water table (30 cm) on the site, and the potential for freeze/thaw cracking of the surface capping layer suggests that, however, some of the drilling fluids may have escaped.

3.2 DISCONTINUOUS PERMAFROST ZONE - B53, B62 and N37

3.2.1 Soils/Vegetation

Generally, soil conductivities for sumps in this zone were low with relatively small but distinctive differences between capping soils and control soils (Table 3). At B53 the difference is quite small (.84 mS/cm vs. 1.30 mS/cm). This difference is primarily the result of higher levels of calcium, magnesium and sulphates in the capping soils (Appendix D). There is a greater difference (.28 to 2.03 mS/cm) at N37 indicative of more significant differences in salt levels. In addition, N37 exhibits a slight increase in surface soil conductivity downslope of the cap (sample site 1 vs. site 2), at both the 20 cm and 100 cm depths

TABLE 3. NEAR SURFACE SOIL CONDUCTIVITY AND APPARENT CONDUCTIVITY (EM31) ON SELECTED DRILLING SUMP SITES IN THE DISCONTINUOUS PERMAFROST ZONE, MACKENZIE VALLEY N.W.T. AUGUST 1987

Site	Sample #		Soil[c] Conductivity (mS/cm)	Sample Depth (cm)	Permafrost (PF)/Water Table (WT) Depth (cm)	EM31 Apparent Conductivity[d] (mS/m) 3.5 m	7 m	Ion Concentration Rating of Drilling Fluid
B53	Cap	1[a]	1.30	40	80 PF	2.8	2.5	very low (58)
	Cap	2	0.72	40		4.8	5.6	
	Control	3	0.84	40	60 PF	3.7	3.8	
B62	Cap	1	0.68	40	40 PF	59	97	high (1090)
	Cap	2	0.63	40		43	81	
	Control	3	0.09	40	60 PF	3	4.4	
N37	Cap	1	1.64	100	100 PF	13.5	23	low (218)
	DS[b] Cap	2	1.03	100		12	15	
	DS Cap	3	0.48	100		11	11	
	Control	4	0.28	40	45 PF	4	5	

[a] See figures for soil sample locations

[b] DS = Downslope of

[c] For complete chemical analysis see Appendix D

[d] For an explanation of conductivity units see Appendix A

(Appendix D). At Sump B62 the soil conductivities are low but the differences between conductivities of the capping soil and control soils are large (.09 to .68 mS/cm). However in this case the conductivity differences are more a function of differences in soil type, (the undisturbed control soils being organic and the capping material a mixture of organic and mineral soils) as well as small increases in sodium, calcium and sulphates in the capping soil.

Revegetation efforts were not successful at any of the sites. Seeded cover was less than 10% at B62 and B53, and less than 1% at N37. Common species were creeping red fescue, bluegrass and timothy. Surface soils were classified as non saline (Dumanski, 1978) and salinity levels were rated as having a negligible effect on the growth of most plants (Richards, 1969).

3.2.2 EM31 Apparent Conductivities

Site B53 (Figure 4) had very low apparent conductivities over the entire site (less than 6 mS/m), which indicates frozen ground and no indication of conductive fluids inside or outside the sump. This agrees well with information received from INAC (personal comm. Dan Elliot) that this sump developed a leak during the drilling operation and all the fluid escaped. The fluid was rated as having a very low ion concentration (Table 3) and there is no indication from EM31 readings as to where the fluid has gone.

The apparent conductivity values measured at Site B62 (Figure 5) indicate the presence of very conductive sump fluids. These conductivity values reached 120 mS/m for the

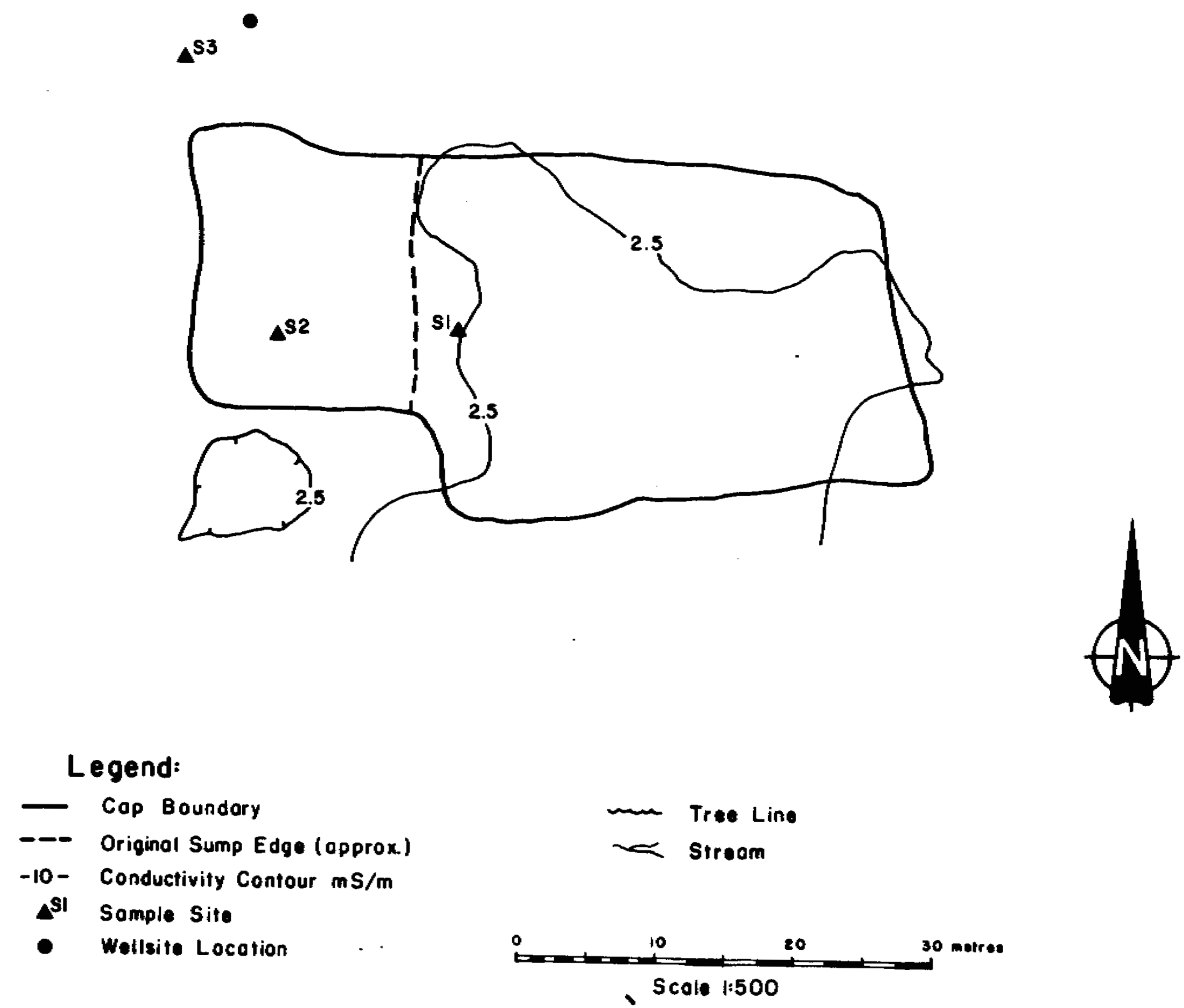

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Figure 4.
Apparent Conductivity Contour Map: B53
Depth of Investigation 7.0m
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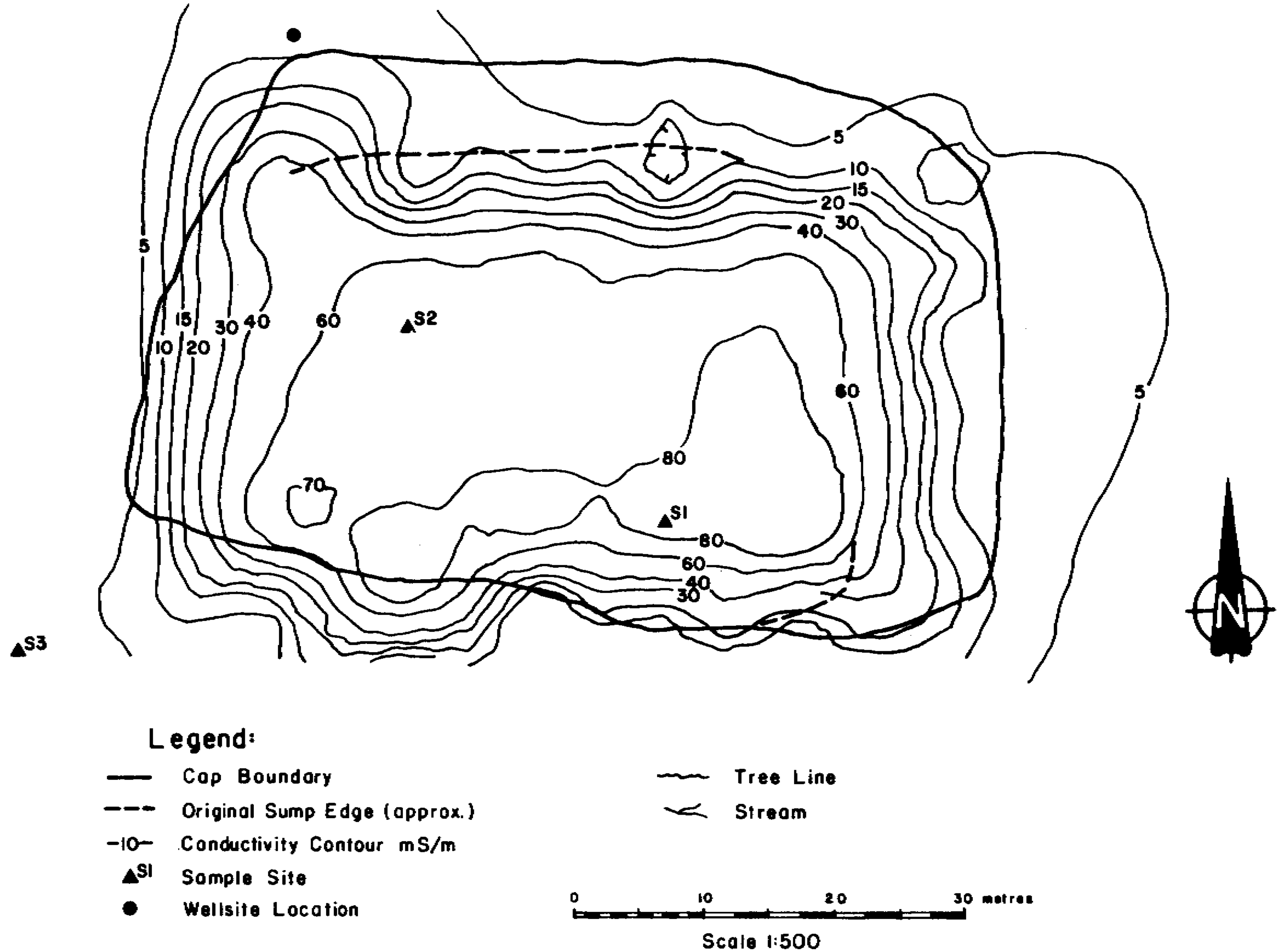

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Figure 5.

Apparent Conductivity Contour Map: B62

Depth of Investigation 7.0m

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7.0 m depth of investigation (Figure C8, Appendix C). Background values were less than 4 mS/m, which is indicative of frozen ground. The conductivity contours shown on Figure 5 do not suggest any migration of contaminants away from the sump. Although several of the high conductivity contours plot outside the southwest corner of the sump, this is due to edge effects (ie. the conductive material within a sump can influence the conductivity measurement within a 5 m radius). The ion concentration rating for this sump (Table 3) is high which corresponds well with the geophysical data.

Site N37 (Figure 6) is situated in a burned-out area and has a sump cover of dry sand and silt. The apparent conductivity data show above-background levels near the center of the sump (20 mS/m vs. 5 mS/m background). A 15 mS/m contour is protruding away from the sump in a downslope direction and may indicate a migration of wastes from the sump. It is possible, however, that this contour reflects the wet surface clay layer observed at this site. Surface soil analysis indicates somewhat higher soil conductivities both on the sump cap and downslope of the cap (Table 3). Whether this is from seepage or from surface contamination during clean-up could only be determined by obtaining soil samples from depths of several meters. There is a marginal correlation between the surface soil conductivities and apparent conductivities ($r=0.80, P< 0.10$).

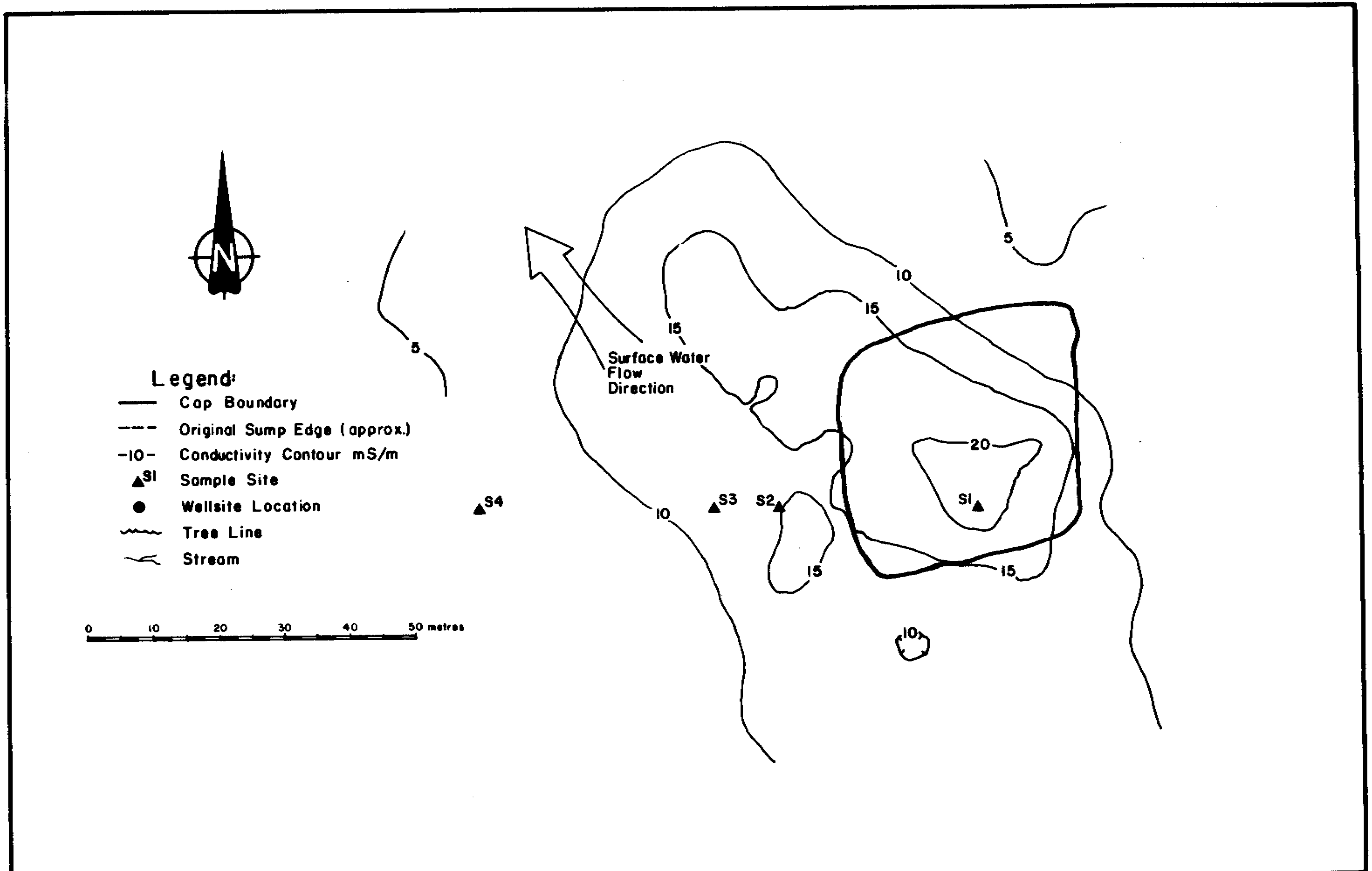

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Figure 6.
Apparent Conductivity Contour Map: N37
Depth of Investigation 7.0m
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3.3 CONTINUOUS PERMAFROST ZONE - D52, L28, and D20

3.3.1 Soils/Vegetation

Soil conductivity readings for surface soils of sumps in this zone varied widely with one sump essentially showing no differences in salt concentration on and off the cap and two sumps having large differences indicative of salt movement out of the sump (Table 4).

Although rated as having a sump fluid of medium salt concentration (Table 4), L28, located in the outer delta of the Mackenzie River, showed relatively low and uniform soil conductivities for both the sump cap (1.10 mS/cm) and nearby controls (1.66 mS/cm). In contrast both D52 and D20 showed large soil conductivity differences between control and capping soils (0.26 to 10.9 mS/cm and 0.96 to 13.5 mS/cm respectively) (Table 2). High soil conductivities both on the cap and at areas away from the cap suggest a movement of salts away from the sump at both sites. Both sites show visual signs of erosion of the sump cap. At D52 water intercepted by the upper edge of the cap has resulted in small channels being eroded along the downslope perimeter. At D20 there is less channelling but the presence of a sediment plume in the lower corner of the sump indicates the direction of water flow.

Revegetation efforts have been made at all three sites with plant cover ranging from 20% to 40% at D52 and D20 to less than 2% at L28. The most common seeded species (especially at D20) is Nugget Kentucky bluegrass followed by native invaders wild barley, tall arctic grass, hairgrass and sedge (Hultén, 1968). While soil salinity at L28 is quite low and not a

TABLE 4. NEAR SURFACE SOIL CONDUCTIVITY AND APPARENT CONDUCTIVITY (EM31) ON SELECTED DRILLING SUMP SITES IN THE CONTINUOUS PERMAFROST ZONE, MACKENZIE VALLEY N.W.T. AUGUST 1987

Site	Sample #		Soil[c] Conductivity (mS/cm)	Sample Depth (cm)	Permafrost (PF)/Water Table (WT) Depth (cm)	EM31 Apparent Conductivity[d] (mS/m)		Ion Concentration Rating of Drilling Fluid
						3.5 m	7 m	
D52	Cap	1[a]	10.90	80	80 PF	37	29	low (279)
	DS Cap	2	9.05	80		20	20	
	DS Cap	3	0.75	80		6.5	7	
	Control	4	0.26	20	30 PF	3	4.5	
L28	Cap	1	1.10	60	70 PF	11	11	medium (430)
	Cap	2	1.09	60		10	10	
	DS[b] Cap	3	1.41	60		12	12	
	Control	4	1.66	60	70 PF	10	8.5	
D20	Cap	1	13.50	60	80 PF	74	81	very high (2724)
	DS Cap	2	2.70	60		41	21	
	DS Cap	3	8.80	60		55	48	
	DS Cap	4	9.70	60		50	38	
	Control	5	0.96	60	60 PF	5	5	

[a] See figures for soil sample locations

[b] DS = Downslope of

[c] For complete chemical analysis see Appendix D

[d] For an explanation of conductivity units see Appendix A

factor in the low plant cover at this site, salinities at D20 and D52 are high enough in places to limit the growth of most plants. At D52 surface soils at sample sites 1 and 2 (Figure 7) are in the 4-5 mS/cm range (Appendix D) which is considered restrictive to the growth of many plants (Richards, 1968). At D20, surface soils at sites 1,3 and 4 have conductivities of 22.5, 18.1 and 10.7 mS/cm respectively (Appendix D) all highly to extremely limiting to the growth of plants. Geophysical conductivity contours associated with these surface readings roughly outline the areas of lowest vegetation cover, the 15 mS/cm and higher contours for D52 and the 40 mS/m contour and higher for D20. This does not hold true in more than a rough fashion because the salinity at depth is not always reflected in higher salinity levels at the surface (eg. site B62). The lack of plant cover at L28 may be for a variety of reasons such as poor seed, improper species etc. none of which are obvious from a site visit.

3.3.2 EM31 Apparent Conductivities

Site D52 (Figure 7) showed signs of accelerated erosion especially around the cap perimeter. The apparent conductivity contours indicated a background level of less than 5 mS/m for the frozen tundra. Although the sump ingredients were rated as having a low ion concentration, the conductivities recorded over the sump ranged as high as 48 mS/m for the 3.5 meter depth of investigation in the southeast corner of the sump (Figure C11, Appendix C). The shallower depth readings were higher than the deeper ones, indicating a shallow source for the conductive material. This is consistent with the observation that the permafrost table is close to the ground surface on this site, and hence any

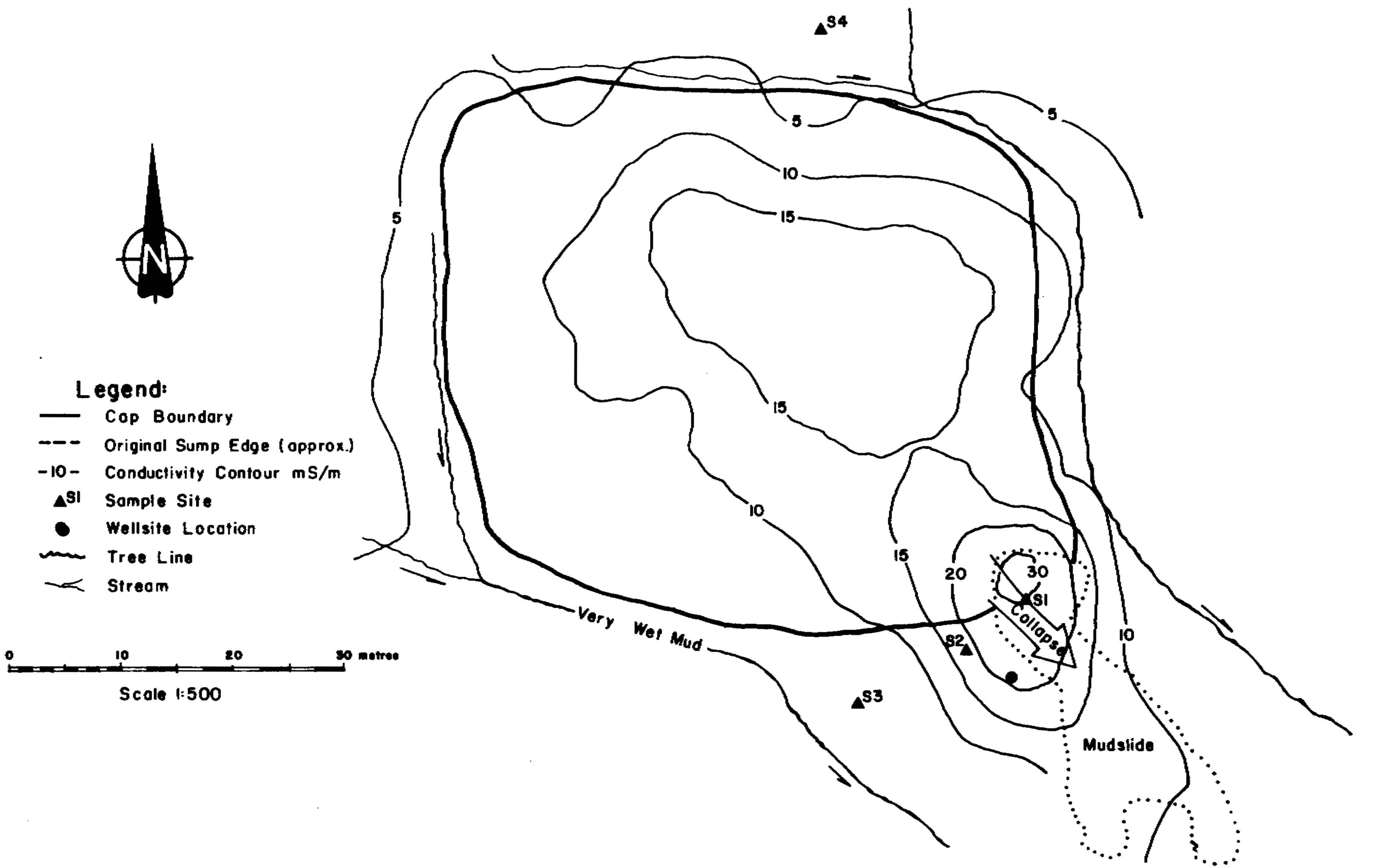

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Figure 7.
Apparent Conductivity Contour Map: D52
Depth of Investigation 7.0m
CE00947

HBI T 15 - 87/05

migration of contaminants would be within the active layer. In addition, the high apparent conductivities observed on this site shows a high correlation ($r=0.94$, $P<0.05$) with the near surface soil conductivities presented in Table 2.

At Site L28 (Figure 8) there were no significant differences observed in the apparent conductivities between the sump and background; background readings were ranging between 8.5 and 10 mS/m and sump cap readings between 10 and 11 mS/m (Table 4). That the fluid ingredients for this sump were rated as having a medium ion concentration (1.5 times that of D52) suggests that these fluids may no longer be present at this site.

Site D20 (Figure 9) is in an area of shallow permafrost as is indicated by background apparent conductivity readings of 5 mS/m. The ion concentration of the fluids at this site were rated as very high. The conductivity contours indicate the presence of sump fluids both in the sump and migrating outward in two locations. Here, again, the readings at the shallower depth of investigation are higher, reaching 74 mS/m in one of the contaminant plumes (Figure C15, Appendix C) indicating near-surface contaminants. As at D52, the apparent conductivities show a high correlation ($r=.91$, $P<0.05$) with the surface soil conductivities.

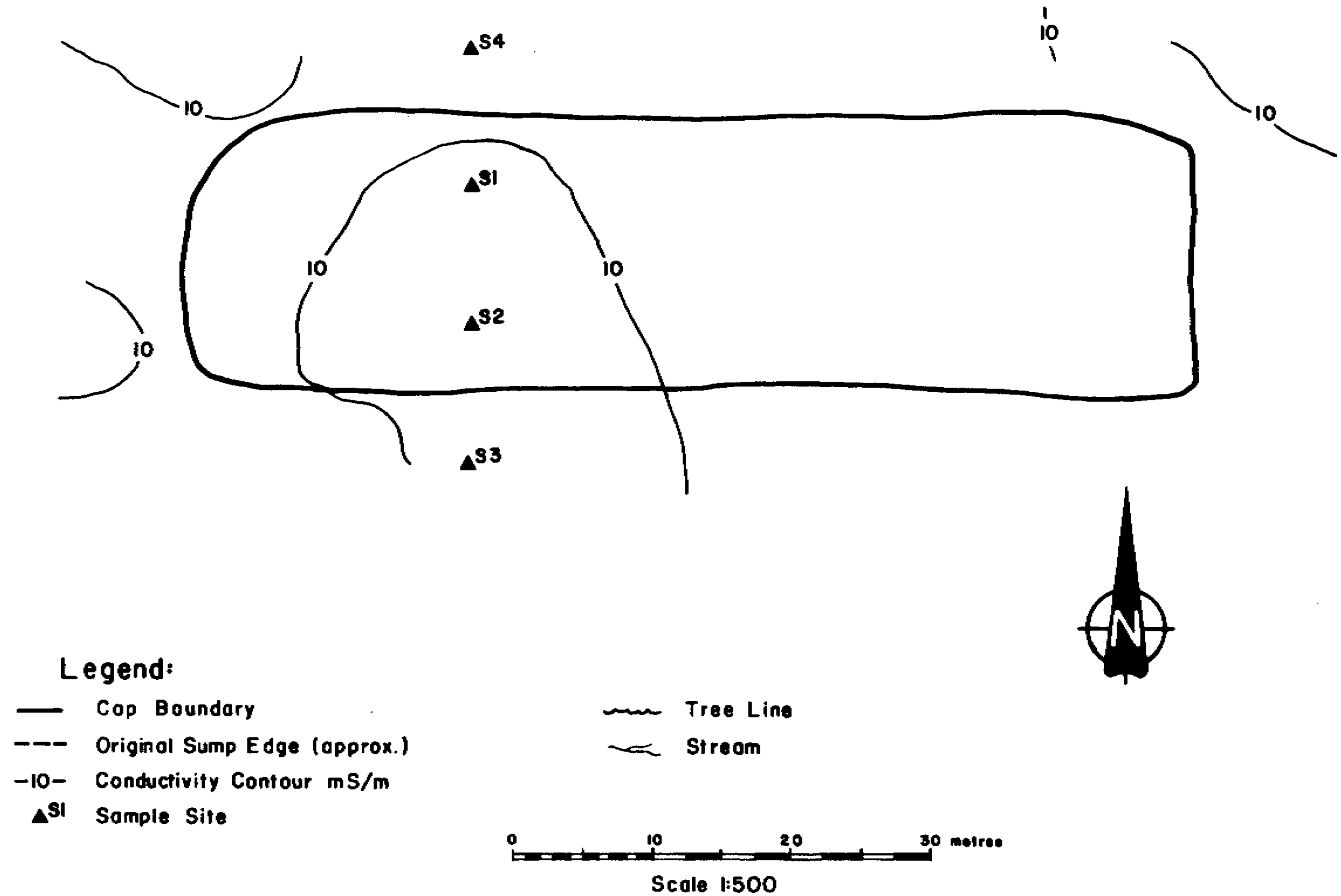

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Figure 8.
Apparent Conductivity Contour Map: L28
Depth of Investigation 7.0m
CE00947

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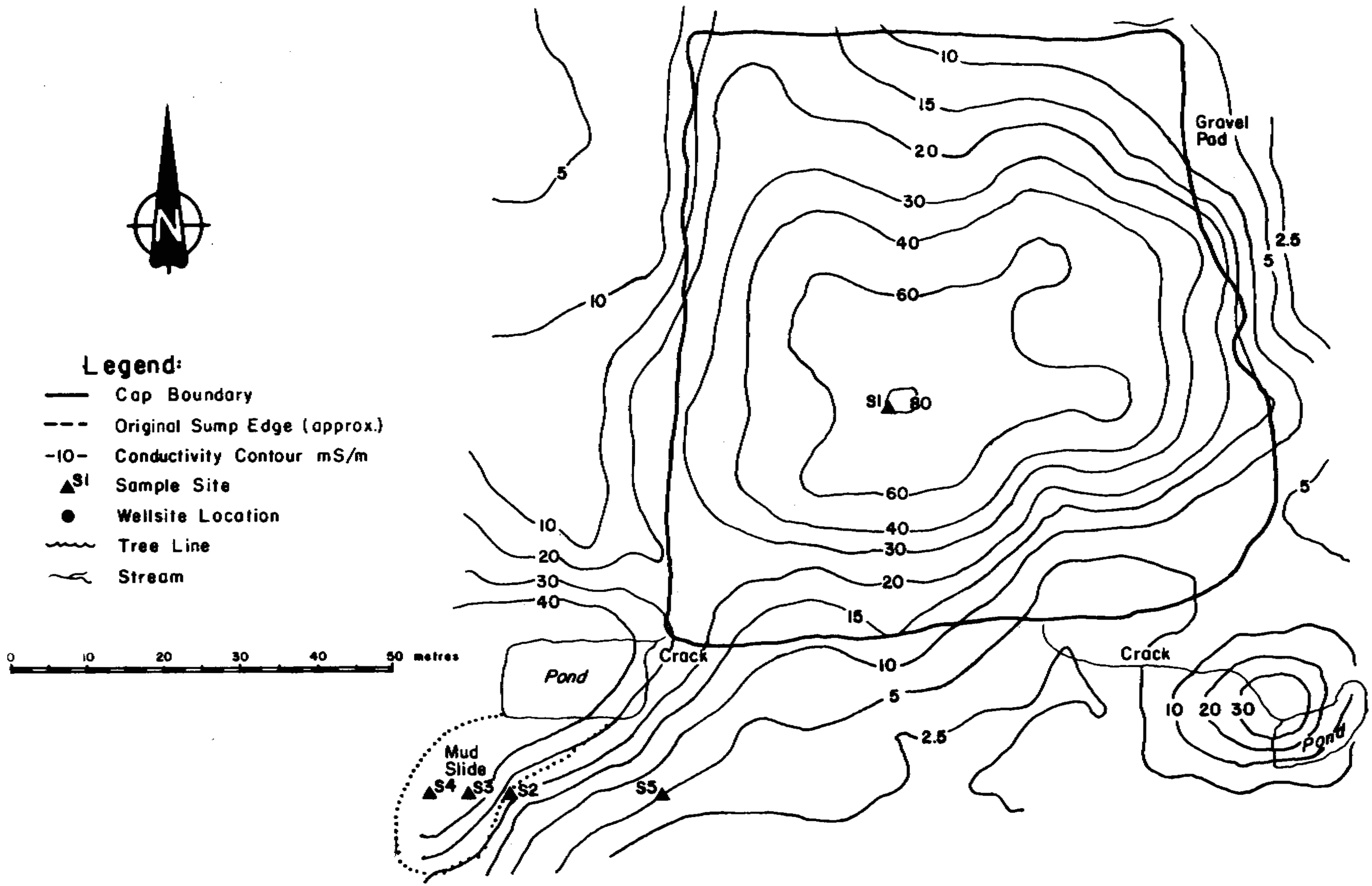

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Figure 9.
Apparent Conductivity Contour Map: D20
Depth of Investigation 7.0m
CE00947

4.0 DISCUSSION

4.1 GEOPHYSICAL EVIDENCE OF CONTAINMENT

This survey was to provide evidence, using geophysical soil conductivity measurements, of the success of waste drilling fluid containment in abandoned sumps. Eight sumps were examined over a range of permafrost conditions and contour maps of apparent conductivity at 3.5 m and 7 m were interpreted along with the results of the surface soil chemical analysis. Because salts are a common ingredient of most sump fluids and because inductive geophysical techniques respond positively to salt concentration, the use of geophysical methods is appropriate for detecting and outlining the location of salt bearing fluids. The use of this method assumes, however, that detectable concentrations of salts are in the fluid and that other factors known to effect apparent conductivity readings can be accounted for or explained. As an indirect measurement of soil conductance, geophysical methods do not provide conclusive evidence of the cause of any detected change in soil conductance and must be combined with other forms of evidence to develop a reasonable hypothesis. Apparent conductivity readings well above background levels, as was the case in several sumps, are reasonable evidence of increased soil conductivity at depth. However, to assess if this is related to salts, other factors which are known to effect apparent conductivity readings such as permafrost, soil moisture and soil texture must be eliminated by reviewing the background levels and evaluating the magnitude of the increase.

It is not possible to define actual salt concentration levels from apparent conductivities. This can only be determined by analysis of soil samples taken at depth. Surface soil samples, particularly in areas suggestive of seeps, may provide some indication of the nature of salt contamination at depth.

Where apparent conductivities are low and near background levels one may assume that either the fluids have seeped away or they are fully contained but too low in salts to be detectable. Under these circumstances it is important to look at those factors which influence containment and detectability. In this study these included the existance of permafrost, texture of subsurface materials, depth of water table, chemistry of the drilling fluids and surface contamination.

4.2 ENVIRONMENTAL ISSUES

The possibility of sumps leaking raises questions concerning the potential for environmental hazard. Past studies have suggested that the greatest hazard from waste drilling fluids was related to their salt content and in some cases to diesel fuel (Younkin et al, 1980; Millar and Honarvar 1975). Heavy metals, often a concern, are generally in low levels or tied up in unavailable forms. Concern remains because of the variety of ingredients that can go into a drilling mud, many of which have not undergone complete environmental testing.

This study identified that a number of the sumps are possibly leaking, however, it was not designed to deal with environmental issues. Plant establishment on abandoned sumps was looked at primarily as it was affected by salt concentrations in the surface soils. Revegetation success was generally poor with only 3 of 8 sumps having a plant cover of greater than 20%. On only two of the sumps (D20 and D52) were salt levels high enough in localized areas to hinder the establishment of grasses. On much of the remainder of these two sites grass cover ranged from 20 to 40%. On the remainder of the sumps soil chemistry did not restrict plant establishment and the application of the appropriate seed mix to a properly prepared and fertilized surface should have resulted in the establishment of a good grass cover. Numerous abandoned sumps and other disturbances have been seeded over the past 15 years in the Mackenzie Valley region and revegetation covers between 20 to 30% after two growing seasons should be expected in most locations (Hardy Associates 1980; Younkin and Martens 1985).

5.0 CONCLUSIONS

The collected evidence regarding the likelihood of fluid containment was evaluated for each of the eight sumps and each sump was given an overall containment rating ranging from definite leakage to probable containment. On this basis six of the eight sumps were rated as having some likelihood of leakage. The sump ratings and evidence are presented below:

1. The sump at B53 was rated as a definite leakage on the basis of land use inspection reports which indicated that this sump was noted as leaking during the drilling operation and that there were no fluids in the sump at the time of capping. Without the land use report it would have been difficult to determine that this sump had leaked as it was over permafrost, had a fluid with a very low ion concentration rating and apparent conductivities as well as surface soil chemistry showed no indication of salts.

2. Two sumps, D52 and D20, were rated as having a high probability of leakage. Both had very high apparent conductivities over the sump as well as in drainage channels leaving the sump. In addition the salt concentrations of surface soils were strongly correlated with the areas of high apparent conductivities. Surface erosion was evident at both sites and corresponded closely with the areas of suspected leakage.

3. Three sumps, F8, J29, and N37, were rated as possible leakages. At F8 and J29 waste drilling fluid ion concentration levels were rated as low and apparent conductivity readings and surface soil conductivity

readings were similar to background levels. As well both sumps were in a clay till material which is considered reasonably impermeable. However both sites were permafrost free and had water tables within 30 cm of the surface. Although the terrain here is nearly level, a great deal of water held in surrounding peat bogs seeps through this region during the summer and it seems likely that the supernatent portion of the waste fluids has thawed and gradual seepage is taking place.

At N37 the waste drilling fluid was rated as having a low ion concentration yet there was a definite zone of higher conductivity over the sump and somewhat higher moving away and downslope from the sump. In addition surface soils chemistry was somewhat correlated to apparent conductivities. It is possible, however, that the high conductivity zone moving away from the sump represents only surface contamination related to well site activities.

4. Sump L28 was rated as probable containment. Although the sump fluid was rated as low to medium in ion concentration, apparent conductivities and surface soil salinity measurements were similar to background levels. Geophysical evidence indicated that even with the close proximity of the river channel that subsoils were frozen to 7 m and probing of the surface showed the permafrost table at 60 cm. Although this area undergoes regular flooding the existance of permafrost both on the surface and at depth suggests that these fluids are still in place.

5. Sump B62, was rated as a highly probable containment. This sump located over permafrost had a sump fluid with a high ion concentration rating. Apparent conductivity contours showed high values and a steep gradient right to the edge of the sump. No where did the high conductivities indicate a plume or seep. Surface soil samples showed no indication of surface contamination and did not correlate with contours of high apparent conductivities.

In summary, a combination of all available evidence indicates that:

1) One sump (B53) was known to have leaked.

2) Two sumps (D52 and D20) were rated as having a high probability of leakage.

3) Three sumps (F8, J29 and N37) were rated as having some possibility of leakage.

4) One sump (L28) was rated as a probable containment.

5) One sump (B62) was rated as a highly probable containment.

6.0 RECOMMENDATIONS

6.1 OPERATIONS

From investigation of 8 sumps it appears that poor containment resulted primarily from factors related to the location of sumps. The following are recommendations from this study to enhance the containment of drilling wastes in sumps.

1. Locate sumps on flat or gently rolling terrain. Avoid side hill locations.
2. Avoid conflict with natural drainage and if necessary install appropriate drainage and erosion control measures.
3. In non-permafrost areas do not install sumps at sites with a high water table.
4. Enhance freezing of fluids with a high salt content by diluting them during discharge into sumps.
5. Implement an inductive conductivity survey on future sumps at the time they are closed to provide a baseline should their containment be questioned in the future.

6.2 EXTENSION OF PRESENT STUDY

Selected abandoned drilling waste sites examined in the present study should be revisited and deep soil sampling (5-7 m) and detailed chemical analysis (salts, heavy metals organics) undertaken to confirm and expand the results of the geophysical survey. A second geophysical survey should be run at that time to determine if there are any changes in the areal extent of waste fluid zones from the previous year. Sites visited on a priority basis should include:

1. D52, D20 and N37. Deep sampling and detailed chemical analysis should be undertaken at these sites to define the boundaries of waste fluid in the sumps and in apparent seepage zones away from the sumps. Where seepages are confirmed the environmental hazard should be assessed and plans for stabilization and rehabilitation developed.

2. L28, B62 and F8. Samples should be collected from appropriate depths and detailed chemical analysis undertaken to confirm the location and chemistry of fluid contained within the sump.

6.3 FUTURE STUDIES

As a reconnaissance survey this study was to provide a general assessment of the containment of waste drilling fluids in abandoned sumps. The results of the study suggest that leakage or seepage is more prevalent than expected. A key question which needs to be dealt with in any future work is does seepage from abandoned sumps pose a significant environmental hazard? Because of the potential range in both drilling fluid ingredients and receiving environments this question can not be easily answered. Two basic approaches are available - 1) an environmental assessment of all potential fluid components and combinations using standardized laboratory procedures, or; 2) an environmental assessment of selected environmental parameters at representative abandoned sump locations. The first approach, while more precise in terms of standarized testing of various fluid components, is only a rough approximation of what is actually deposited in an abandoned sump and what may happen in that environment. The second, while less precise, uses abandoned sumps and the local environment as a source of information concerning environmental hazard. As well the latter has the advantage of allowing an assessment of field practice in sump location, construction and abandonment.

Approximately 1500 wells have been drilled in the Yukon and Northwest Territories and a great deal of information concerning drilling operations is available in industry and government files. A proper selection and organization of this information towards environmental hazard assessment would be the first step in a process leading to the classification and cataloguing of environmentally pertinent information on all abandoned sumps. Based on this, representative sumps could be selected for field investigation and assessment of containment, environmental hazard and appropriateness of current practice. A more detailed breakdown of these recommendations is as follows:

1. Catalogue and classify the approximately 1500 sumps in the Territories. Information should be collected from both operators and government agencies, the latter including GSC, COGLA and INAC. A standard set of data should be abstracted for each site, formulated and stored in a microcomputer database (dBase III+). Data should include site location, terrain type, vegetation type, proximity to water bodies, sump dimensions, date of caping, drilling mud system, sump fluid ingredients, etc. Such a database would provide land managers with a quick reference on location and basic environmental parameters known about each site.

2. On the basis of 1 above;

   a) select representative sumps from which to collect field data to assess containment and environmental implications,

   b) conduct a geophysical survey to detect and map zones of potential leakage,

c) collect water, soil and vegetation samples for chemical analysis. Analysis could be tailored to the ingredients known or suspected to be in the sump or could be comprehensive and include standard characterization tests (eg., pH, EC, ions, etc.) as well as ICP/AA analysis for trace elements and heavy metals and trace organics by gas chromatography,

d) implement field reconnaissance to evaluate sump location, construction clean-up, abandonment and rehabilitation practices,

e) evaluate the environmental implications of each sump, based on the results from the chemical analysis,

f) recommend improvements concerning sump location, construction, clean-up, abandonment and rehabilitation practices to limit potential environmental impact.

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APPENDIX A

DESCRIPTION OF THE PRINCIPLES OF OPERATION

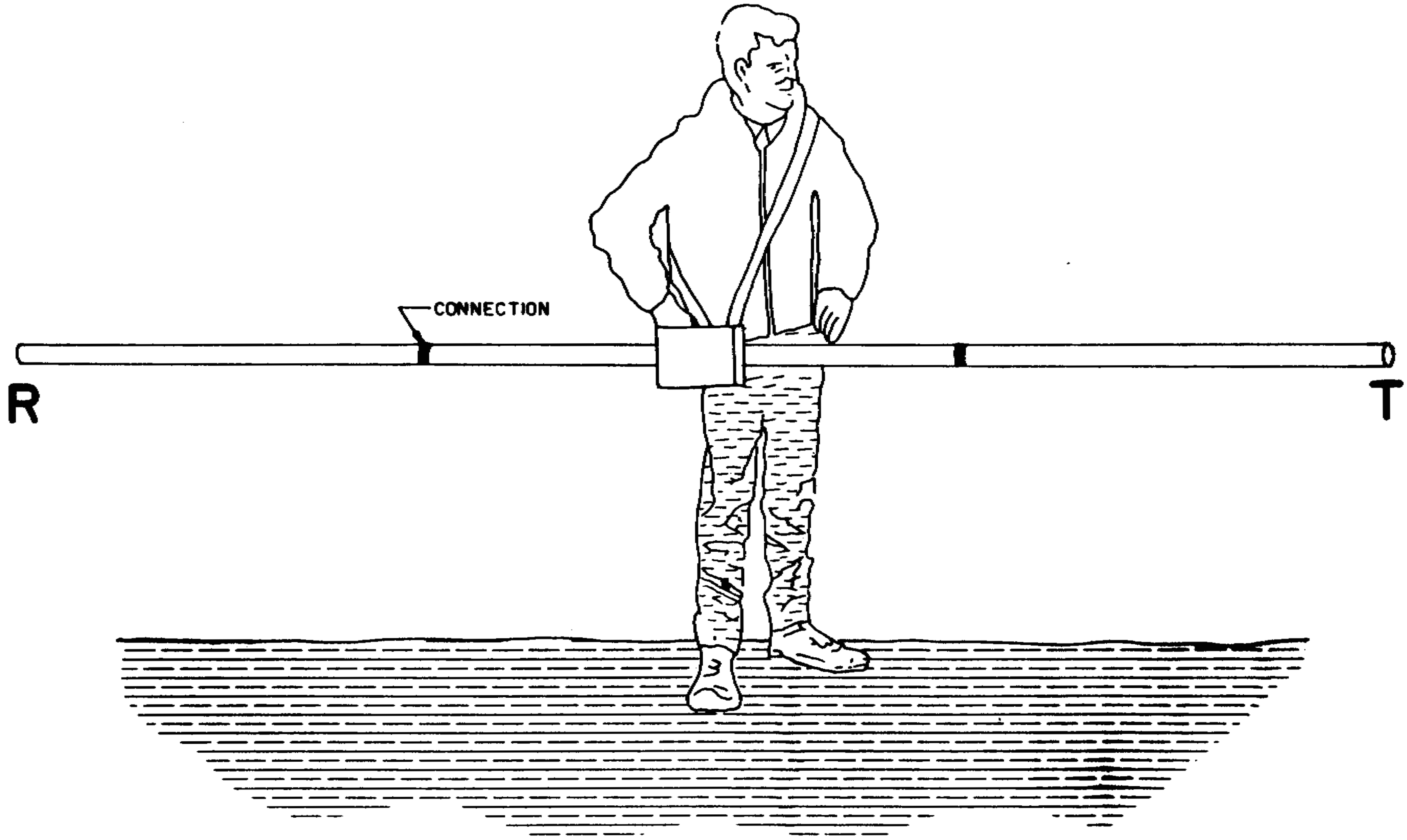
INDUCTIVE CONDUCTIVITY-MEASURING SYSTEMS

GEONICS EM 31

The Geonics EM 31 system consists of transmitter and receiver coils mounted in the ends of a rigid boom 4 metres in length (Figure 1a). Current flowing in the transmitter coil generates an electromagnetic field which in turn causes small electrical currents, called secondary currents, to flow in the ground under the instrument (Figure 1b). The strength of these currents depends on the resistivity of the ground. These secondary currents in turn create a secondary electromagnetic field which is measured by the receiver coil in the instrument. The instrument is calibrated to read ground conductivity directly. Electrical resistivity is the reciprocal of electrical conductivity and so can be easily calculated.

The operating frequency of the instrument is chosen so that depth of measurement is controlled by the geometry of transmitter and receiver coils. When the plane of the coils is horizontal, penetration is about 7 metres below the instrument; when the plane of the coils is vertical, penetration is reduced by one half. By taking readings in both coil positions it is possible to determine whether the conductivity increases or decreases with depth. The EM 31 is normally carried on the operator's hip, approximately 1 metre above ground surface, and is calibrated for readings in that position. Operation of the instrument on the ground surface provides further penetration.

Over a uniform half space or uniform layering, rotation of the instrument through 90° in a horizontal plane will produce no change in measured conductivity. Thus lateral inhomogeneities in conductivity are indicated if there is a change in the reading as this procedure is



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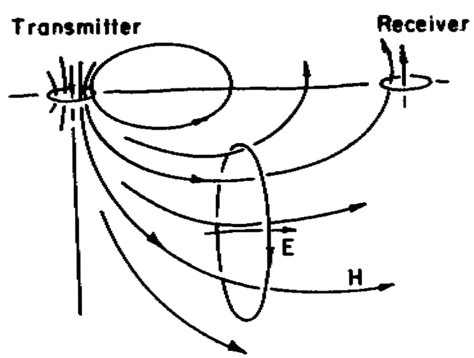
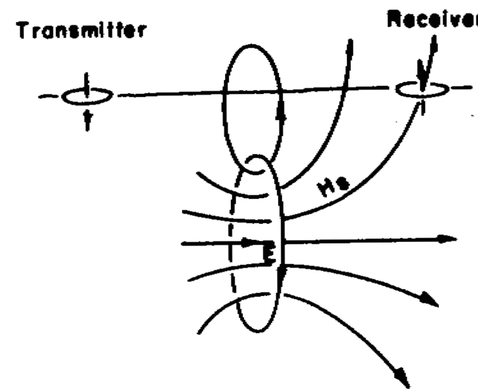
INDUCTIVE CONDUCTIVITY-MEASURING SYSTEMS
SCHEMATIC ILLUSTRATION OF THE GEONICS EM 31

Fig. 1a



a) Transmitter – receiver } coupling
Transmitter – eddy current }



b) Eddy current – receiver coupling

Schematic illustration of the primary magnetic field (H), the eddy current flow (E) in the ground, and the resulting secondary magnetic field (Hs).

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INDUCTIVE CONDUCTIVITY MEASURING SYSTEMS
ELECTROMAGNETIC FIELD RELATIONSHIPS

Fig. 1b

carried out. A local conductor such as a buried pipe gives rise to a sharp, clearly defined response. Figure 2 shows schematically the profile obtained in crossing a buried pipe or cable with the instrument boom perpendicular to the pipe. Directly over the pipe a strong decrease in apparent conductivity is observed. The centre of this minimum is directly over the buried pipe. If the instrument is held over the pipe and rotated about a vertical axis until the boom is parallel to the pipe, the reading will change to a positive value, which is greatest when the boom is exactly parallel to the pipe. This behaviour allows determination of both location and direction of a buried pipe, wire, or other linear conductor.

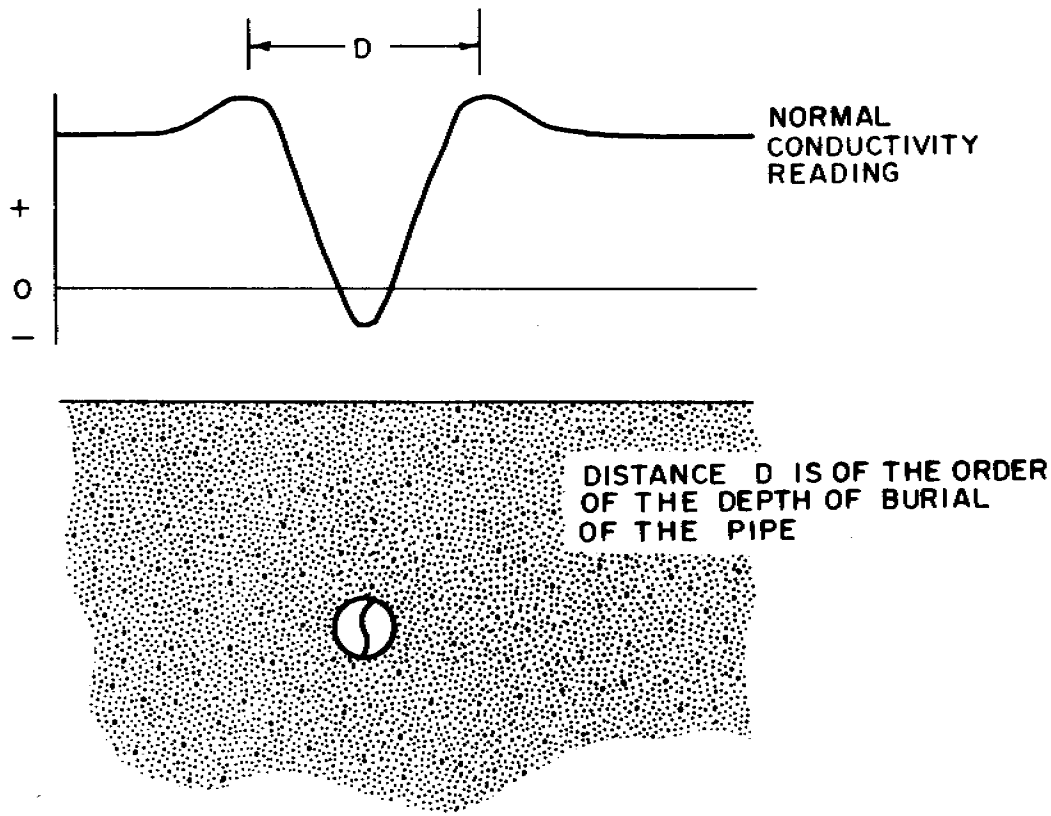
The EM 31 is calibrated to read apparent conductivity directly in millisiemens/metre (mS/m). Conductivity and resistivity are inversely related, and conversion from conductivity to resistivity can be effected as follows:

1 ohm-metre (resistivity) = 1/(1 siemen/metre) (Conductivity)

For example: 100 mS/m = 0.1 S/m = 10 ohm-metres,
= 1000 ohm-centimetres

and 5 mS/m = 0.005 S/m = 200 ohm-metres,
= 20000 ohm-centimetres

The EM 31 can read apparent conductivities as low as about 0.5 mS/m. At low levels such as these, the instrument approaches its limits of resolution and significant errors may be present in the reading. Direct conversion to resistivity may enhance this error. For example, a reading of 0.5 mS/m may contain a 20% error of +0.1.
0.5 mS/m = 200 ohm-m but 0.4 mS/m = 2500 ohm-m. This represents a 25% error in resistivity. Because of this possibility for increased error at low conductivity values, results are normally presented as apparent conductivities rather than being converted to apparent resistivities.



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INDUCTIVE CONDUCTIVITY-MEASURING SYSTEMS
TYPICAL RESPONSE OVER A PIPE

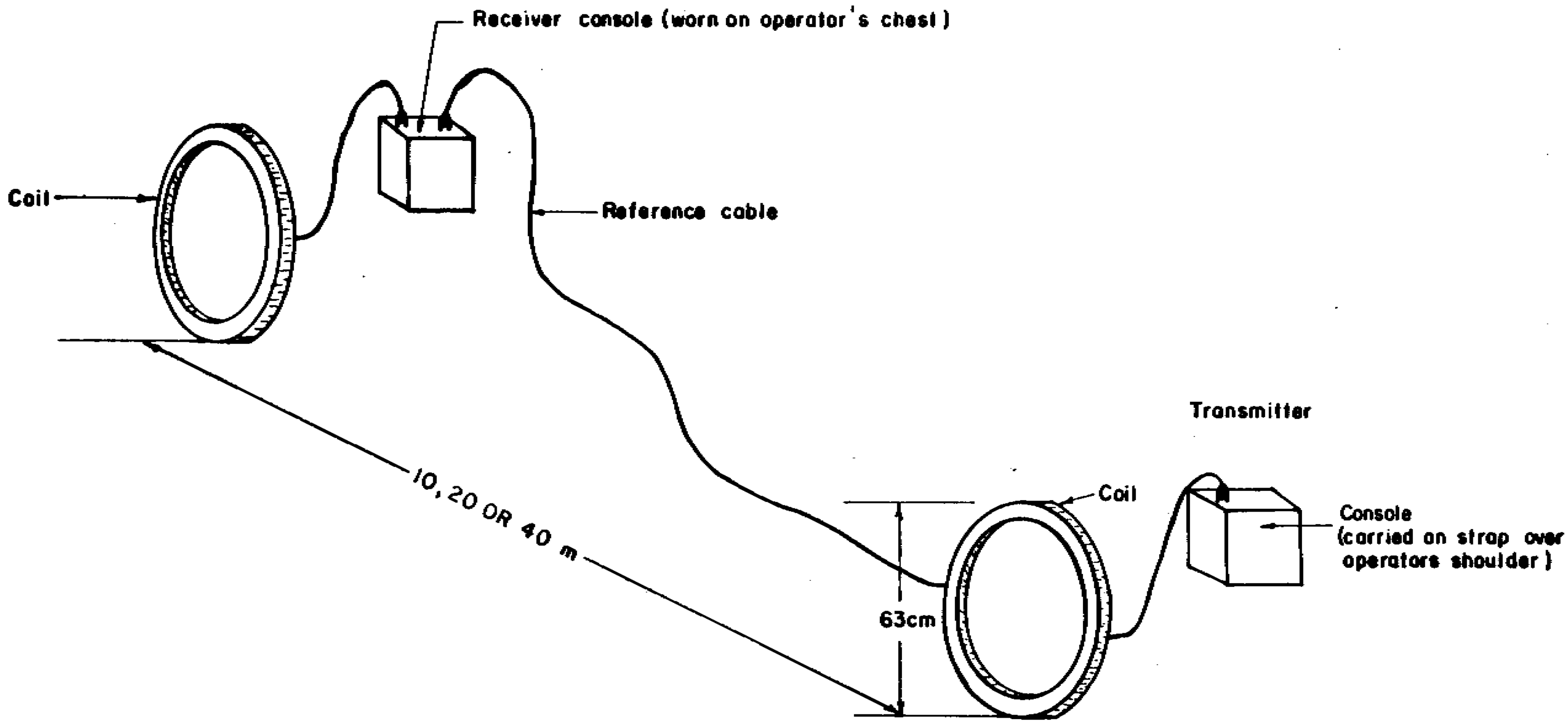
Fig. 2

GEONICS EM 34-3

The Geonics EM 34-3 system is a larger version of the EM 31. The EM 34-3 consists of separate transmitter and receiver coils and consoles, linked by a reference cable (Figure 3). It can be operated with coil spacings of 10, 20 or 40 metres. If the transmitter and receiver coils are held vertical and coplanar, then the observed conductivity represents an average value to a depth of about one coil spacing. This is the normal survey mode for the EM 34-3. If the coils are held horizontal, then penetration increases to somewhat less than twice the coil spacing.

The units of measurement for the EM 34-3 are the same as discussed for the EM 31.

0.118



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INDUCTIVE CONDUCTIVITY-MEASURING SYSTEMS
SCHEMATIC ILLUSTRATION OF THE GEONICS EM 34

Fig. 3

APPENDIX B

LIST OF INGREDIENTS USED IN EACH DRILLING MUD

SULPETRO et al TROUT LAKE J-29
Coordinates 60°38'N; 121°10'W
Land Use Permit N85A447
D.A. NUMBER 1296

BENTONITE Gel 46,440 kg.

CAUSTIC 713 kg

DRISPAC (Polyanionic Cellulose Polymer) 168 kg

SAPP (Sodium Acid Pyrophosphatre) 80 kg

SODA ASH (Na_2 CO 3) 135 kg

SULPETRO et al NORTH TROUT Lake F-08
Coordinates 60°37'N ; 121°01'W
Land Use Permit N85A446
D.A. Number 1295

BENTONITE	45,270 kg
CAUSTIC	782 kg
DRISPAC	92 kg
SAPP	80 kg
SODA ASH	315 kg

YPC - 71 (POLYACRYLAMIDE - Viscosifier) 1432 L.

NSM RESOURCES WINDY LAKE B-53
Coordinates 64°52'N ; 125°40'W
LAND USE PERMIT N83A012
D.A. NUMBER 1202

BENTONITE	23,670 kg
BARITE	21,060 kg
BICARBONATE OF SODA	900 kg
CAUSTIC	805 kg
KELZAN	125 kg
SAPP	360 kg

PETRO CANADA K'ALO B-62
Coordinates 65°11'N 125°27'W
LAND USE PERMIT N85A455
D.A. NUMBER 1309

BENTONITE	30,870 kg
BARITE	11,925 kg
BICARBONATE OF SODA	200 kg
CAUSTIC	1,541 kg
KELZAN	1,525 kg
SALT	102,920 kg
SODA ASH	990 kg

EXCO et al TUNAGO 2N-37
Coordinates 66°07' N ; 126°22' W
LAND USE PERMIT N84A 233
DA NUMBER 1212

BENTONITE	16,020 kg
CAUSTIC	345 kg
DURAPLEX	4770 kg
DURAFOAM	10 BBLS
DIESEL	20 BBLS
KELZAN	275 kg
KWIK SEA	1800 kg
RM-66 (Polymer)	945 kg
SALT	19,783 kg

GULF ONIGAT D-52
Coordinates 68°41'N ; 133°44'W
LAND USE PERMIT N84A274
DA NUMBER 1222

BARITE	3600 kg
BENTONITE	4000 kg
BICARBONATE OF SODA	360 kg
CAUSTIC	598 kg
KELZAN	1,675 kg
POTASH	28,825 kg
SODIUM SULPHATE	69 kg
STAFLO (Polymer)	1,100 kg
SAPP	280 kg

GULF MOBIL PARSONS LAKE D-20
Coordinates 68°59;09"N ; 133°34'25'W
LAND USE PERMIT NUMBER N76A223
DA NUMBER 842

BARITE	92,475 kg
BENTONITE	197,775 kg
BICARBONATE OF SODA	500 kg
CALCIUM CHLORIDE (K CL)	147,925 kg
CAUSTIC	14,329 kg
DIESEL	1,984 BBLS
POTASH	83,900 kg
SODA ASH	1,665 kg
STAFLO (Polymer)	2,725 kg

SHELL et al UNAK L-28
Coordinates 68°47'38.90" N ; 135°22'06.17" W
LAND USE PERMIT NUMBER N85A451
DA NUMBER 1319

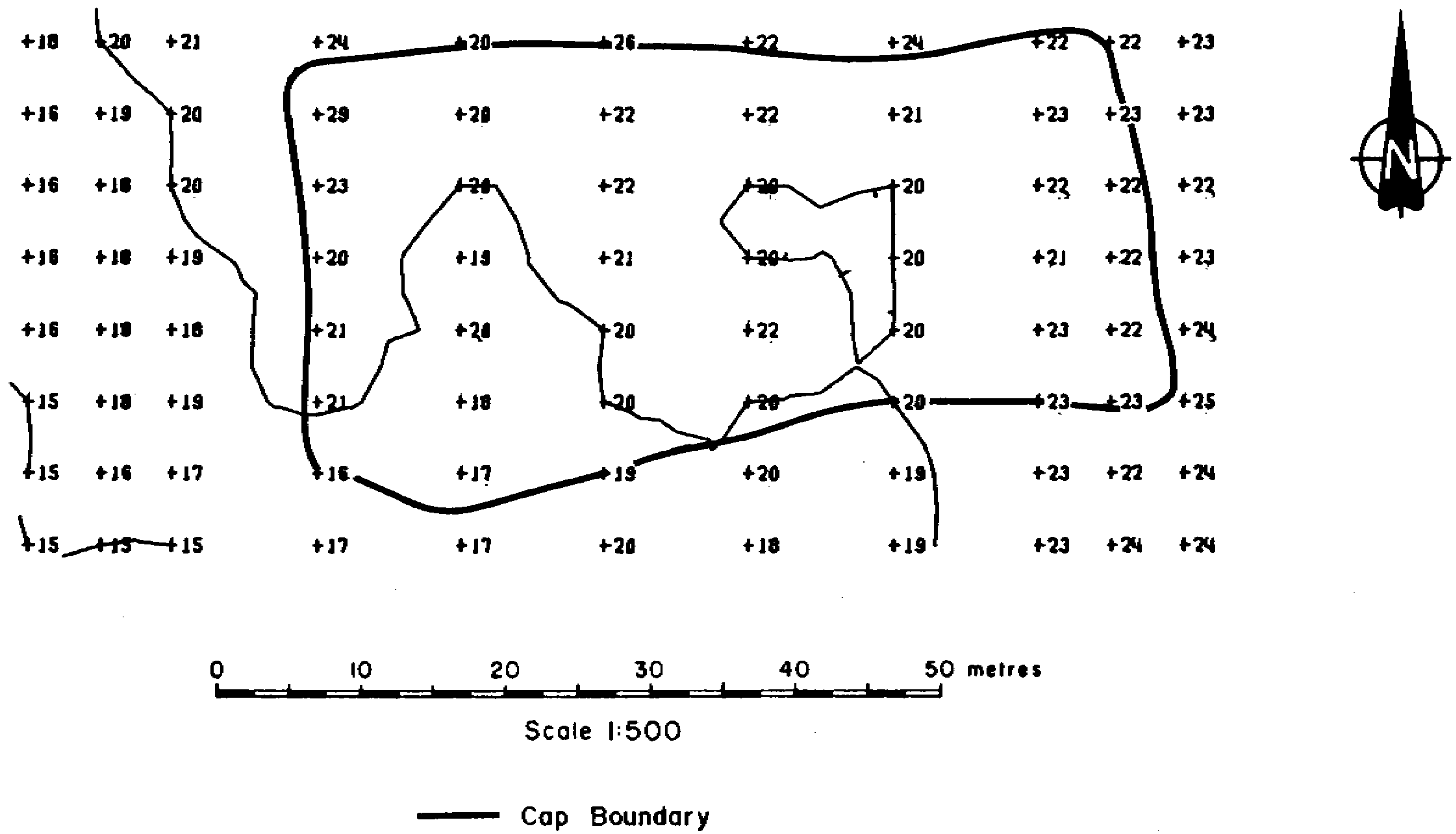
BARITE	172,000 kg
BENTONITE	13,400 kg
CAUSTIC	4,324 kg
DIESEL	662 BBLS
DMS (modified phenol)*	3,000 BBLS
KCL	19,700 kg
LIME	8,595 kg
SODA ASH	80 kg

* technical data is limited - LC50 is approximately 1,300 PPM (discussion w/manufacturer), no data available re salinity or its affect on plant life.

APPENDIX C

APPARENT CONDUCTIVITY CONTOUR MAPS

Contour Interval (mS/m): 2.5
5
10
15
20
30
40
60
80



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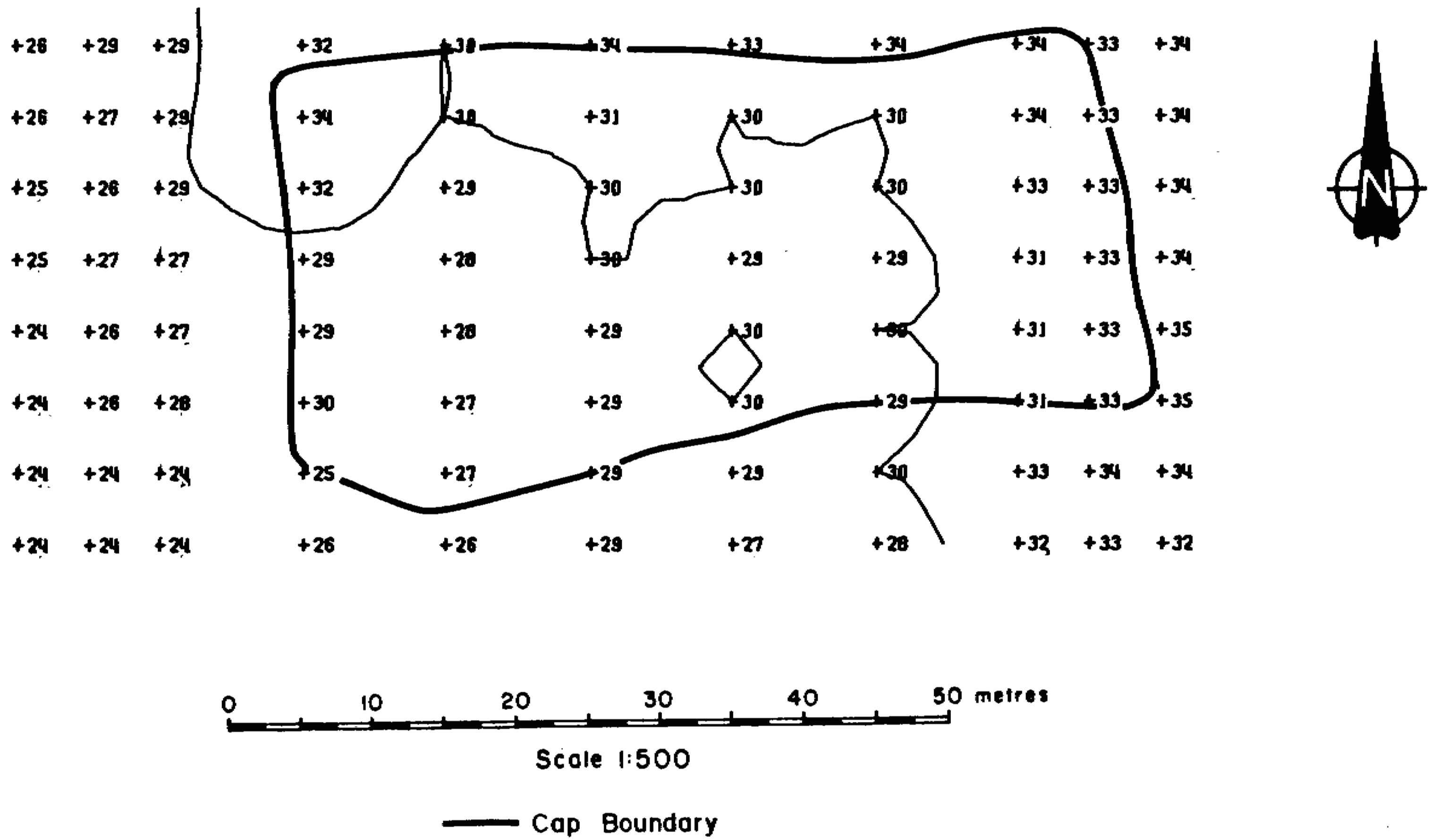
Indian and Northern Affairs Canada
TOTAL CONTAINMENT SURVEY
Apparent Conductivity Contour Map
Depth of Investigation: 3.5m
Site: J29

CE00987

Figure. C.1



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Indian and Northern Affairs Canada
TOTAL CONTAINMENT SURVEY
Apparent Conductivity Contour Map
Depth of Investigation: 7.0m
Site: J29

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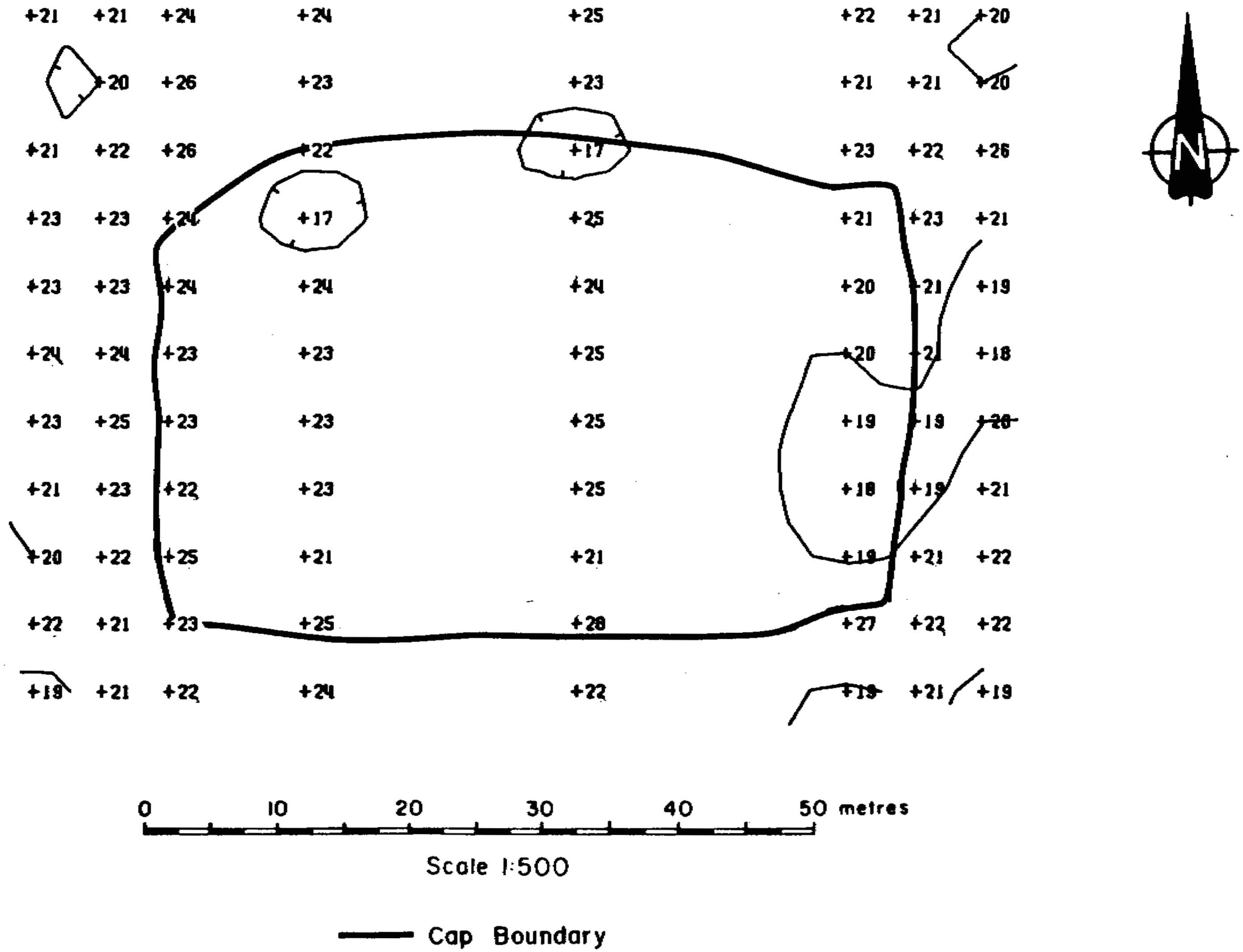
Figure. C.2



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Indian and Northern Affairs Canada

TOTAL CONTAINMENT SURVEY

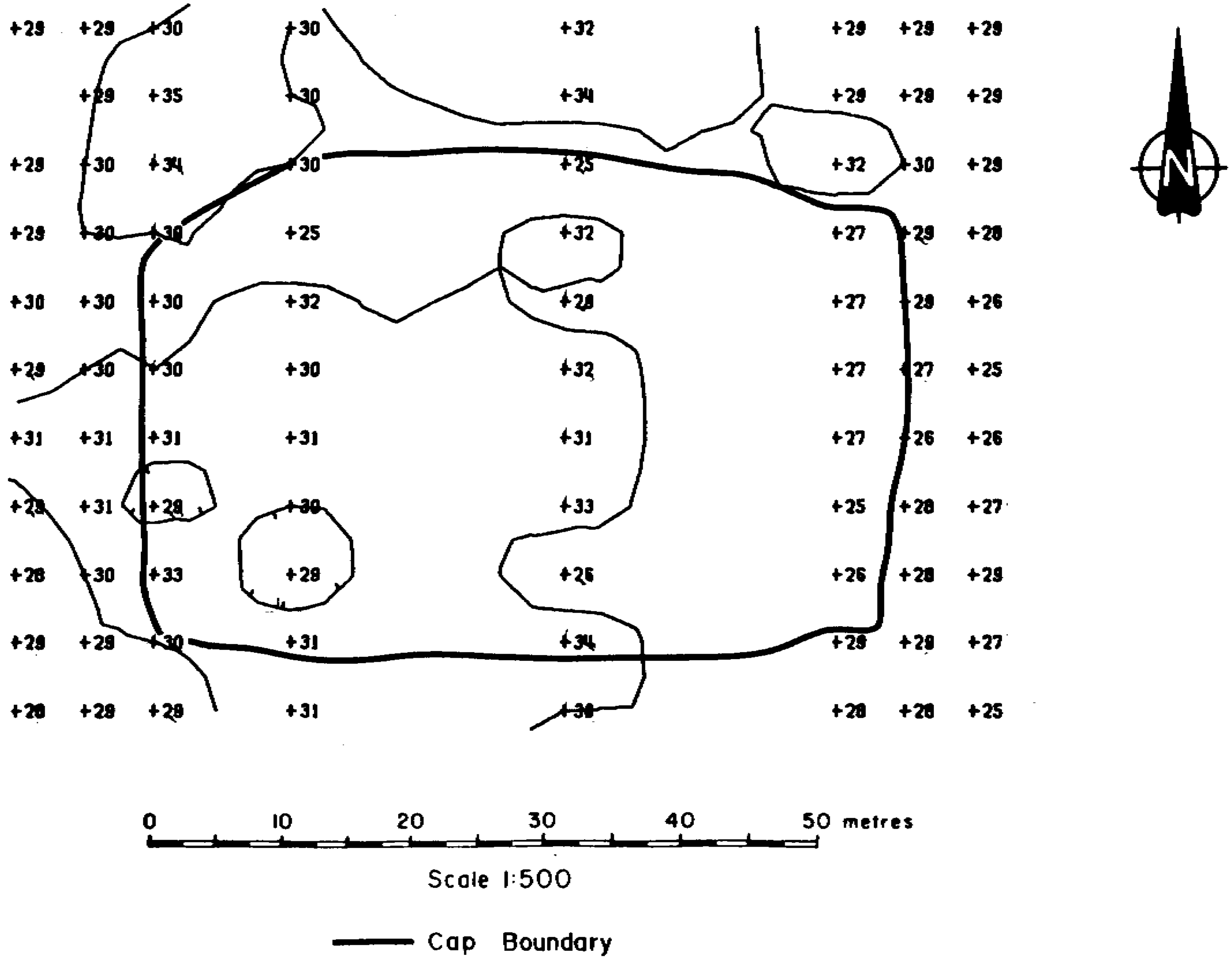
Apparent Conductivity Contour Map

Depth of Investigation: 3.5m

Site: F08

CE00947

Figure. C.3



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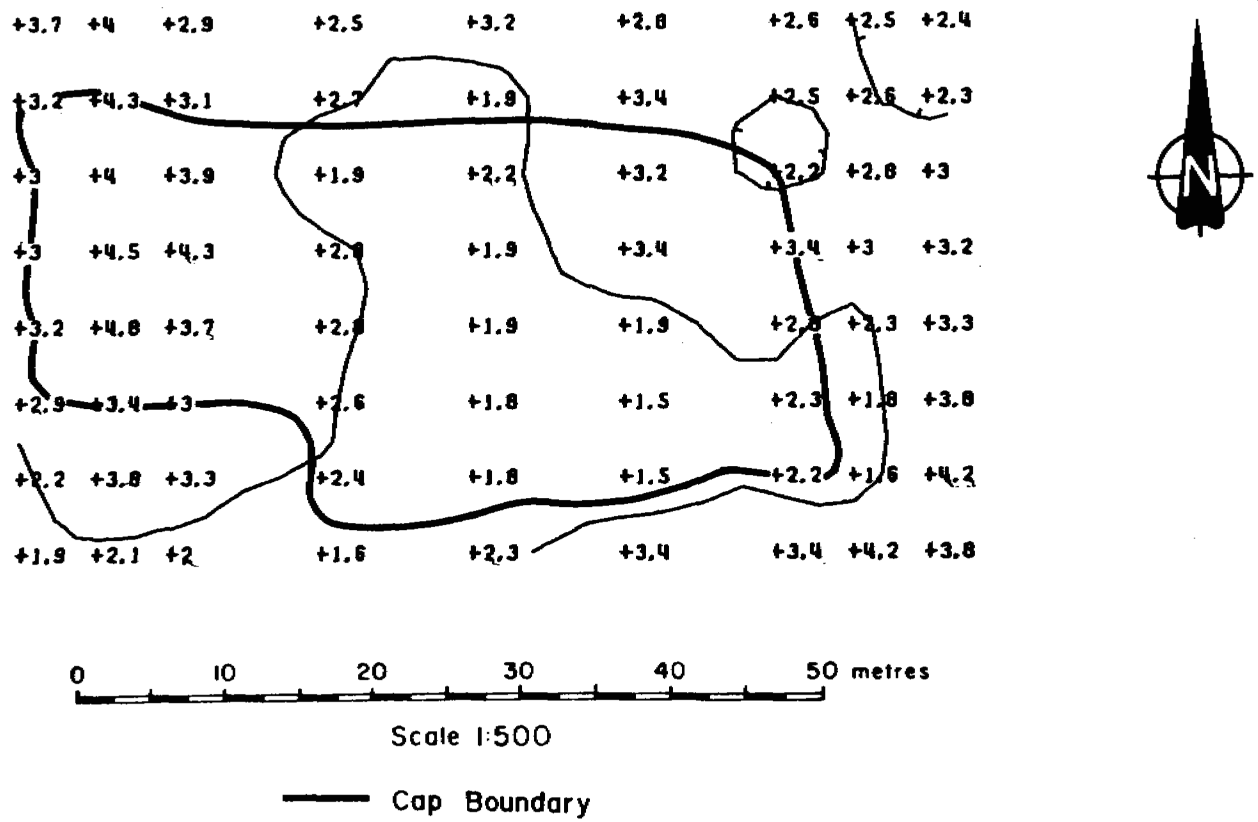
Indian and Northern Affairs Canada
TOTAL CONTAINMENT SURVEY
Apparent Conductivity Contour Map
Depth of Investigation: 7.0m
Site: F08

CE00947

Figure. C.4



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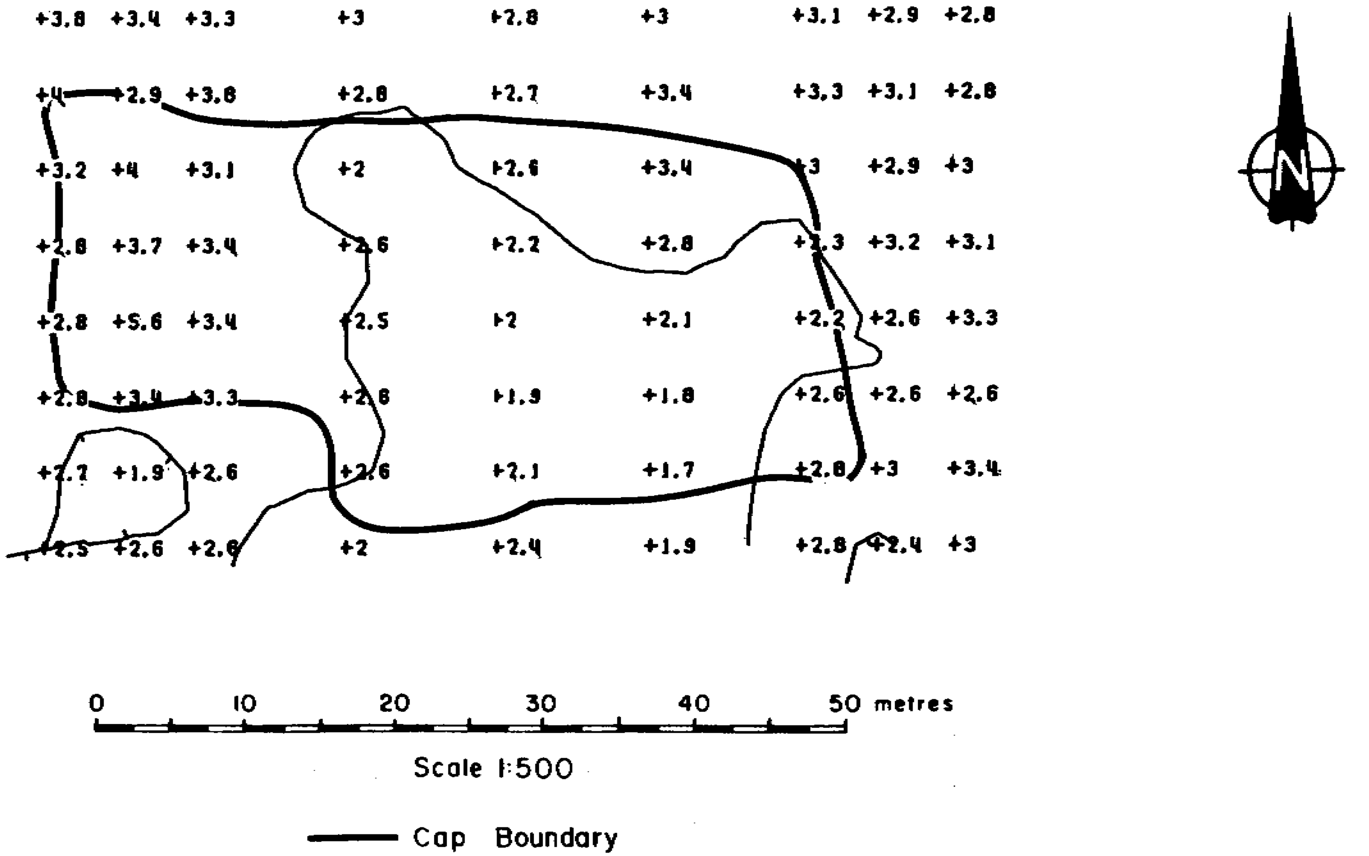
Indian and Northern Affairs Canada
TOTAL CONTAINMENT SURVEY
Apparent Conductivity Contour Map
Depth of Investigation: 3.5m Site: B53

CE00947

Figure. C.5



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TOTAL CONTAINMENT SURVEY

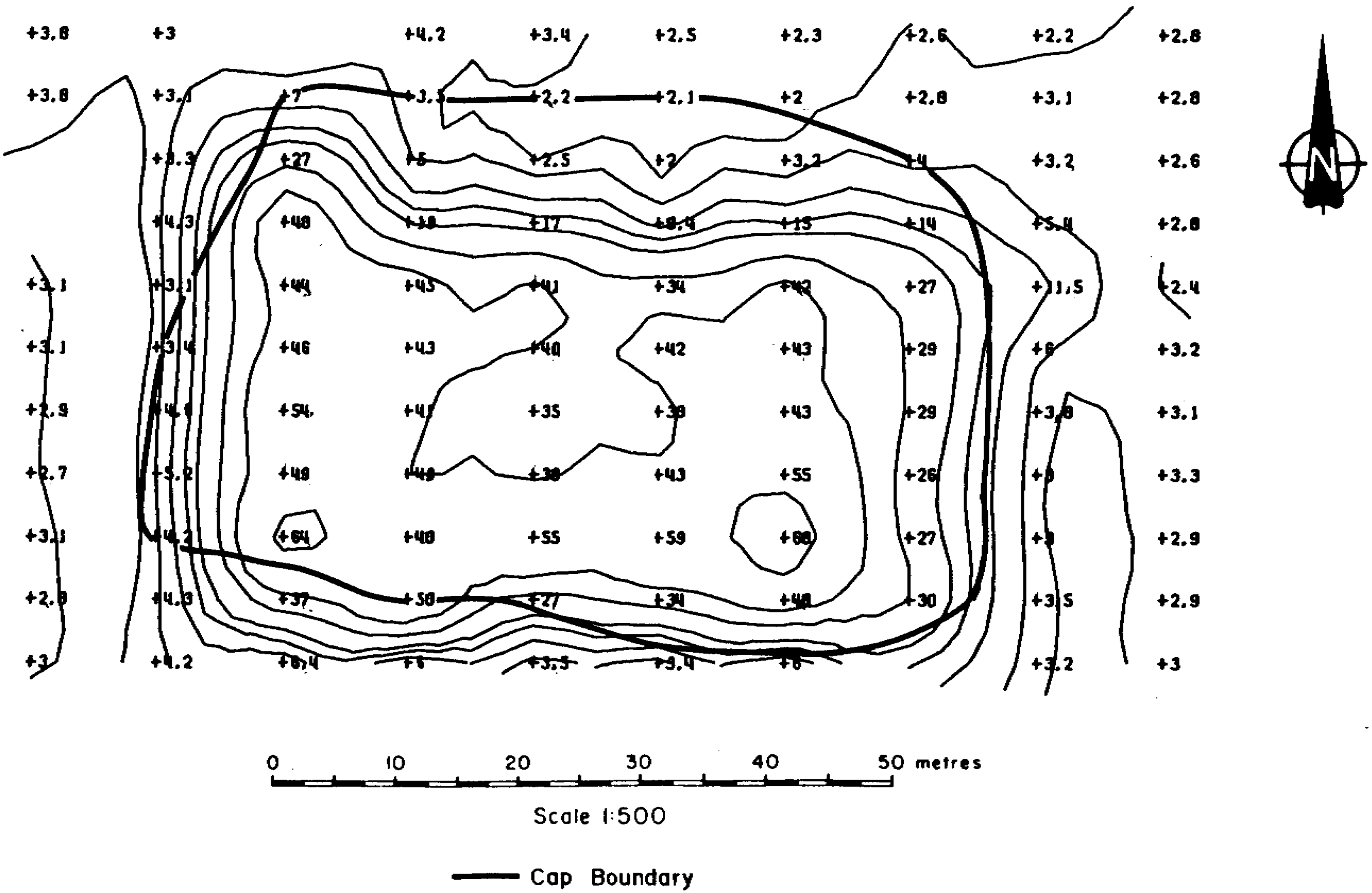
Apparent Conductivity Contour Map

Depth of Investigation: 7.0m

Site: B53

CE00947

Figure C.6



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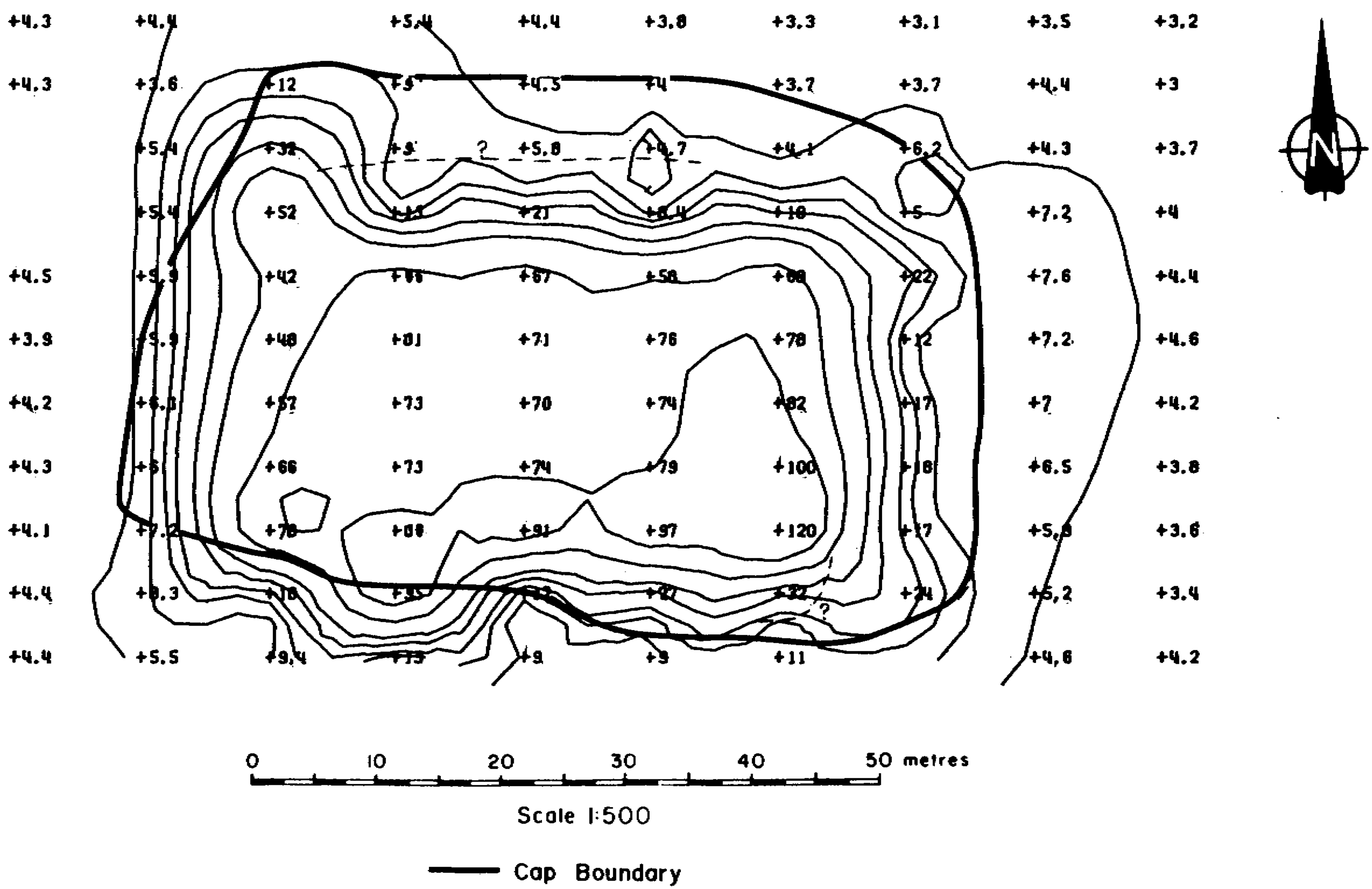
Indian and Northern Affairs Canada
TOTAL CONTAINMENT SURVEY
Apparent Conductivity Contour Map
Depth of Investigation: 3.5m
Site: B62
CE00947
Figure C.7



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TOTAL CONTAINMENT SURVEY
Apparent Conductivity Contour Map
Depth of Investigation: 7.0m
Site: B62

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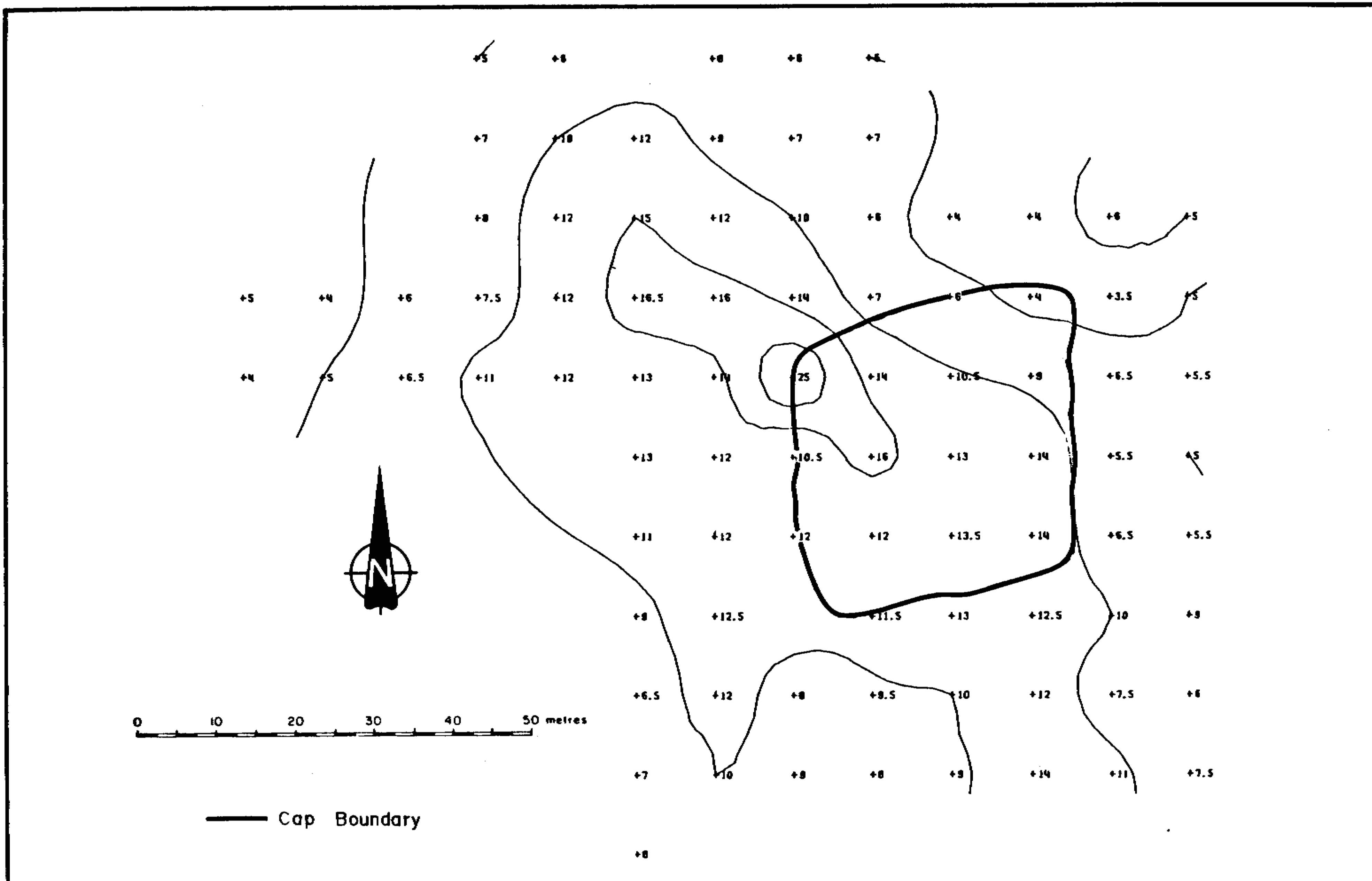
Figure. C.8



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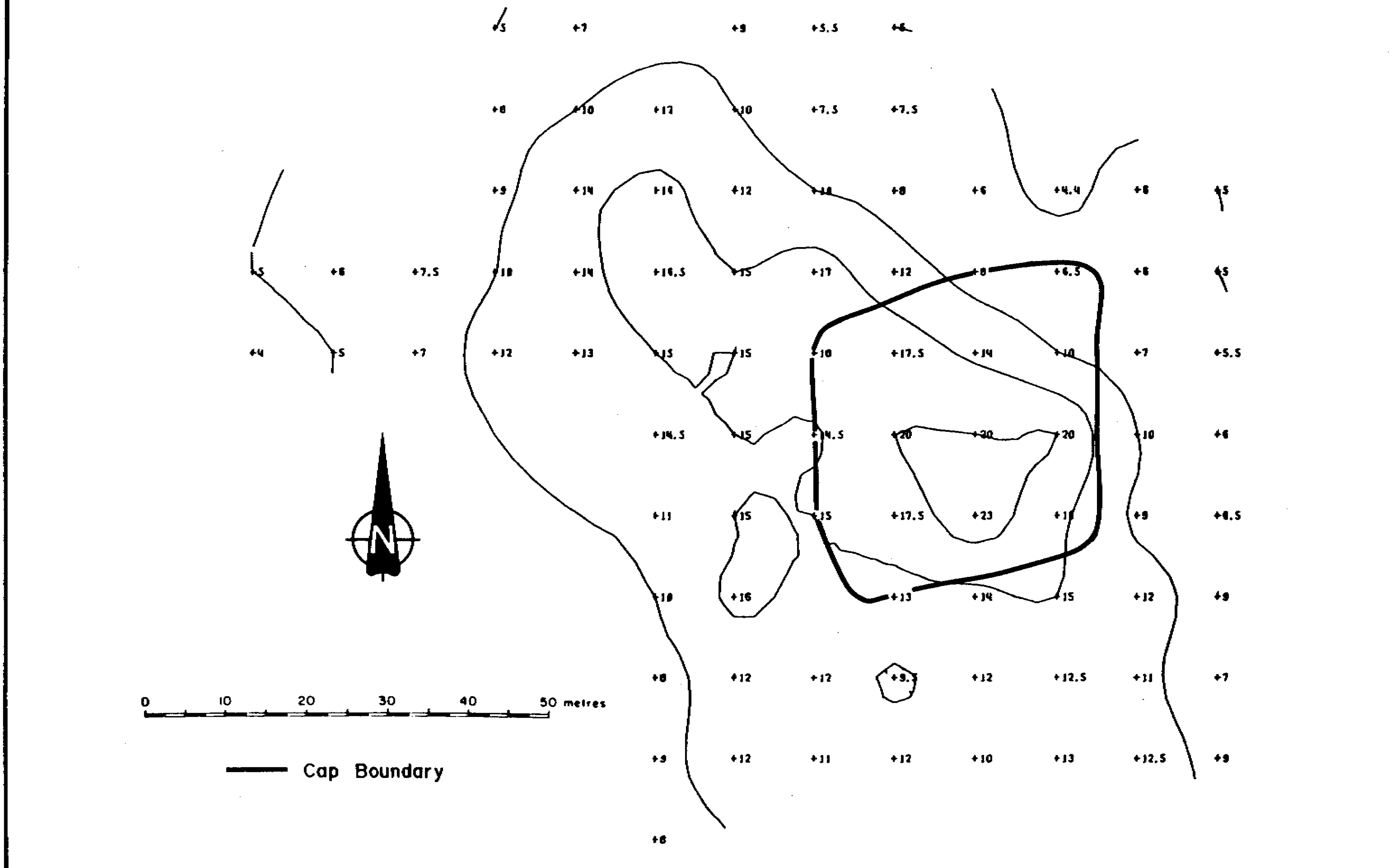
Indian and Northern Affairs Canada
TOTAL CONTAINMENT SURVEY
Apparent Conductivity Contour Map
Depth of Investigation: 3.5m
Site: N37
CE00947
Figure. C.9



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TOTAL CONTAINMENT SURVEY
Apparent Conductivity Contour Map
Depth of Investigation: 7.0m
Site: N37

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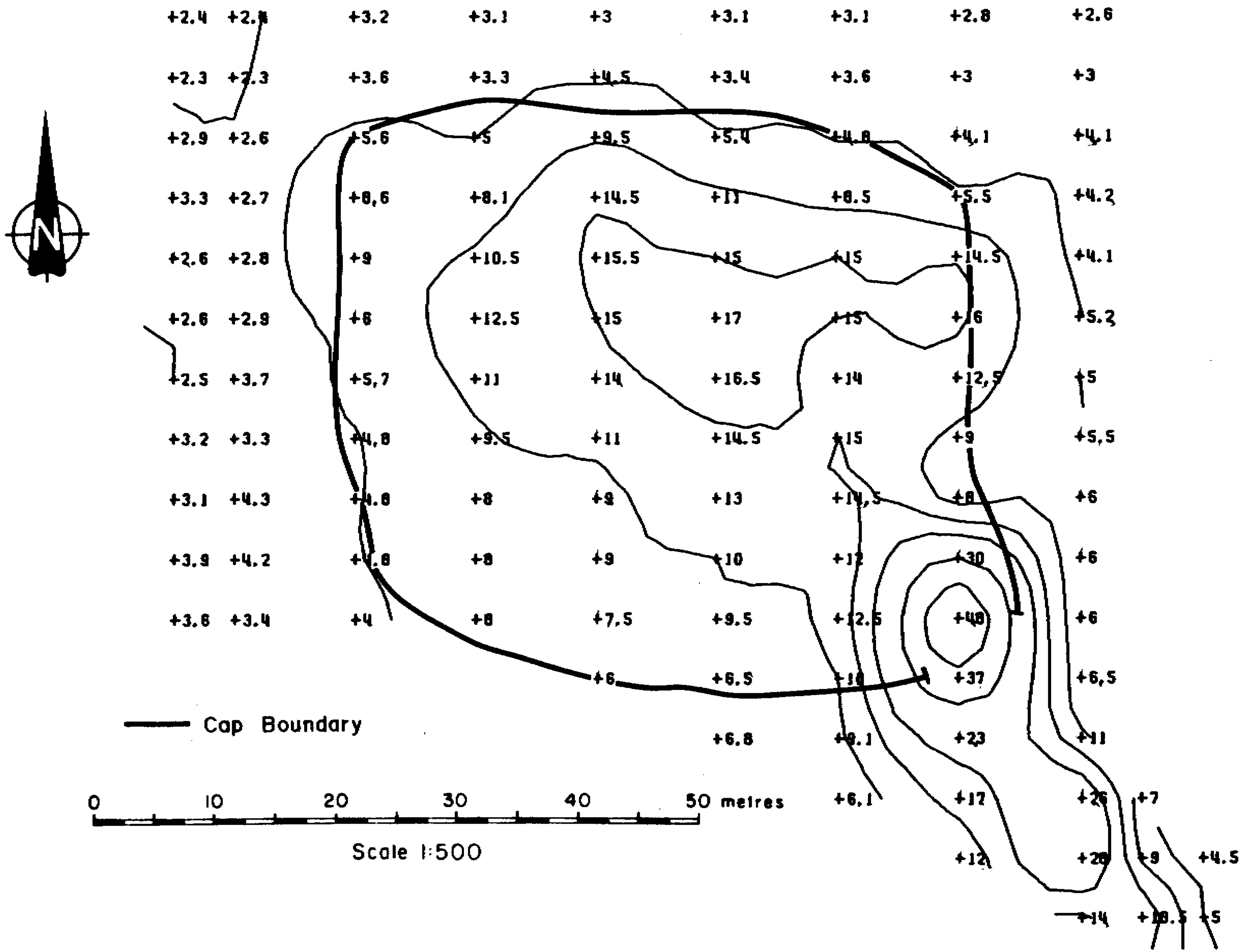
Figure. C.10



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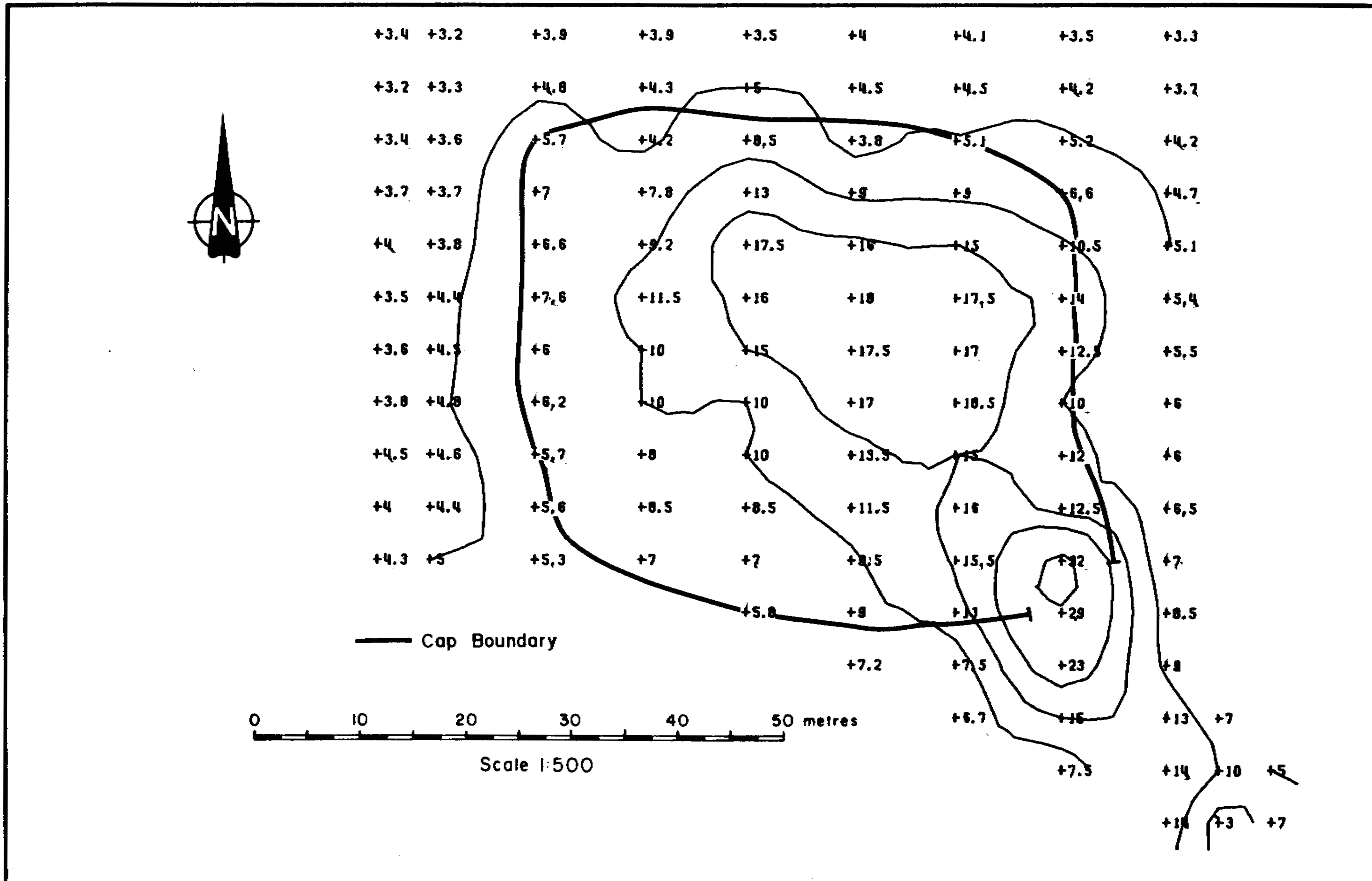
TOTAL CONTAINMENT SURVEY
Apparent Conductivity Contour Map
Depth of Investigation: 3.5m
Site: D52
CE00947
Figure. C.11



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TOTAL CONTAINMENT SURVEY

Apparent Conductivity Contour Map

Depth of Investigation: 7.0m Site: D52

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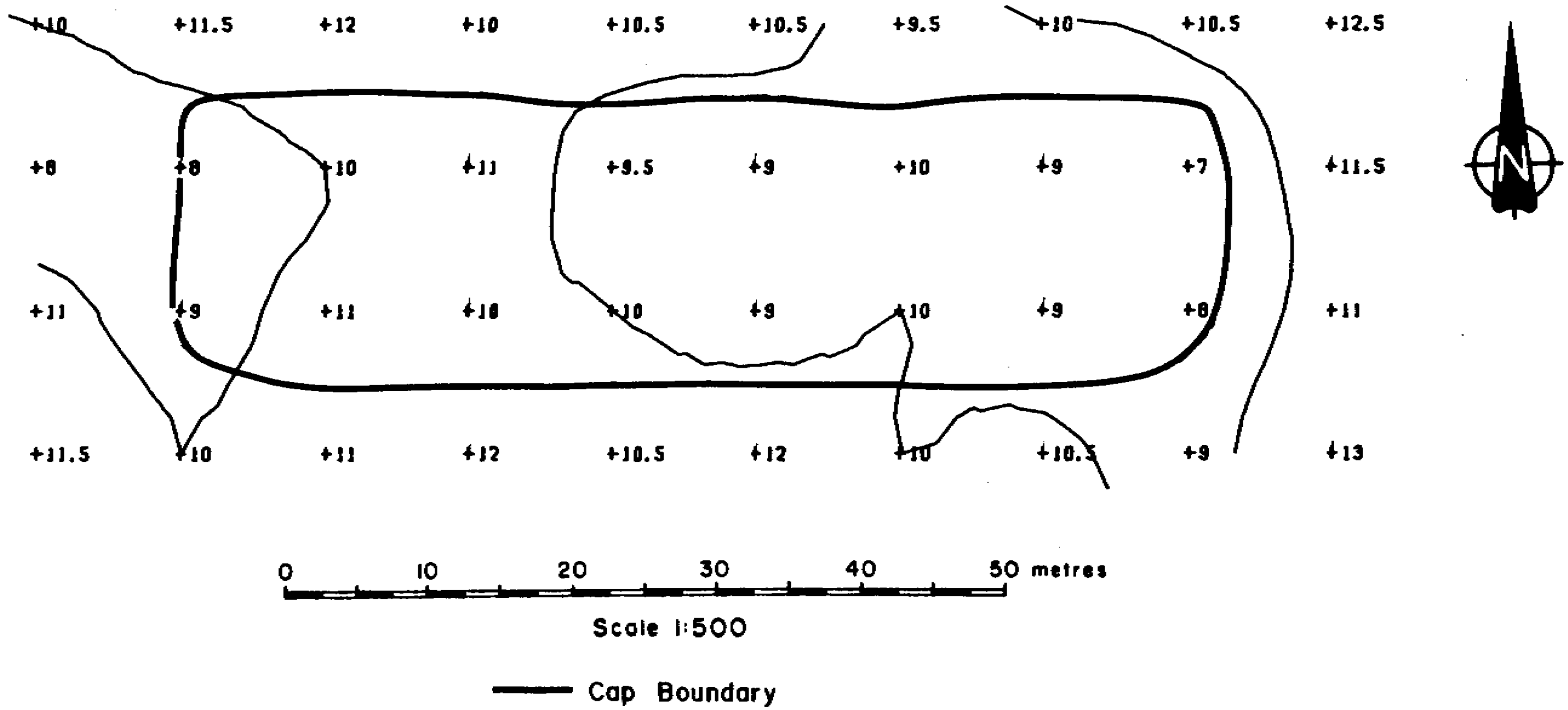
Figure C.12



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TOTAL CONTAINMENT SURVEY

Apparent Conductivity Contour Map

Depth of Investigation: 3.5m

Site: L28

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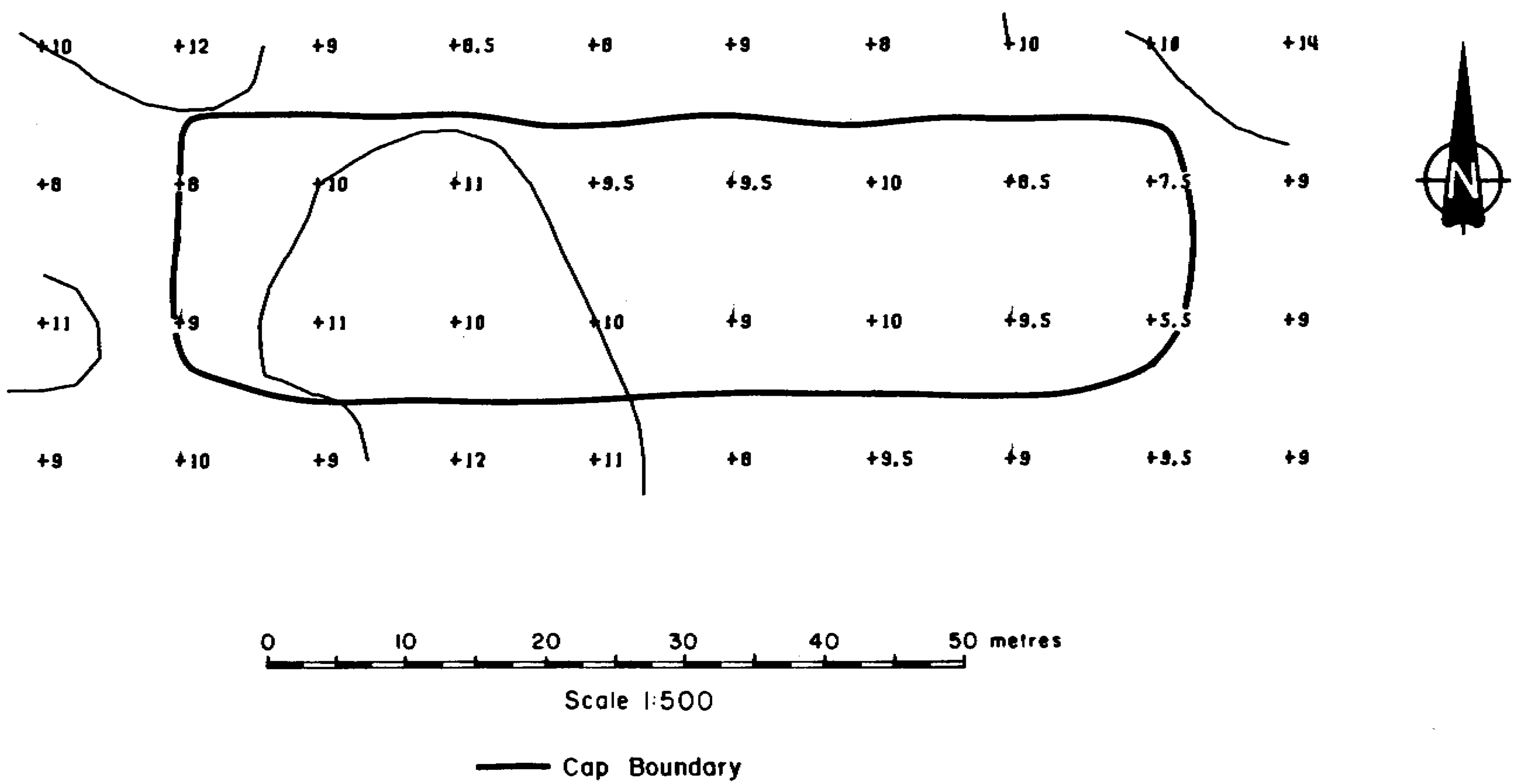
Figure. C.13



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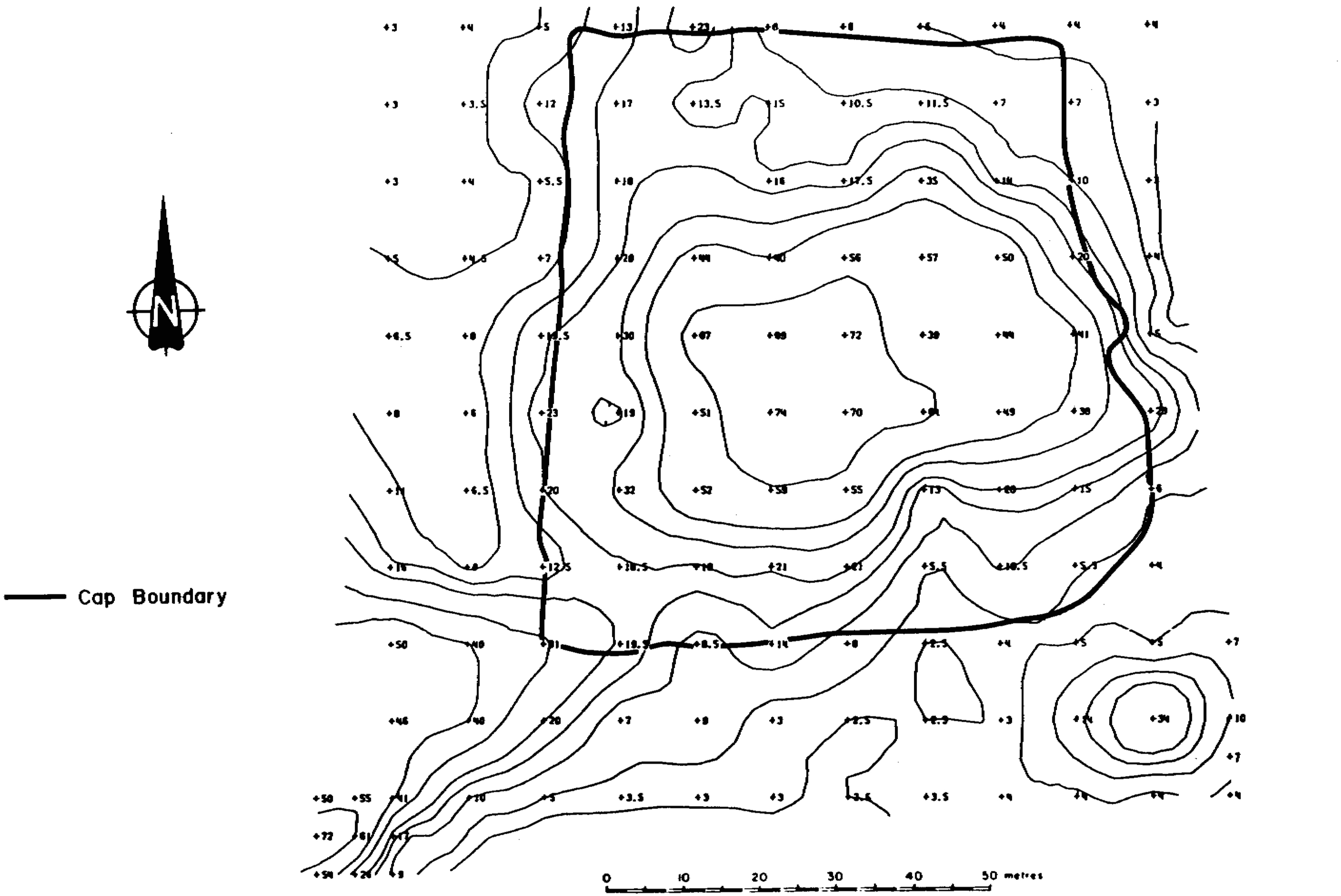
Indian and Northern Affairs Canada
TOTAL CONTAINMENT SURVEY
Apparent Conductivity Contour Map
Depth of Investigation: 7.0m
Site: L28
CE00947
Figure C.14



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Indian and Northern Affairs Canada

TOTAL CONTAINMENT SURVEY

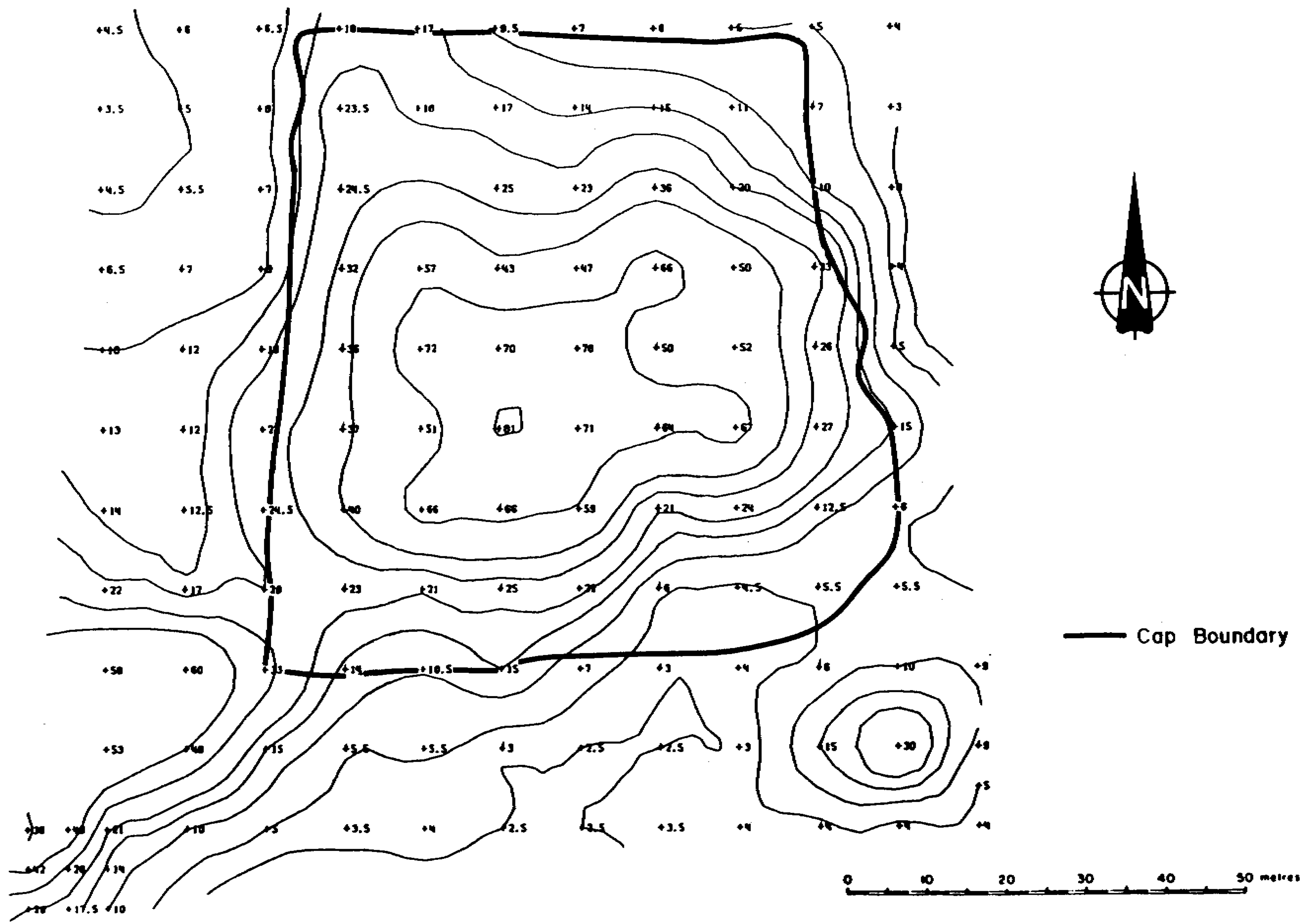
Apparent Conductivity Contour Map

Depth of Investigation: 3.5m

Site: D20

CE00947

Figure. C.15



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Indian and Northern Affairs Canada

TOTAL CONTAINMENT SURVEY

Apparent Conductivity Contour Map

Depth of Investigation: 7.0 m

Site: D20

CE00947

Figure. C.16

APPENDIX D

SURFACE SOIL ANALYSIS RESULTS

Table D-1. Salinity of Soils on Selected Waste Drilling Fluid Sump Sites in the Mackenzie Valley, N.W.T., August, 1987

Sample Site	J29				F8			B53			
	1 Cap	2 *DS Cap	3 DS Cap	4 Control	1 Cap		2 Control	1 Cap	2 Cap		3 Control
Depth (cm)	30	30	30	30	20	40	40	40	40	80	40
pH	7.92	8.05	7.49	7.04	6.68	6.58	6.96	7.37	7.36	7.03	7.93
Electrical Conductivity (mS/cm)	0.522	0.770	0.345	0.353	0.332	0.502	0.734	1.30	0.720	0.960	0.840
Saturation Percent	33.0	29.9	29.5	25.0	31.1	30.3	28.1	55.3	31.3	33.4	57.0
Sodium (meq/L)	0.811	0.894	0.270	0.473	0.976	1.18	2.13	1.70	0.943	1.50	1.42
Potassium (meq/L)	0.188	0.040	0.034	0.046	0.293	0.202	0.125	0.411	0.306	0.226	0.394
Calcium (meq/L)	3.99	6.46	3.01	2.71	2.01	3.51	4.88	9.90	5.66	6.94	5.80
Magnesium (meq/L)	1.96	3.10	0.891	1.19	1.01	1.51	2.28	7.49	4.12	6.04	5.09
Chloride (meq/L)	0.677	0.395	0.324	0.536	0.959	0.888	1.24	1.59	1.31	0.959	1.31
Sulphate (meq/L)	<0.2	8.33	0.365	<0.2	<0.2	2.71	2.08	17.9	0.313	3.39	0.469
Sodium Adsorption Ratio (SAR)	0.470	0.409	0.193	0.339	0.794	0.745	1.13	0.577	0.426	0.589	0.609

Sample Site	B62			N37							
	1 Cap	2 Cap	3 Control	1 Cap		2 DS Cap		3 DS Cap		4 Control	
Depth (cm)	40	40	40	20	100	20	100	20	100	20	40
pH	7.32	6.42	4.33	8.10	7.30	7.09	7.10	7.42	7.16	6.47	6.04
Electrical Conductivity (mS/cm)	0.680	0.630	0.095	0.750	1.64	1.38	1.03	0.905	0.481	0.308	0.285
Saturation Percent	75.5	78.7	94.9	37.1	33.6	35.6	39.0	28.1	27.5	94.2	92.6
Sodium (meq/L)	0.698	0.376	0.156	1.94	5.43	2.63	1.29	0.514	0.358	0.294	0.217
Potassium (meq/L)	0.267	0.215	0.050	0.216	0.196	0.141	0.134	0.193	0.084	0.143	0.063
Calcium (meq/L)	5.90	5.81	0.321	5.32	12.5	8.56	6.65	6.70	3.15	1.44	1.92
Magnesium (meq/L)	3.56	1.75	0.277	3.57	7.64	7.87	7.10	5.99	3.75	1.45	1.86
Chloride (meq/L)	0.550	0.409	0.254	0.423	4.94	6.91	6.77	2.26	1.69	0.846	1.20
Sulphate (meq/L)	7.92	0.208	<0.2	8.75	13.3	10.7	0.521	6.25	<0.2	<0.2	0.292
Sodium Adsorption Ratio (SAR)	0.321	0.193	0.285	0.920	1.71	0.918	0.492	0.204	0.193	0.245	0.158

Table D-1 (Continued)

Sample Site	D52							L28							
	1 Cap		2 DS Cap		3 DS Cap		4 Control	1 Cap		2 Cap		3 DS Cap		4 Control	
Depth (cm)	20	80	20	80	20	80	20	20	60	20	60	20	60	20	60
pH	5.18	6.16	5.76	6.91	6.04	5.24	4.91	7.93	7.95	8.38	8.22	7.90	7.47	8.24	7.82
Electrical Conductivity (mS/cm)	4.01	10.9	5.20	9.05	0.610	0.750	0.260	1.78	1.10	2.10	1.09	2.65	1.41	1.30	1.66
Saturation Percent	75.5	30.4	31.8	37.2	35.9	23.2	27.6	23.3	25.4	31.1	33.8	30.5	33.6	27.6	26.6
Sodium (meq/L)	8.74	25.7	14.5	20.8	0.960	0.821	0.429	1.75	1.72	3.36	1.71	4.35	3.18	2.35	1.71
Potassium (meq/L)	2.41	21.5	2.98	45.6	0.233	0.240	0.108	0.246	0.227	0.247	0.454	0.413	0.295	0.191	0.253
Calcium (meq/L)	24.9	81.0	39.4	39.1	2.23	2.23	1.30	9.49	8.43	19.5	9.16	30.4	10.4	11.0	10.6
Magnesium (meq/L)	16.5	39.6	20.2	15.9	1.90	1.25	0.539	4.88	4.34	10.0	4.34	11.6	4.63	4.88	5.35
Chloride (meq/L)	42.7	125	71.2	77.3	4.37	2.68	0.888	3.53	2.75	5.08	2.82	10.3	4.65	3.81	3.60
Sulphate (meq/L)	6.46	34.9	20.8	39.1	0.781	1.04	0.260	9.06	8.54	12.5	7.81	26.6	10.8	9.06	9.90
Sodium Adsorption Ratio (SAR)	1.92	3.31	2.66	3.97	0.668	0.662	0.447	0.653	0.681	0.875	0.658	0.949	1.16	0.834	0.606

Sample Site	D20									
	1 Cap		2 DS Cap		3 DS Cap		4 DS Cap		5 Control	
Depth (cm)	20	60	20	60	20	60	20	60	20	60
pH	6.93	7.24	7.01	7.04	6.88	6.61	6.78	6.79	7.69	7.89
Electrical Conductivity (mS/cm)	22.5	13.5	0.940	2.70	18.1	8.80	10.7	9.7	1.87	0.961
Saturation Percent	27.7	22.9	35.7	29.0	36.1	37.9	24.2	30.9	33.4	38.4
Sodium (meq/L)	43.8	31.6	1.62	2.75	41.1	15.2	23.1	15.2	1.96	1.14
Potassium (meq/L)	1.03	4.40	0.493	0.473	72.8	5.31	34.2	22.8	0.358	0.210
Calcium (meq/L)	188	114	6.12	14.2	106	66.0	60.0	59.4	16.0	6.91
Magnesium (meq/L)	209	98.9	4.70	13.3	86.4	50.6	41.8	41.7	9.10	6.17
Chloride (meq/L)	344	187	2.54	16.9	244	108	135	98.7	7.90	3.95
Sulphate (meq/L)	27.1	32.3	4.27	9.38	26.6	20.3	18.8	26.6	4.79	7.71
Sodium Adsorption Ratio (SAR)	3.11	3.06	0.696	0.742	4.19	1.99	3.24	2.14	0.553	0.446

DS - Downslope of

21.79/2