DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

REPT BK NO. 89/67

REPORT ON GEOPHYSICAL CONTRIBUTIONS TO SOIL SALINITY STUDIES AT **BORRIKA**, NEAR KAROONDA, SA

OIL, GAS AND COAL DIVISION

by

A.R. DODDS

GEOPHYSICS

SEPTEMBER, 1989 DME 594/75

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SOUTH AUSTRALIA

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GEOPHYSICS CONTRIBUTIONS TO SOIL SALINITY STUDIES AT BORRIKA NEAR KAROONDA, SA

Abstract

Attention is being focussed more and more on groundwater salinity problems caused by past and present agricultural practices. The removal of mallee scrub, to allow dryland farming, results in increased rainfall penetration to the water table, washing salts down with it, causing increased groundwater salinity and a rise in the water table. The details of the mechanism are not clearly understood.

This study looks at the usefulness of three geophysical electrical methods in mapping the penetration of the water and the rate of salt migration. All methods appeared to map variations in soil salinity. Geonics EM-34 was most economical, but least detailed. The Transient Electromagnetic Technique (TEM) provided more detail, and increased depth penetration. Vertical Electrical Soundings (VES) provided the most detail, but were most expensive in terms of areal coverage. A combination of VES with one of the EM methods seems the most cost effective way of tackling this problem.

The use of airborne EM might be useful, but at present is likely to lack both lateral and vertical resolution. Future developments in techniques may change this assessment.

Introduction

Studies into the effect of dry-land farming on salt migration are being conducted by the Water Resources Division of C.S.I.R.O. The removal of mallee scrub allows rainfall to penetrate the ground, at least while no crops are active, rather than being absorbed by the vegetation, as is the case with virtually all precipitation when mallee scrub is present. The movement of this water removes salts from the soil and carries them down towards the water-table. This process leads eventually to an increase in groundwater salinity and a rise in the water-table.

The study area comprises a 300 by 500 metre portion of a paddock near Borrika, S.A. (Figure 1). The paddock has been under cultivation for some 50 years. The area is bounded by fences on the western and southern sides, and by a mallee scrub covered sand ridge on the northern side. To the east is open paddock. The ground is relatively flat except for the rise into the sand ridge. At the time of surveying, it was fallow.

The zone of interest extends from surface to about 20 metres, below which the salinity levels of the soil are not expected to have changed. Although this zone is above the water-table, and is therefore not expected to be saturated, it was considered that geophysical methods, in particular using the parameter of electrical resistivity, might assist in mapping lateral variations in soil salinity. Even salts in solid state will be inclined to make such moisture as is contained in the soil more conductive, and therefore to lower the formation resistivity. While any quantitative evaluation is obviously dubious in such a case, a qualitative estimate of variation should be possible.

A one-day test SIROTEM transient electromagnetic (TEM) survey was done on 8th September, 1988, to correlate with an EM-34 survey and subsurface chloride sampling, both done by C.S.I.R.O. 46 readings were taken on a 50 metre grid, using 50 metre square coincident loops. The early time window was used to achieve maximum detail in the near surface range.

Six Vertical Electrical Soundings (VES), three within this area and three further north, were done on June 28th, 1989. The objective here was to test another method, particularly one that permits a close look at near surface resistivity variations. The Schlumberger electrode configuration was used, with half-electrode spacings going out from 1 metre to 130-200 metres.

Discussion of Results

TEM Data

The TEM results are shown in two different presentations. The full data set is shown as apparent resistivity time-distance plots (Figures 2-6). These are similar to pseudo-sections, the delay times on the vertical axis having some relation to depth. A qualitative study of these plots shows decreasing resistivities with depth, as would be expected in this environment. While the deeper (later time) resistivities are relatively constant laterally, the near surface, early time, values show considerable and rapid variations. Since the sought for variations in salinity occur in the top 20 metres, it is these early time resistivities that are of prime interest, and channels 3 to 6 are also presented in plan contour form to highlight these lateral variations (Figures 7-10).

Channel 3 (Figure 7) shows the shallowest depth penetration. It is expected that these apparent resistivities are likely to be most compatible with the EM-34 results (Figure 11) which, with the used configuration of vertical coils at a separation of 20 metres, have a nominal depth penetration of 15 metres. The patterns are very similar, both methods showing resistivity lows centred at (100E,100N), (50E,170N) and (150E,450N). These lows correlate with bores BUF-03, BUF-07 and BUF-18, plotted on Figure 11 and with chloride logs on Figure 12, which all show high chloride concentrations within 10 metres of surface. Other bores with lower chloride concentrations correlate with areas of higher resistivity. While more ground truth, in the form of chloride testing over, in particular, the two conductive areas in the south-west corner, is required, these are favourable indications that the resistivity values are reflecting soil salinity.

Channels 4, 5 and 6 (Figures 8,9 and 10) look progressively deeper, and show the gradual smoothing out of these near surface anomalies. The resistivity high at the north end of Line 250E occurs where the line extends over the mallee covered sand ridge.

Although effects from below 30 metres are outside the interest of this study, it would be a waste of good data to ignore such information. TEM data at selected locations have been analyzed and inverted to give the depths and resistivities of the deeper layers. The stations for which the data have been inverted are shown in Figure 13, and the inversion results are shown as sections in Figures 14 and 15.

The inversion process comprised the trial and error selection of a basic model which developed to be a three-layer half-space with progressively decreasing resistivity with depth. This one model was then used as a starting model for the automatic inversion of all data. The end results were remarkably good, with 10 graded as excellent, one as good and two as fair quality of fit. These grades are based on both the statistical output of the inversion package, which invariably showed very low percentage errors, and on a visual examination of the match between data and model curve, which shows whether errors are randomly distributed or systematic. Errors here were generally random. Moreover, in all cases all five parameters, the three resistivities and two thicknesses needed to define the layers, are well defined by the inversion process. The two 'fair' fits are the only ones where one parameter, the thickness of the top layer, is in doubt.

The results show a resistive top layer, varying in thickness from 9 to 42 metres with a resistivity of 11 to 36 ohm-metres. Either the resistivity or thickness of this layer is in doubt at some stations, usually the ones showing extremes of resistivity. (The TEM method is least effective at defining resistive layers, particularly when these are shallow). Below this is a moderately conductive layer which, for the most part, has a resistivity between 7.4 and 8.3 ohm-metres and a depth to base of between 89 and 96 metres. The only anomalous region is in the north, where resistivities go up to 10.1 ohm-metres and depths reach extremes of 73 and 105 metres. Station (150E,450N) produces two of these extremes, and with only a fair fit is regarded as slightly suspect. The greater depth to the lower conductor occurs at a station on the sand ridge, where an increase in elevation may result in both this and the greater thickness of the top layer at 42 metres.

The resistivity of the bottom layer varies from 2.7 to 5.0 ohm-metres, the latter figure again being given by the least reliable inversion. A maximum resistivity of 4.2 ohm-metres for this layer is more likely.

The water table in this area is expected to be at a depth of about 30 metres, so it seems likely that the upper interface detected by TEM is this feature. The variable depth may be a function of porosity (where less porous rock does not allow for a decrease in resistivity at the water-table), but is certainly partly indicative of changes in the elevation of the station, as in the case of point (250E,600N) on the sand ridge. The upper layer resistivity may partly reflect salinity changes in the near surface, but evidently is smoothing effects considerably by giving a constant resistivity for all material above the water-table. Individual channels give better indications of lateral resistivity variations than does the inversion to layer resistivities.

The resistivity of the two layers below the water-table, and the depth to the lower layer, are remarkably constant, even allowing for the averaging processes of the method. A high degree of homogeneity over this area is expected, with an interface between the moderately saline and highly saline groundwater at about 90-95 metres. Drill logs from a few kilometres away show a marl layer at about this depth which could result in lower resistivities.

VES Data

The VES data and inversions are shown in Figures 16 to 21 and the inversions summarized in Figure 22. VES 1,2 and 3 are located to the north of the area, and are analysed independent of any other information. It is understood that C.S.I.R.O. (G. Buselli) took TEM data over this area, but this information has not been made available. The other VES, 4,5 and 6, are close to TEM soundings described earlier, and are analysed in conjunction with this data, as well as independently.

There is a marked difference between the soundings in the study area and those to the north of the sand ridge. On the south side layer 2, with a resistivity of 15 to 20 ohm-metres, is 4 to 7 metres thick. To the north, this layer tapers away from 2 metres to nothing. Also, on the south side the lower layers are conductive, with a resistivity of 5 to 9 ohm-metres coming in at 16 to 23 metres depth. To the north, such resistivities are not seen at depth, even though wider electrode spacings of up to 200 metres were used. The latter soundings all finish on increasing apparent resistivities, while those to the south finish on decreasing resistivities. There is evidently a major change in pattern in the vicinity of the sand ridge, typified by shallower conductive material but an absence of conductors at greater depth on the north side.

The three VES within the study area showed varying degrees of correlation with the TEM inversions. Generally, the TEM does not differentiate layers in the top 10 metres, and tends to yield an average resistivity for this level. On the other hand, the TEM penetrates deeper with the survey parameters used here, particularly where an intermediate depth resistive layer constrains VES currents to the layers above it.

VES 4 is located at the junction of four TEM soundings, all of which gave similar figures. Thus, it is hoped that the ground is relatively homogeneous laterally in this vicinity. Even so, the VES spread extends over 50 metres to either side of the area covered by the TEM loops, and therefore samples some different ground. The TEM combines the top four VES layers into one 22 metre thick layer of 12.4 ohm-metres. VES layer 5 is equivalent to TEM layer 2, at 6 to 7.6 ohm-metres. The TEM also sees a conductive layer at 90 metres depth, resistivity 2.7 ohm-metres and beyond the range of this VES survey. Wider electrode spacings would, doubtless, pick up this layer, since it appears, from other TEM soundings, to be extensive. The match between TEM and VES here is as good as can be expected.

VES 5 gave a good inversion fit, as did the TEM at this location (250E,250N). The correlation between the two is not so good, however. While the top four VES layers are combined by TEM into 14 metres of about 33 ohm-metre resistivity, below this TEM sees a thick 8.1 ohm-metre layer, while VES prefers 5.4 ohm-metres. It seems probable that the wider VES spacings which identify this layer are picking up lateral inhomogeneities. The discrepancy is not too serious, particularly when it is considered that the two soundings are not at precisely the same location. The conductor (4.2 ohm-metres) at 90 metres depth is seen only by the TEM.

VES 6 is located just south of the sand ridge, and correlates with TEM station (150E,450N). Again, the TEM combines the top 5 VES layers into 70 metres of 10 ohm-metres, underlain by a 5 ohm-metre layer. While this layer could not be interpreted from the VES data, it does affect the readings, and can be included in both inversion processes, to improve the evaluation of the shallower layers.

Overall, the VES and TEM soundings are reasonably compatible, but indicate that there are more abrupt lateral changes than might be interpreted from TEM alone. The two data sets point out the relative advantages of each method, and the desirability of having both methods available if a comprehensive study of ground resistivity is required. TEM is economical for rapid lateral coverage of a study area, and more effective for attaining greater depths of penetration without expanding too far laterally. VES, on the other hand, gives greater detail in the near surface, particularly where high resistivity layers are concerned.

Conclusions

The three electrical survey methods used here, EM-34, TEM, and VES have indicated that variations in soil salinity in the top 20 metres of soil can probably be mapped through the resistivity parameter.

The Geonics EM-34 ground conductivity meter is the most economical, but the least discriminatory, so that other variations could be confused with salinity variations.

VES gives the most detailed information on layer thicknesses and resistivities in the surface to 20 metre depth range. However, it is also the least economical, and strays the furthest from a point measurement.

TEM is intermediate in its information detail, and has the added advantage of providing (spurious in this case) information on deeper layers at no extra cost. It is also intermediate in its economy, providing information at a rather slower rate than the EM-34, and requiring a larger crew and more expensive equipment. Data gathering is quicker than with VES, and generally more trouble-free.

It would seem inadvisable to use either EM method without the backup of VES for checking and detailing variations in apparent resistivity/conductivity. Either pairing of methods (VES with either EM-34 or TEM) would appear to give the optimum detail-economy combination.

A.R. DODDS
GEOPHYSICIST

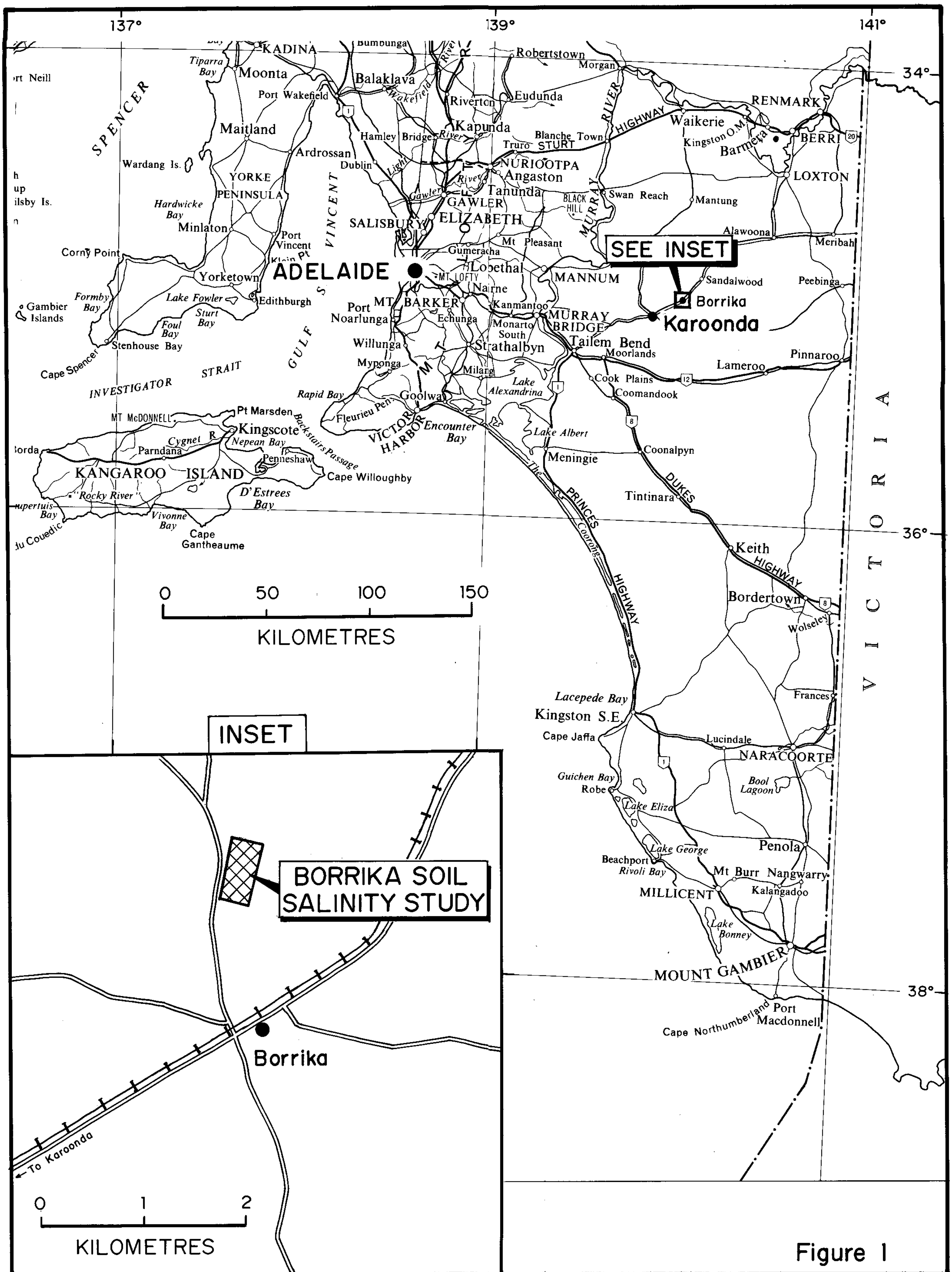

Figure 1

DEPARTMENT OF MINES AND ENERGY
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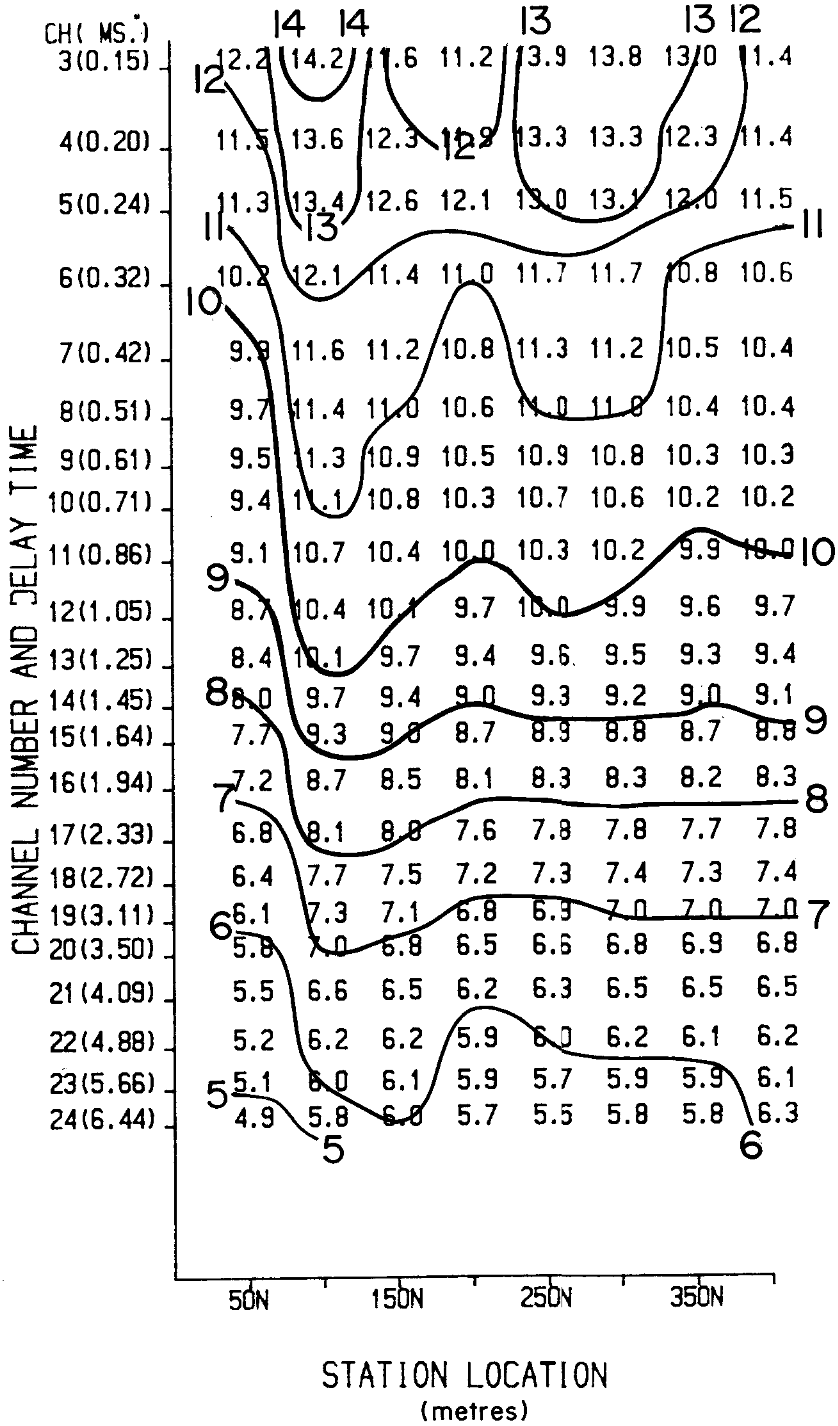
BORRIKA SOIL SALINITY STUDY

LOCALITY PLAN

COMPILED S. DODDS	C.D.O. DATE 24·1·90
DRAWN L.W.	SCALE As shown
DATE JULY '89	PLAN NUMBER S 20973
CHECKED	

4865



NOTE: Contour interval 1 Ohm-metre
50m square coincident loops
SIROTEM survey

Figure 2

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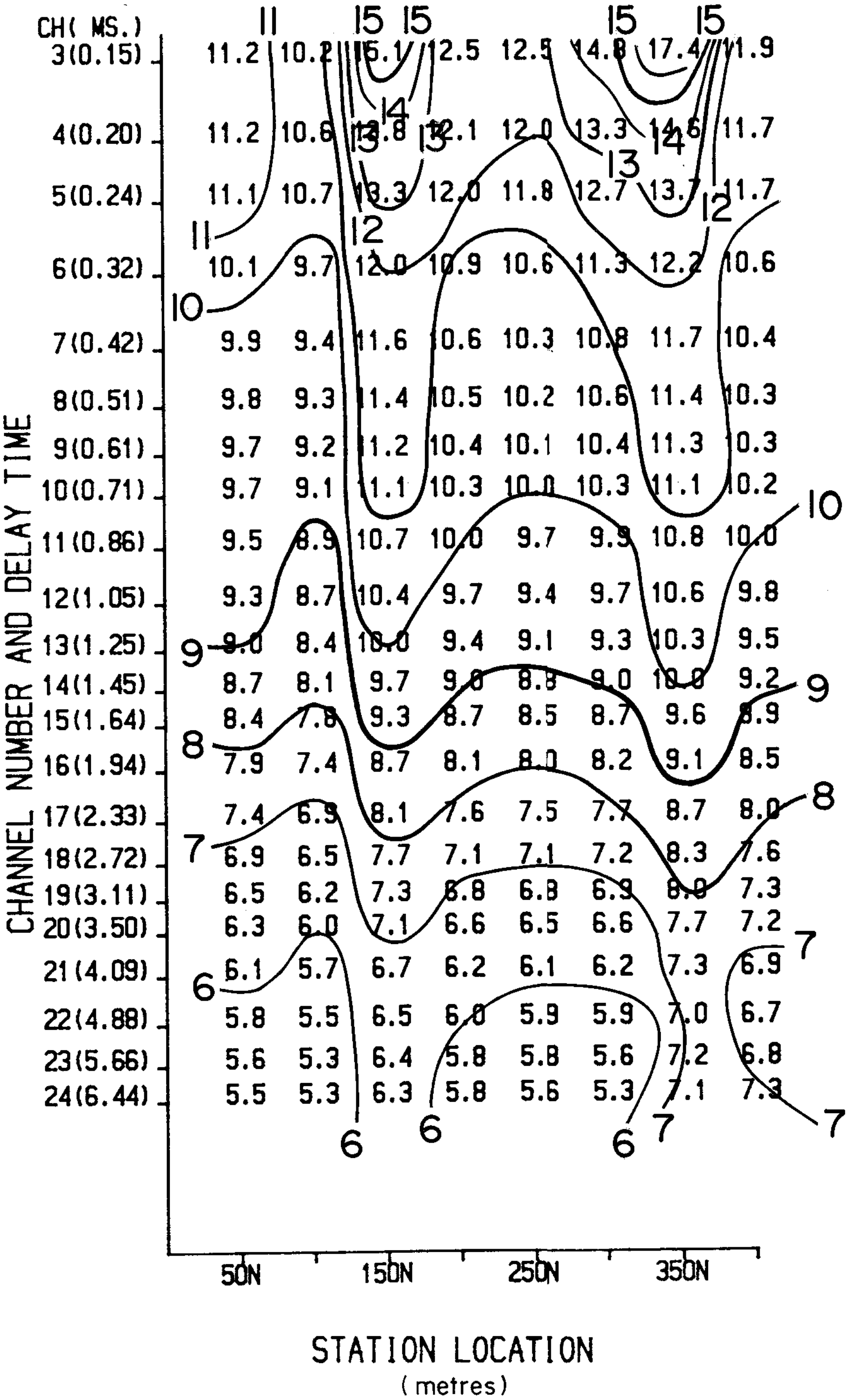
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED S.DODDS	UR 24·1·90 C.D.O. DATE
BORRIKA SOIL SALINITY STUDY	DRAWN D.S.L	SCALE
LINE 50 E	DATE July 89	PLAN NUMBER S 20974
APPARENT RESISTIVITY TIME DISTANCE PLOT	CHECKED	

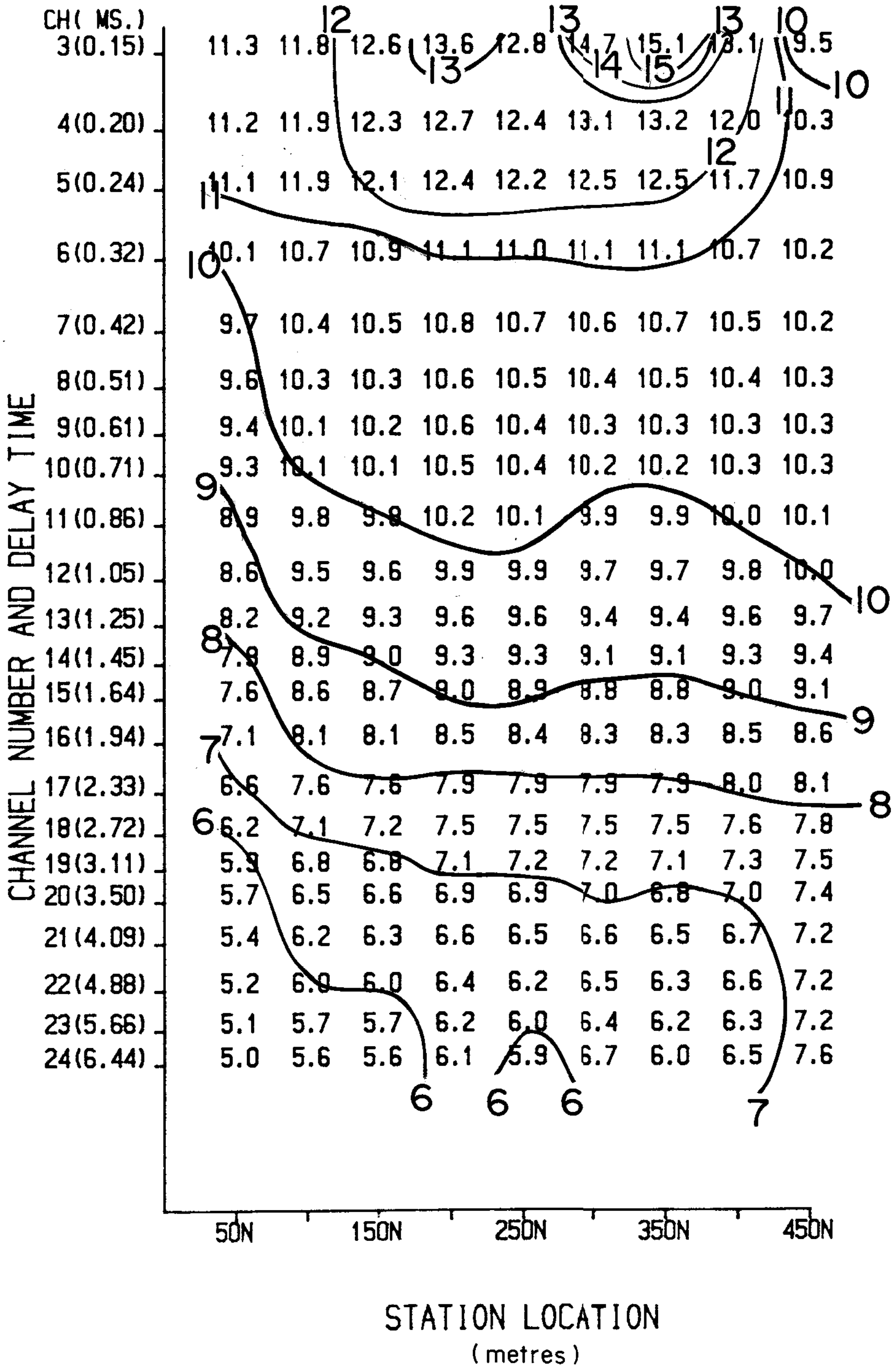


NOTE : Contour interval 1 Ohm-metre
50m square coincident loops
SIROTEM survey

Figure 3

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED S.DODDS	C.D.O. DATE 24-1-90
BORRIKA SOIL SALINITY STUDY	DRAWN D.S.L	SCALE
LINE 100 E	DATE July 89	PLAN NUMBER S20975
APPARENT RESISTIVITY TIME DISTANCE PLOT	CHECKED	

4865



NOTE: Contour interval 1 Ohm-metre
50m square coincident loops
SIROTEM survey

Figure 4

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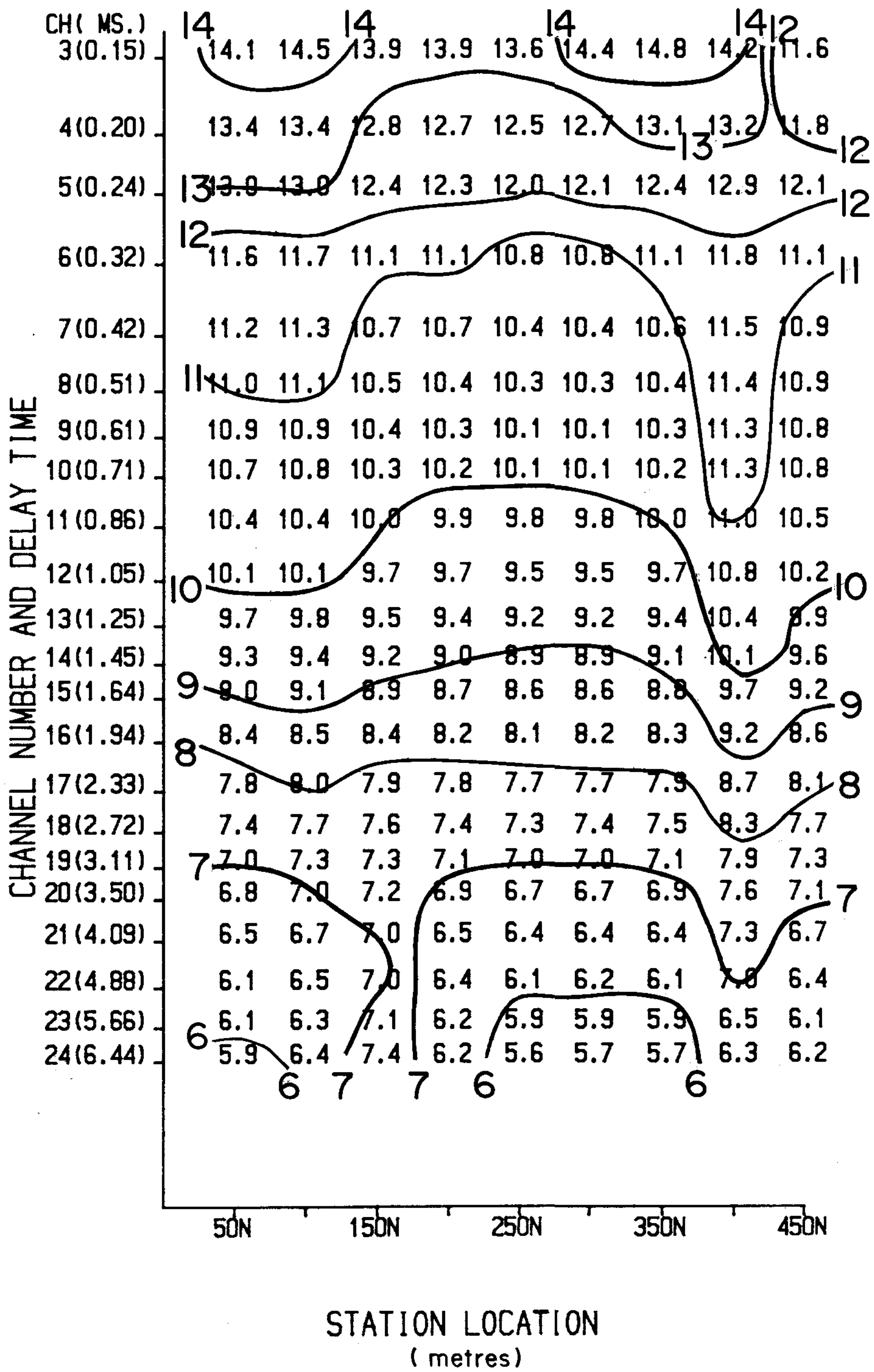
SOUTH AUSTRALIA

BORRIKA SOIL SALINITY STUDY

LINE 150 E

APPARENT RESISTIVITY TIME DISTANCE PLOT

COMPILED S.DODDS	C.D.O. DATE 24-1-90		
DRAWN D.S.L	SCALE		
DATE July 89	PLAN NUMBER S 20976		
CHECKED			

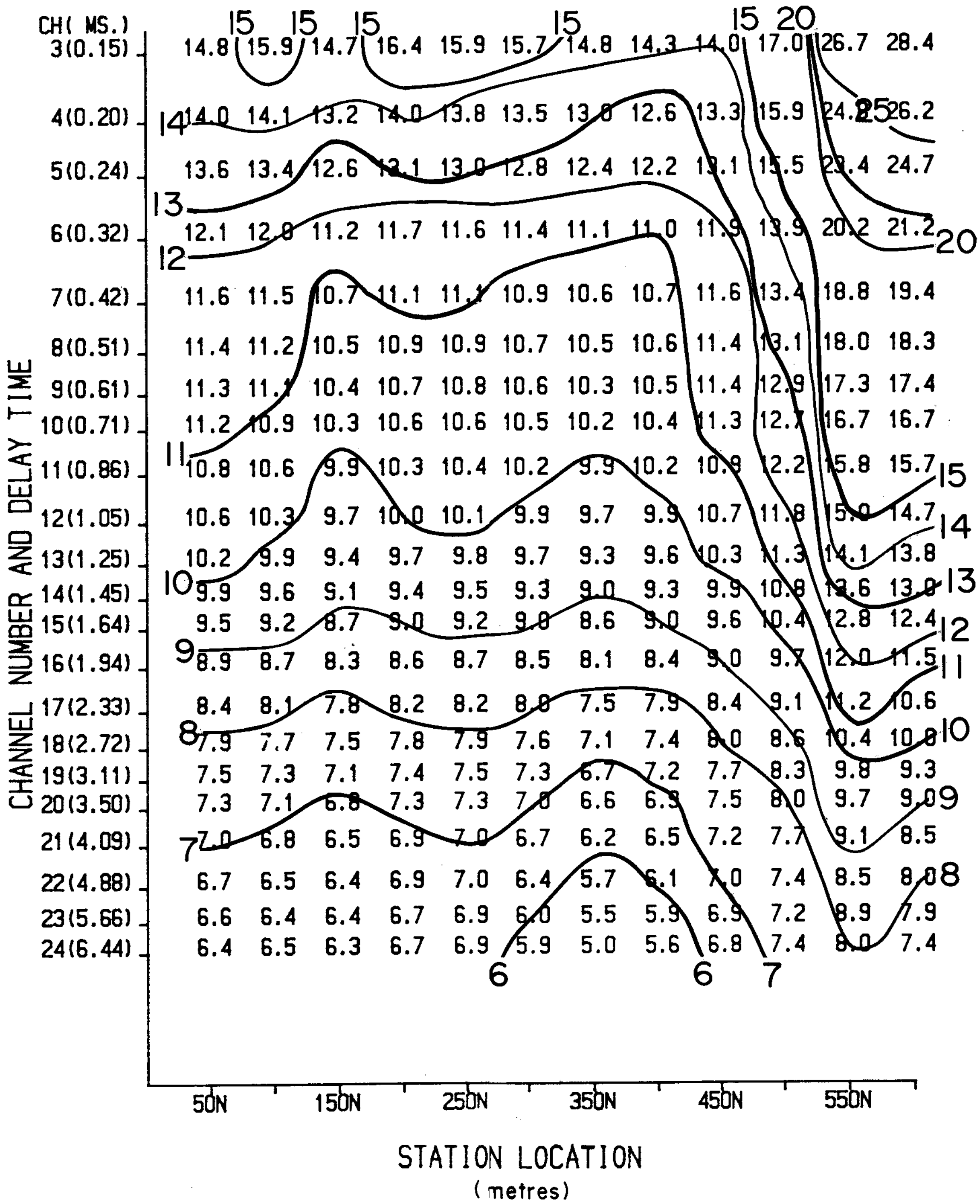


NOTE: Contour interval 1 Ohm-metres
50m square coincident loops
SIROTEM survey

Figure 5

4865

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED S. DODDS	*MR* C.D.O.	*24-1-90* DATE
BORRIKA SOIL SALINITY STUDY	DRAWN D.S.L	SCALE	
LINE 200 E	DATE July 89	PLAN NUMBER S 20977	
APPARENT RESISTIVITY TIME DISTANCE PLOT	CHECKED		



NOTE: Contour interval 1 Ohm - metre
50m square coincident loops
SIROTEM survey

Figure 6

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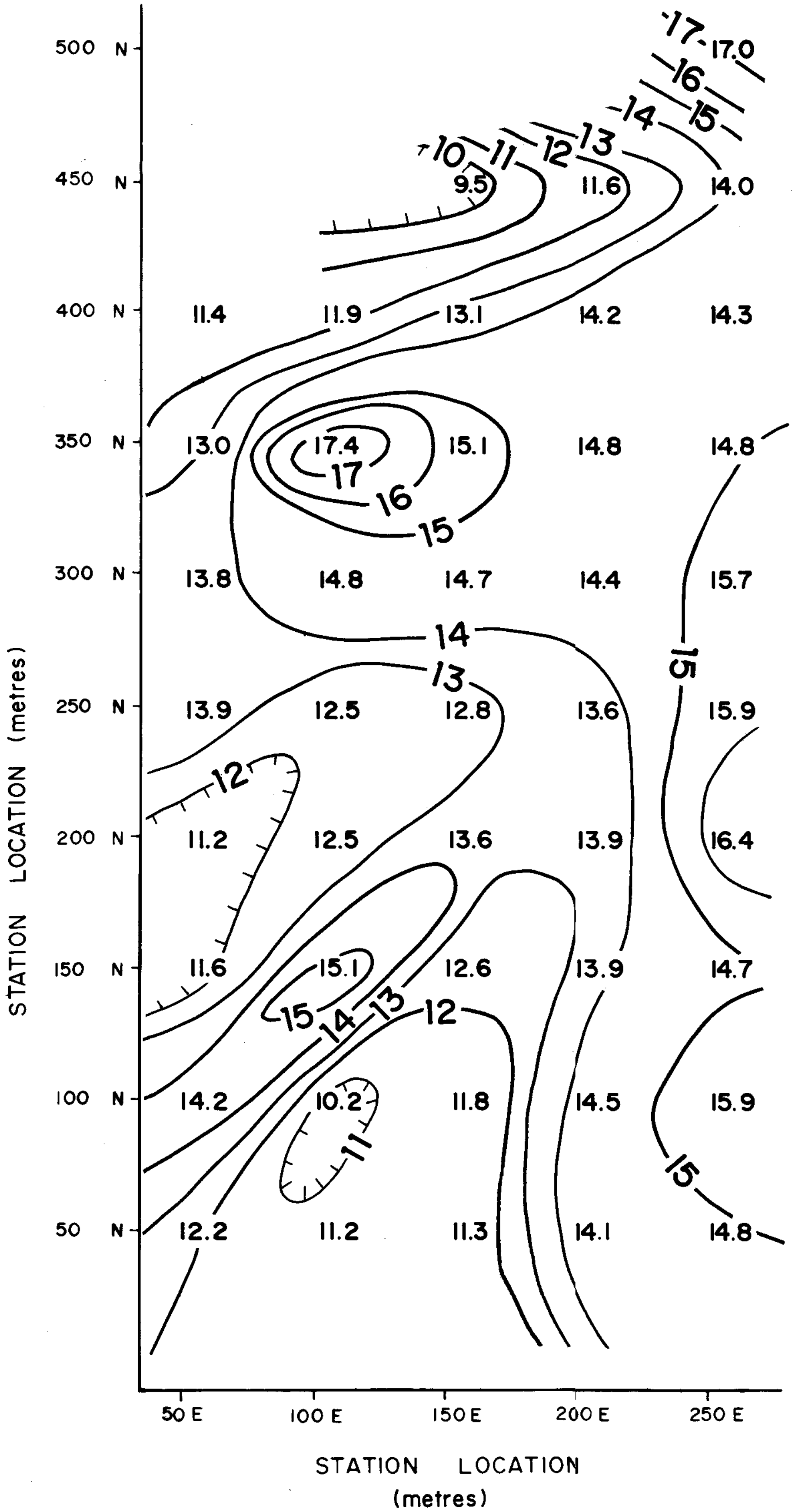
BORRIKA SOIL SALINITY STUDY

LINE 250 E

APPARENT RESISTIVITY TIME DISTANCE PLOT

COMPILED S.DODDS	*[signature]* 24-1-90 C.D.O. DATE
DRAWN D.S.L	SCALE
DATE July 89	PLAN NUMBER S20978
CHECKED	

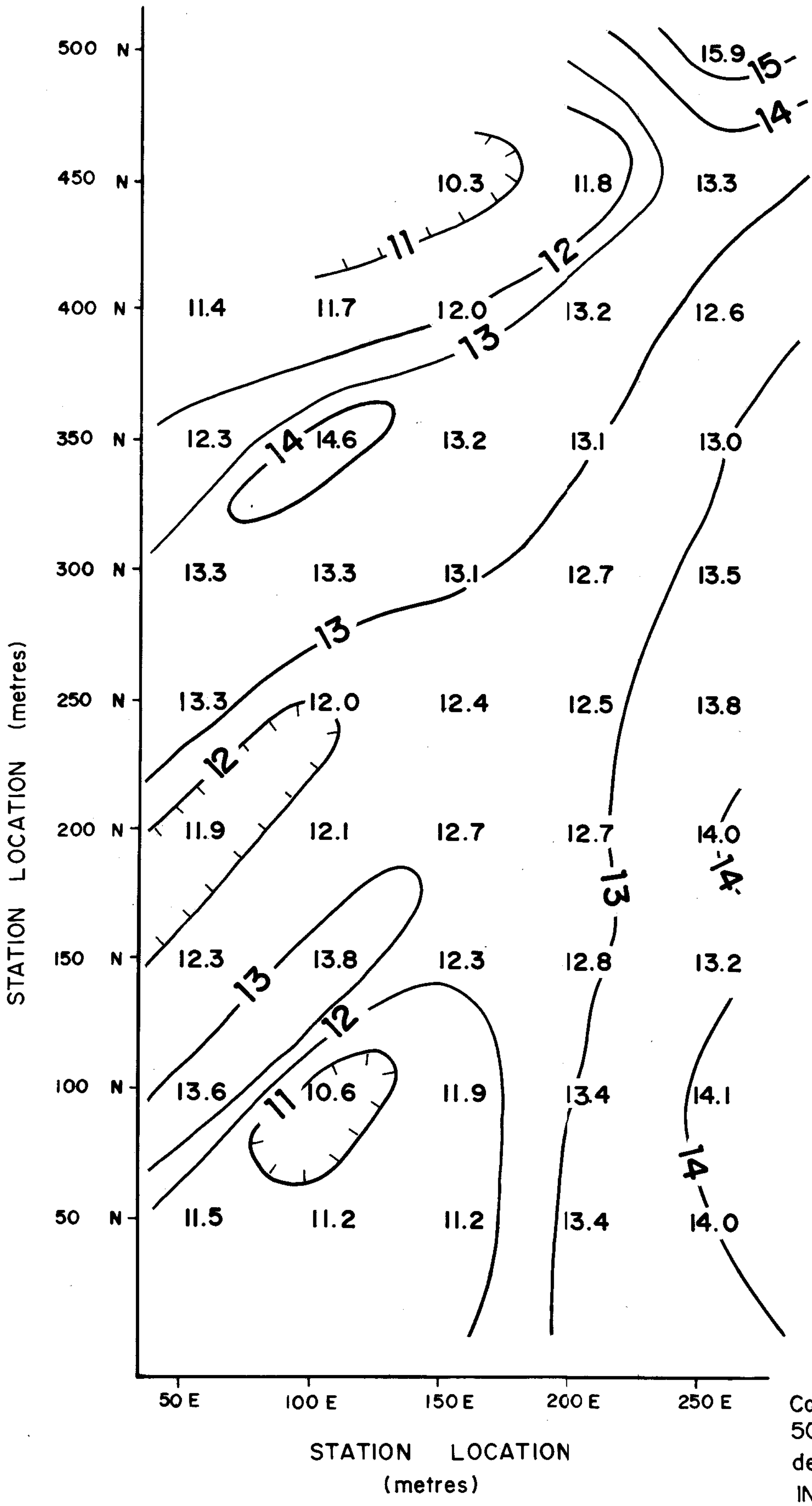


Contour interval 1 Ohm-metre
50m square coincident loops
delay time 0.15m/s
INSTRUMENT SIROTEM

Figure 7

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED S.DODDS	CDO 24·1·90 DATE
BORRIKA SOIL SALINITY STUDY	DRAWN D.S.L	SCALE
CHANNEL 3	DATE July 89	PLAN NUMBER S 20979
APPARENT RESISTIVITY CONTOUR PLAN	CHECKED	

4865

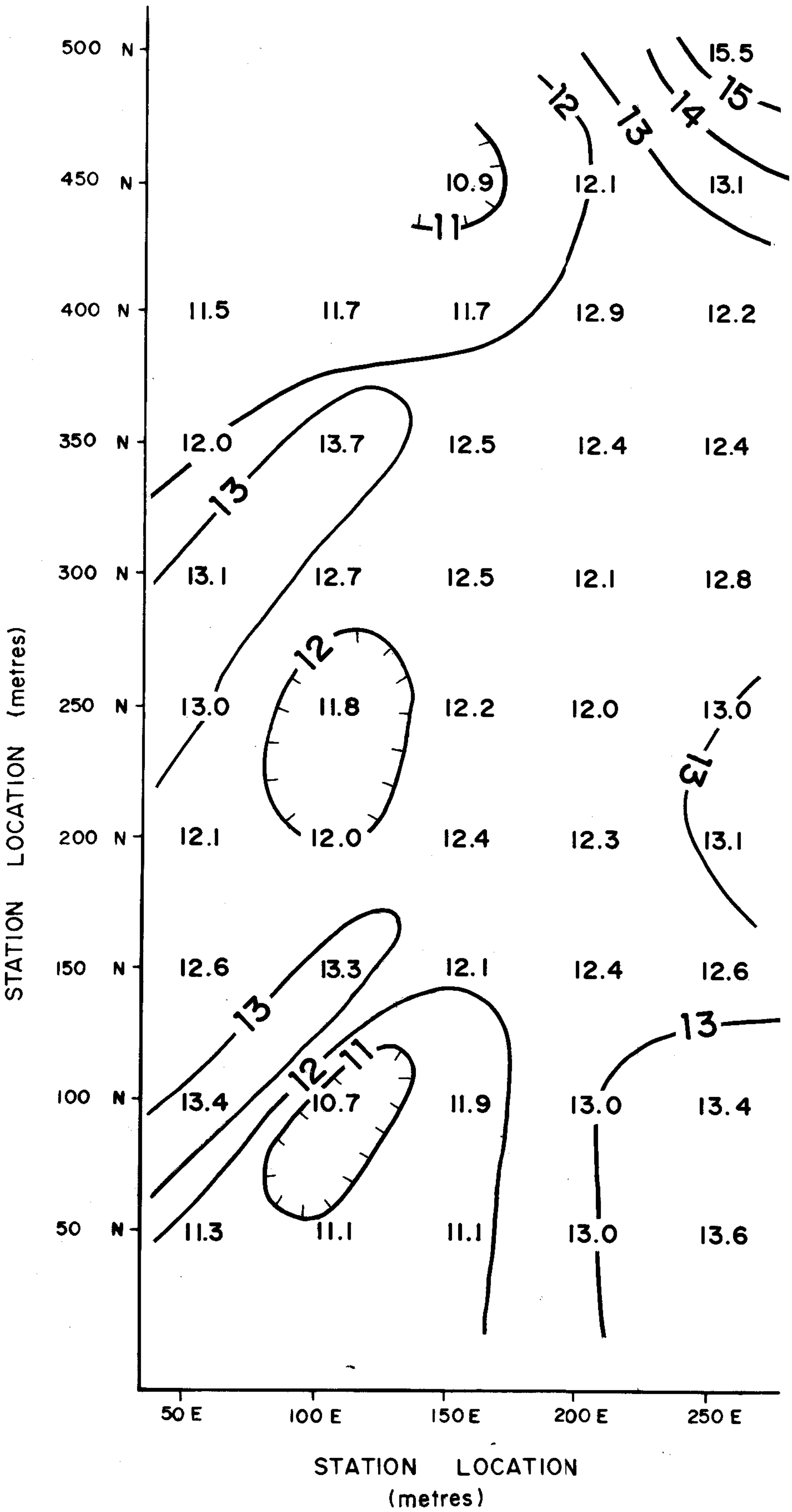


Contour interval 1 Ohm-metre
50 m square coincident loops
delay time 0.2 m/s
INSTRUMENT SIROTEM

Figure 8

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED S.DODDS	*UR* 24-1-90 CDO DATE
BORRIKA SOIL SALINITY STUDY CHANNEL 4 APPARENT RESISTIVITY CONTOUR PLAN	DRAWN D.S.L	SCALE
	DATE July 89	PLAN NUMBER S 20980
	CHECKED	

4865

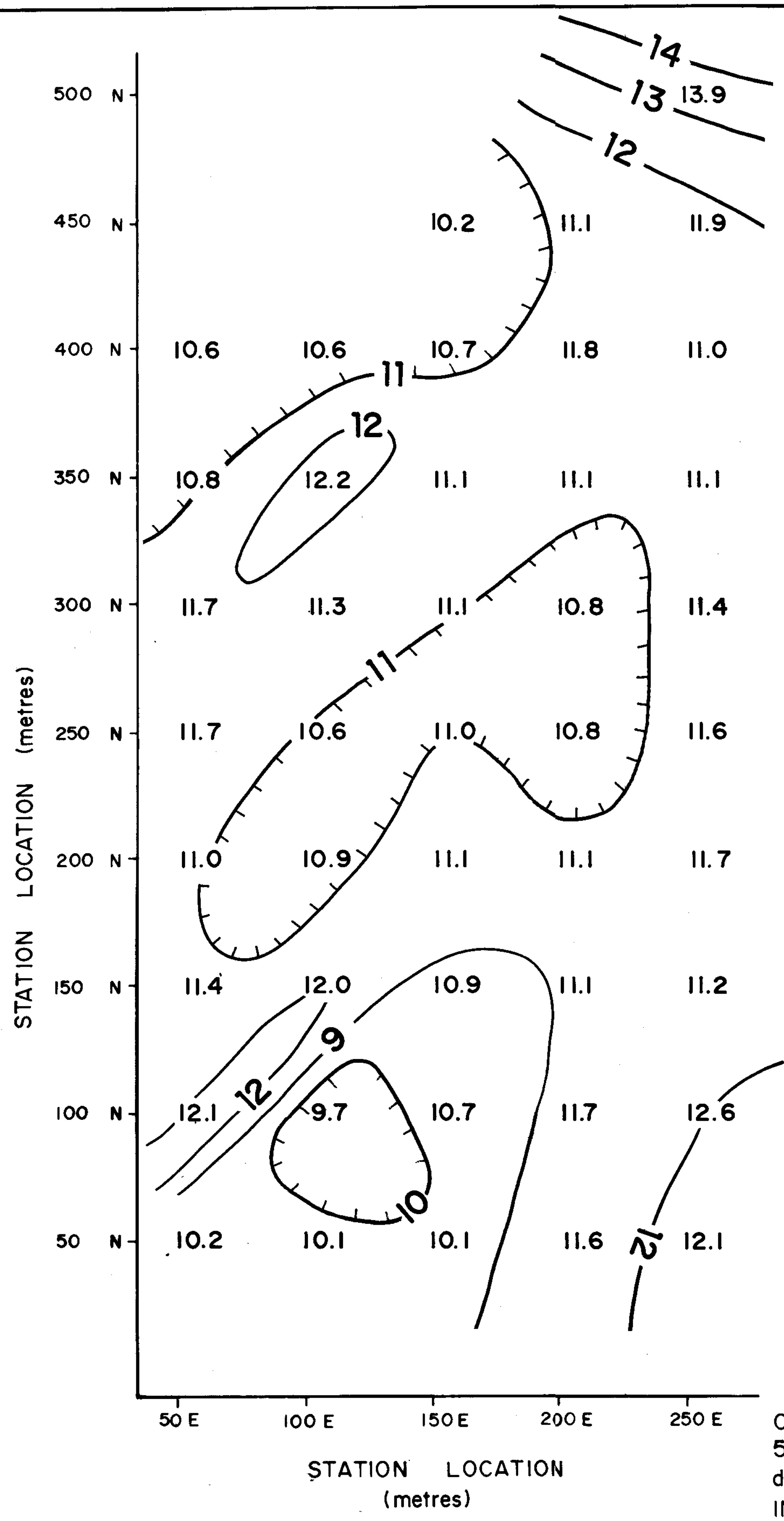


Contour interval 1 Ohm-metre
50m square coincident loops
delay time 0.24 m/s
INSTRUMENT SIROTEM

Figure 9

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED S.DODDS	CDO DATE 24-1-90
BORRIKA SOIL SALINITY STUDY	DRAWN D.S.L	SCALE
CHANNEL 5	DATE July 89	PLAN NUMBER
APPARENT RESISTIVITY CONTOUR PLAN	CHECKED	S20981

4865



Contour interval 1 Ohm-metre
50 m square coincident loops
delay time 0.32 m/s
INSTRUMENT SIROTEM

Figure 10

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

BORRIKA SOIL SALINITY STUDY

CHANNEL 6

APPARENT RESISTIVITY CONTOUR PLAN

COMPILED S.DODDS	CDO DATE 24·1·90	
DRAWN D.S.L	SCALE	
DATE July 89	PLAN NUMBER S 20982	
CHECKED		

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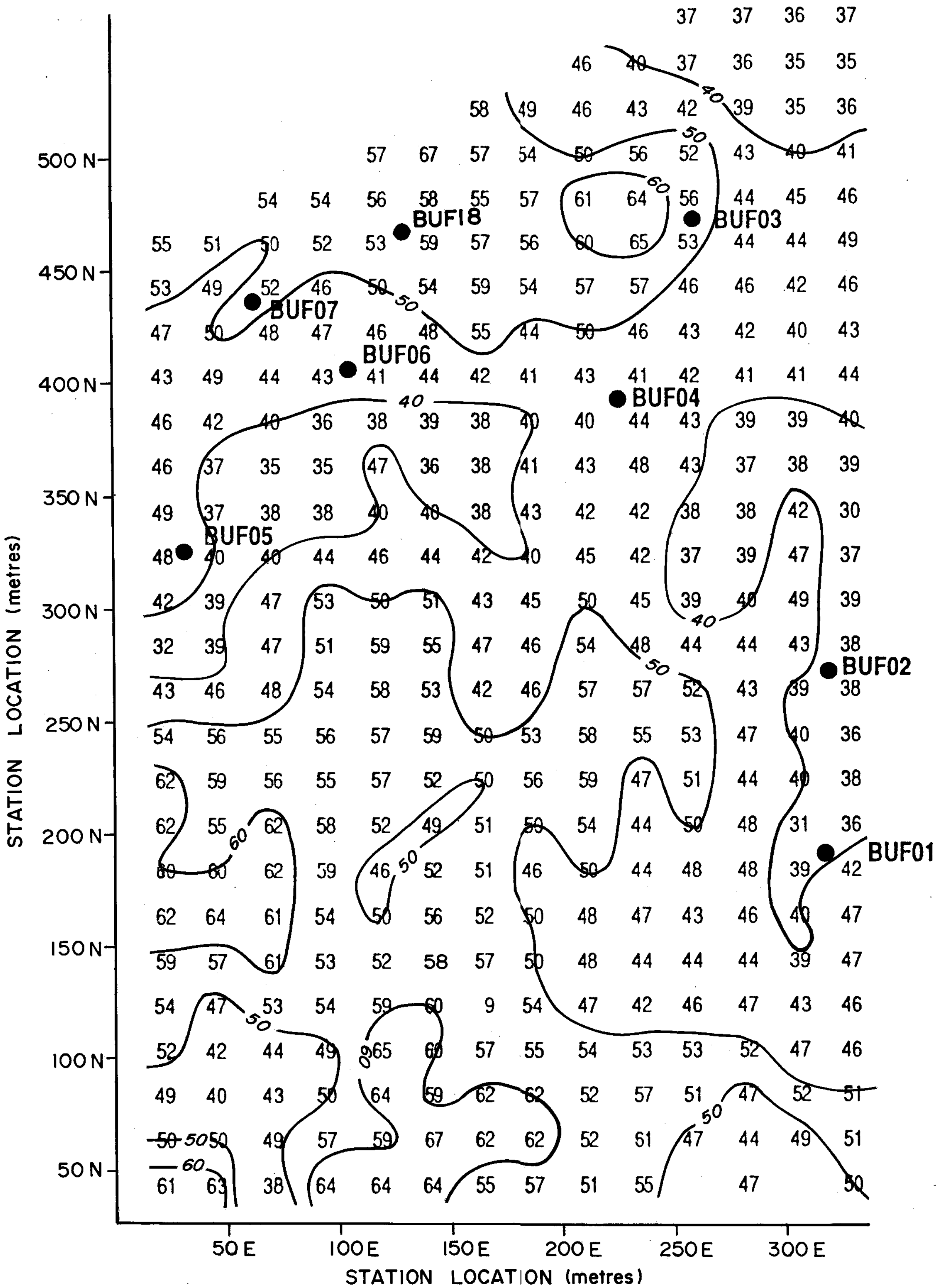
(Data courtesy of C.S.I.R.O. Division of Water Resources)



NOTE: Contour interval 10 millisiemens/metre

Figure 11

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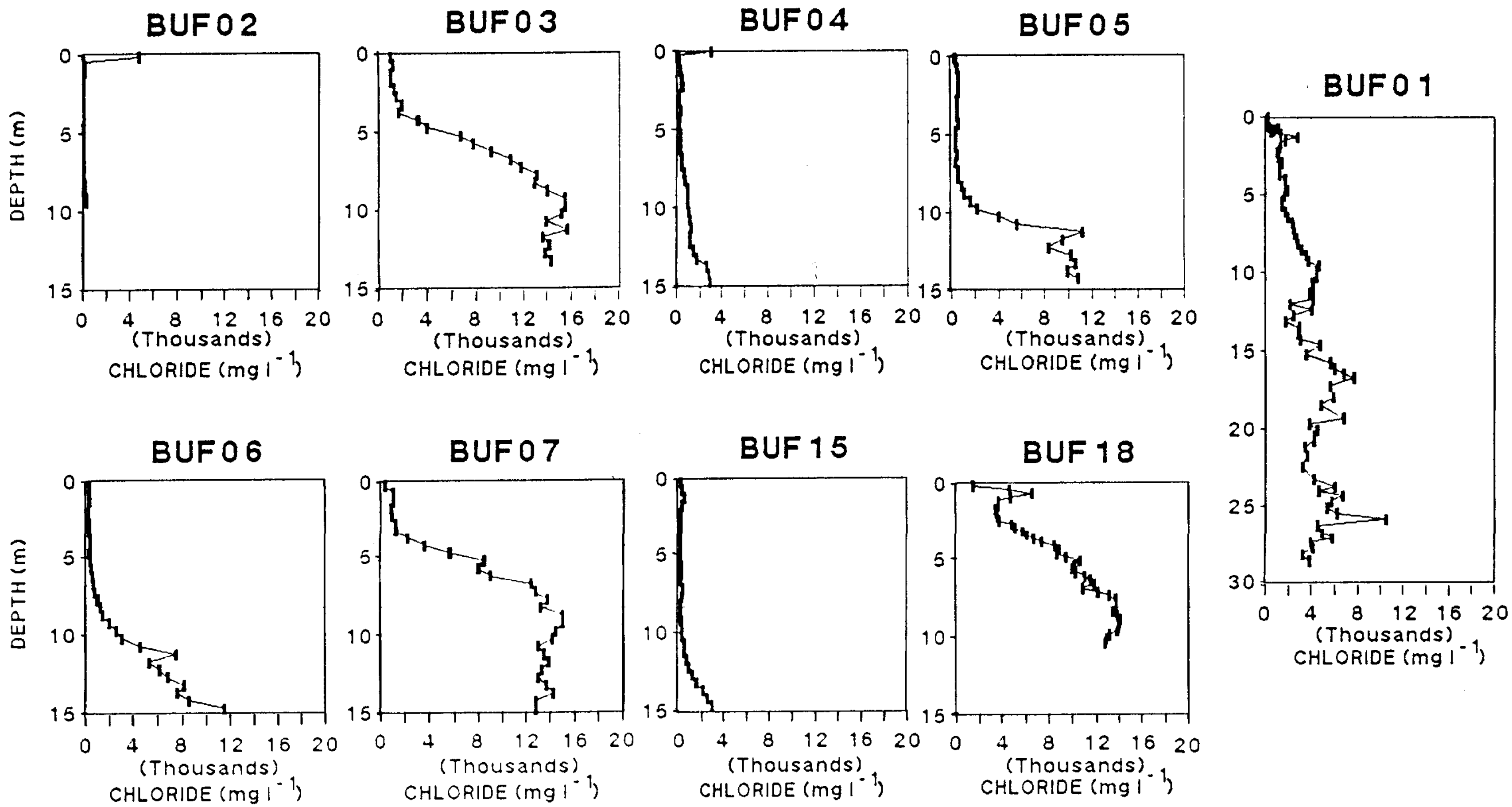
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED S. DODDS	C.D.O. 24·1·90 DATE
BORRIKA SOIL SALINITY STUDY	DRAWN D.S.L.	SCALE
EM-34 GROUND CONDUCTIVITY SURVEY APPARENT CONDUCTIVITY PLAN CONTOURS	DATE AUG 89 CHECKED	PLAN NUMBER S20983



(Courtesy of Division of Water Resources, C.S.I.R.O)

Figure 12 BORRIKA SOIL SALINITY STUDY BOREHOLE SOIL CHLORIDE CONTENT PROFILES

SADME S20984

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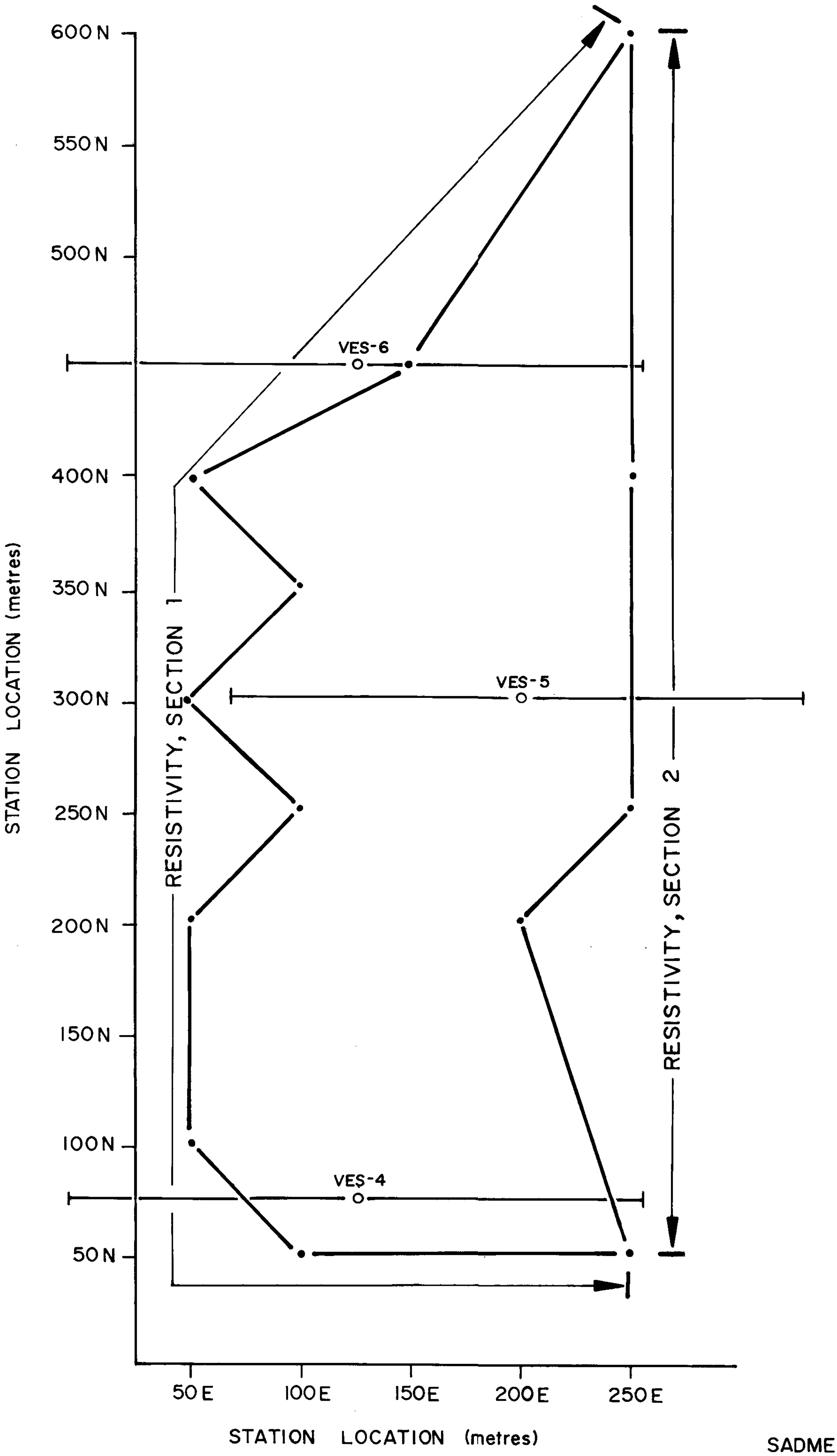
Figure 13

LOCATION OF VES SPREADS AND TEM INVERSIONS



SADME S20985

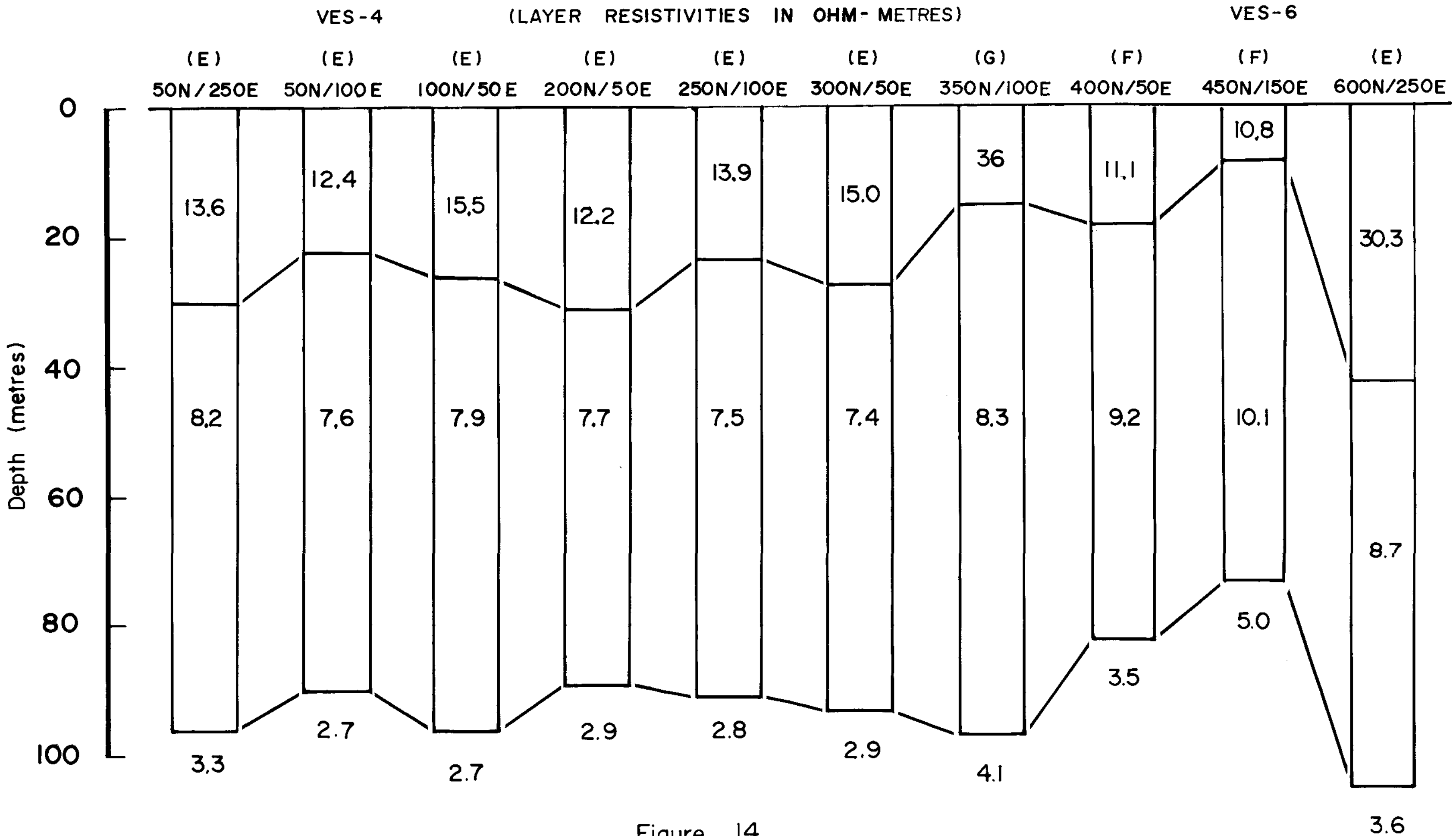


Figure 14

BORRIKA SOIL SALINITY SURVEY

RESISTIVITY SECTION 1, FROM TEM INVERSIONS

NOTE: Quality of inversion

E - Excellant

G - Good

F - Fair

SADME S20986

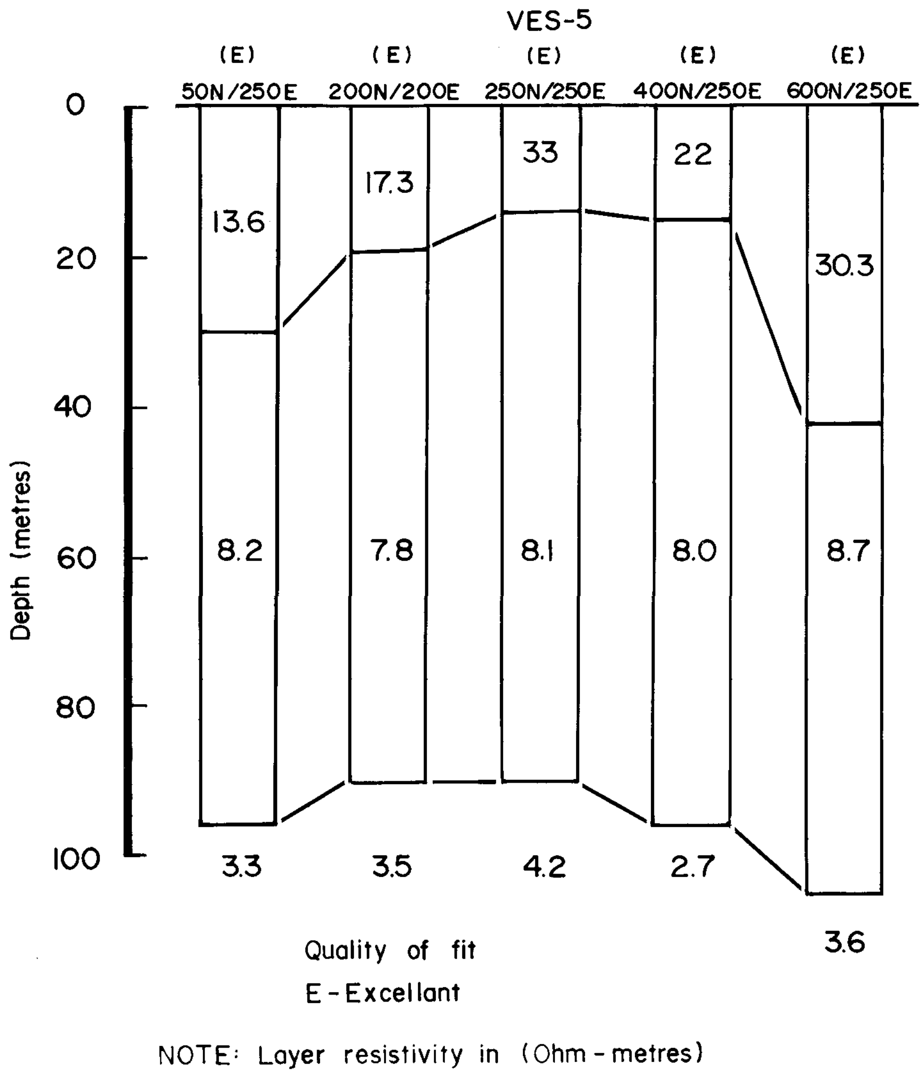


Figure 15

BORRIKA SOIL SALINITY STUDY

RESISTIVITY SECTION 2, FROM TEM INVERSIONS

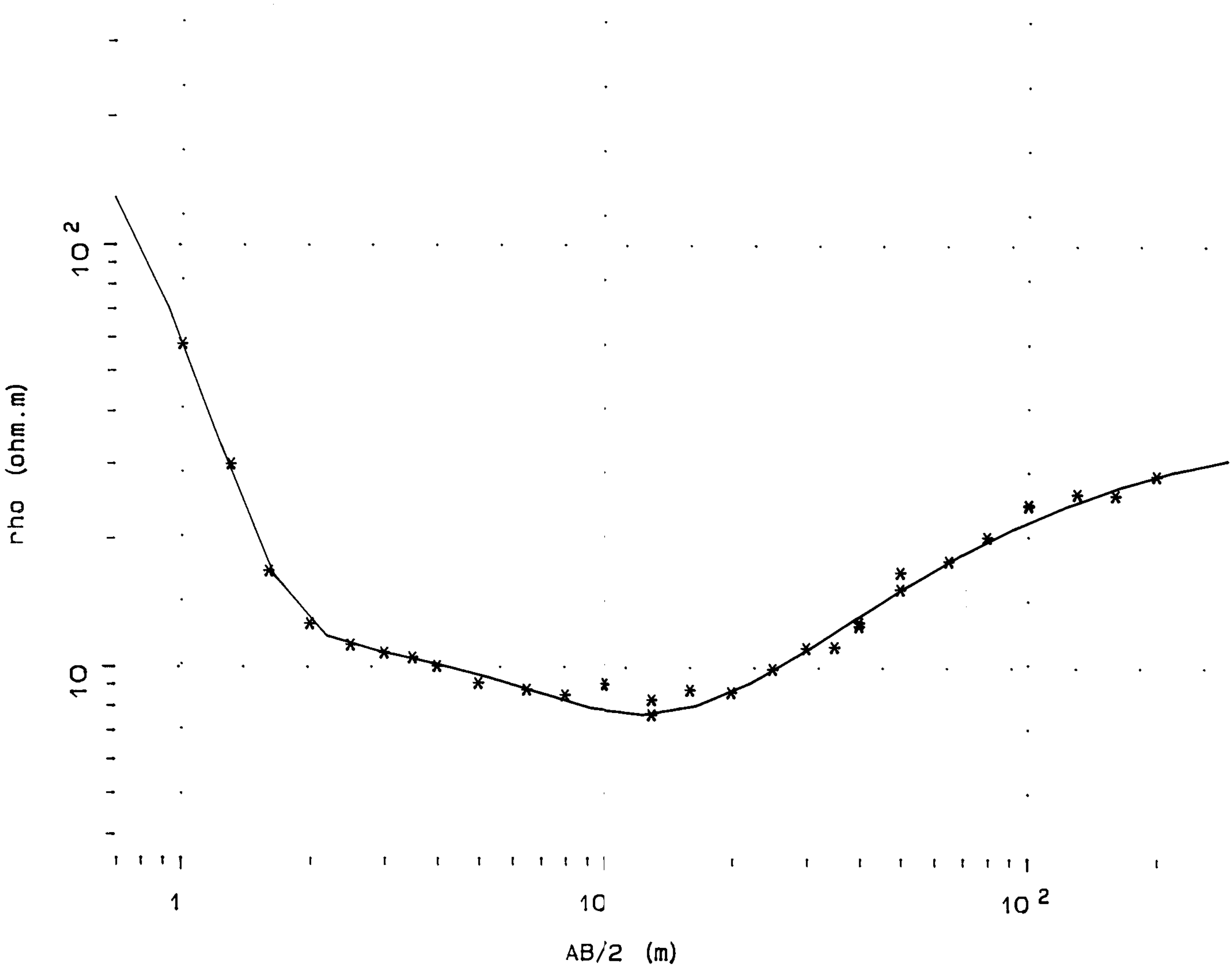
SADME S20987

S.A.D.M.E.

BORRIKA S.A.

Resistivity (ohm.m)	depth (m)
oo	
1	0.000
307.152	
2	0.328
10.419	
3	2.124
34.207	
4	2.371
6.300	
5	14.513
34.729	

VES . 1



* BRGM/GPH * GRIVEL *

Schlumberger

Figure 16. Borrika Soil Salinity Study - VES I Data and Inversion

SADME S20988

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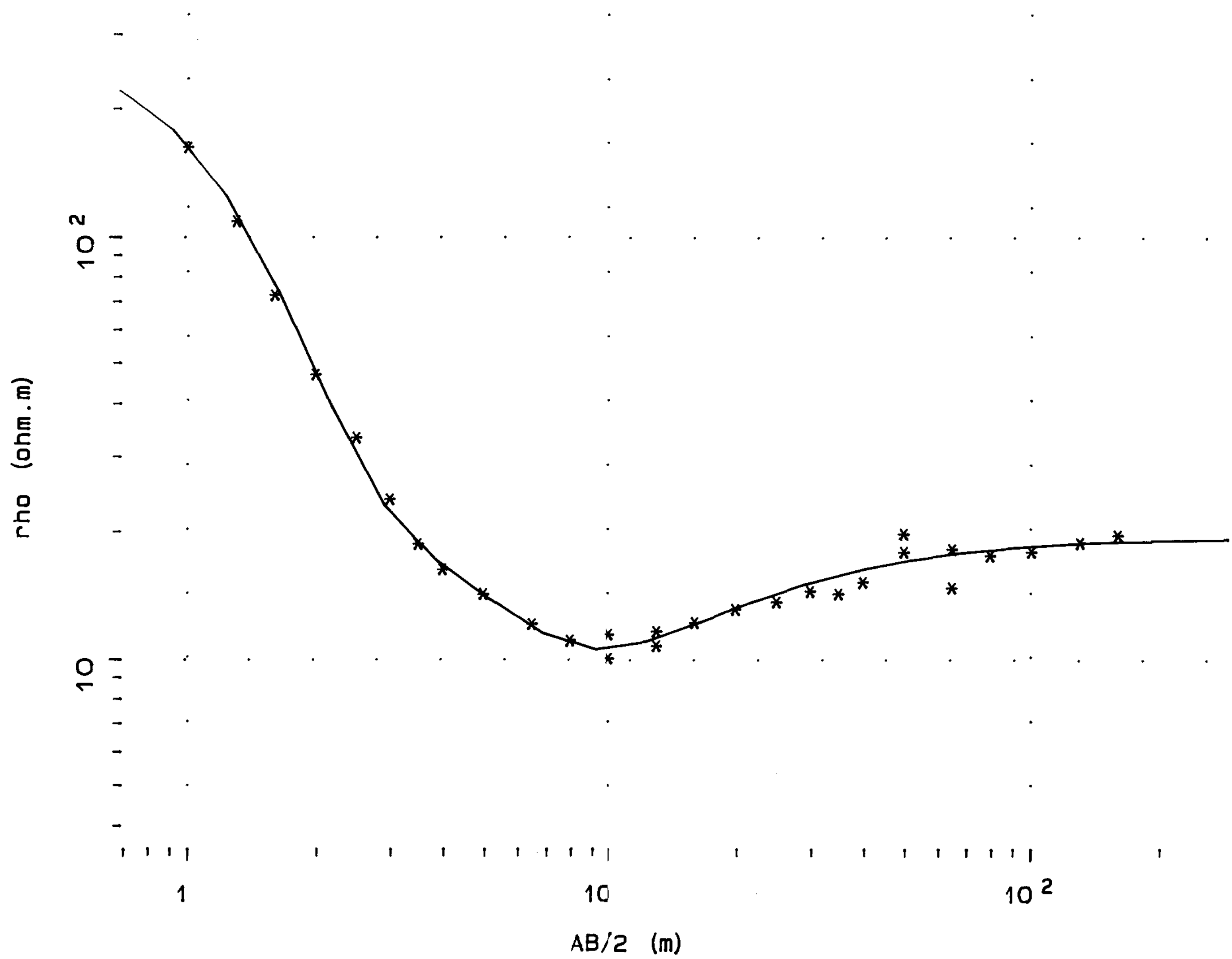
S.A.D.M.E.

BORRIKA S.A.

	Resistivity (ohm.m)	depth (m)
	oo	
1		0.000
	278.596	
2		0.587
	16.163	
3		1.723
	34.207	
4		2.454
	4.701	
5		5.223
	19.338	

VES.2



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* BRGM/GPH * GRIVEL *

Schlumberger

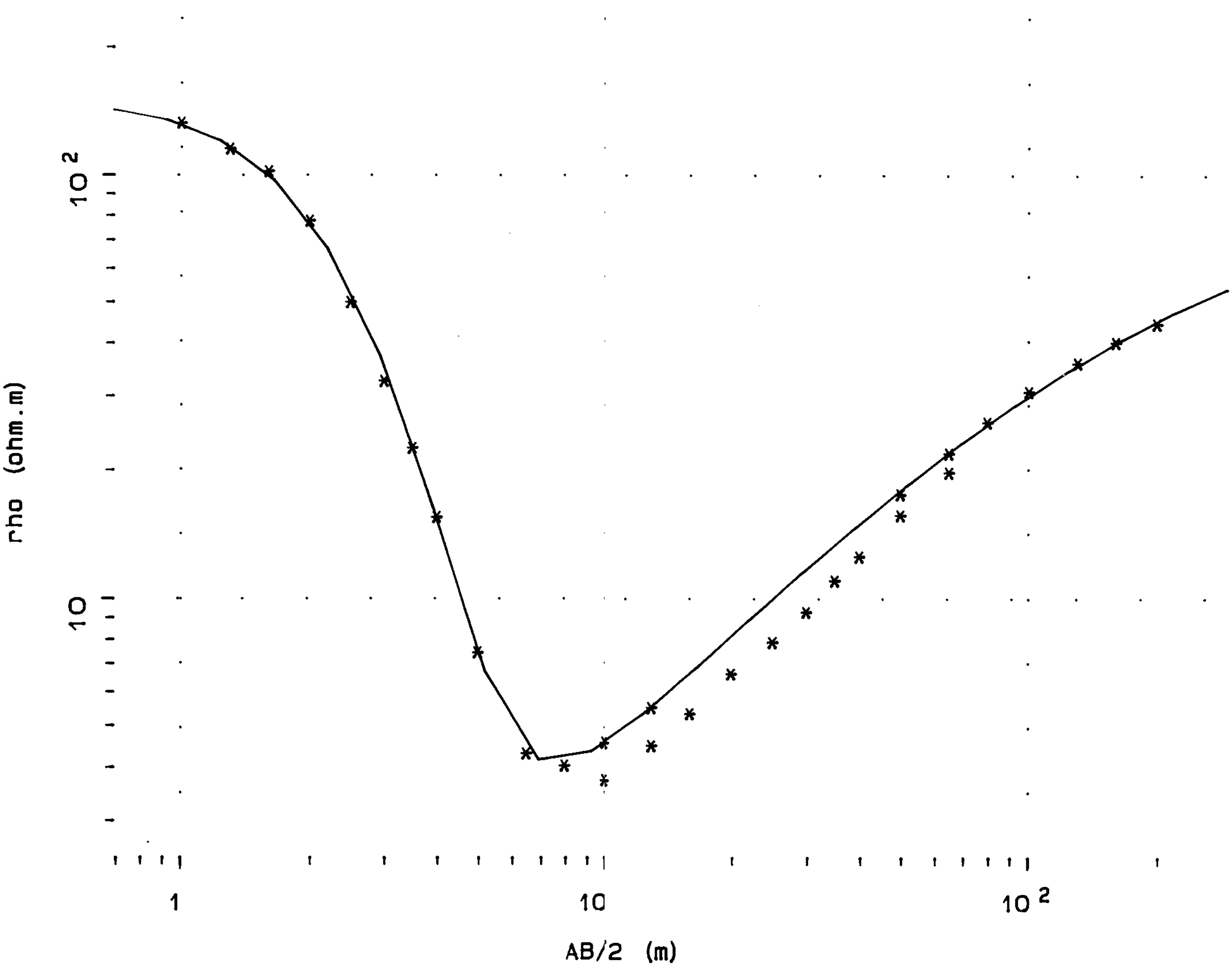
Figure 17. Borrika Soil Salinity Study - VES 2 Data and Inversion

S.A.D.M.E.

BORRIKA

Resistivity (ohm.m)	depth (m)
oo	
1---------------------	0.000
149.243	
2---------------------	1.103
2.814	
3---------------------	7.304
77.175	

VES.3



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* BRGM/GPH * GRIVEL *

Schlumberger

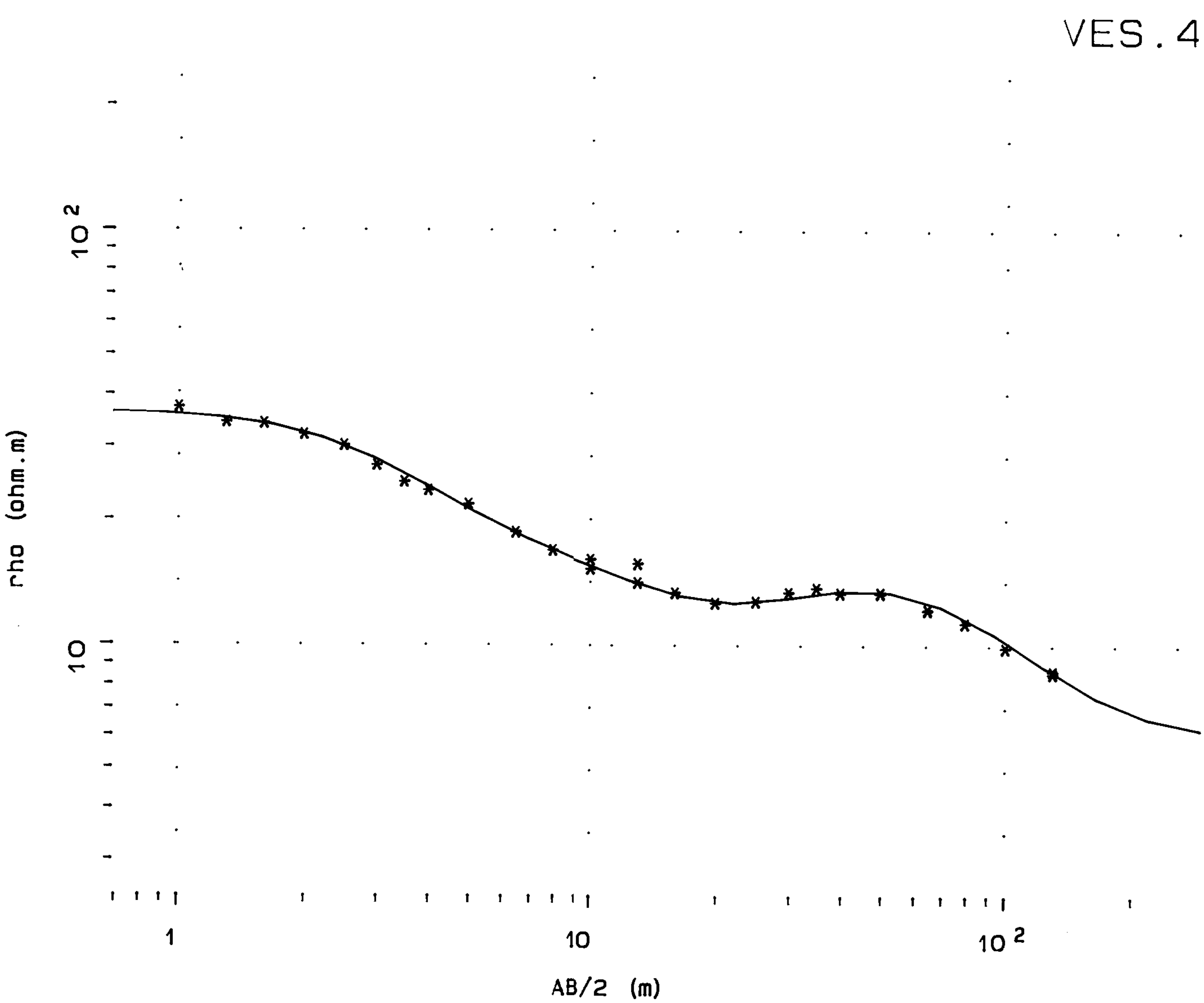
Figure 18. Borrika Soil Salinity Study- VES 3 Data and Inversion

SADME S20990

S.A.D.M.E.

BORRIKA

	Resistivity (ohm.m)	depth (m)
	oo	
1		0.000
	36.750	
2		1.575
	16.081	
3		8.501
	4.041	
4		12.477
	51.310	
5		21.050
	5.970	



* BRGM/GPH * GRIVEL *

Schlumberger

Figure 19. Borrika Soil Salinity Study - VES 4 Data and Inversion

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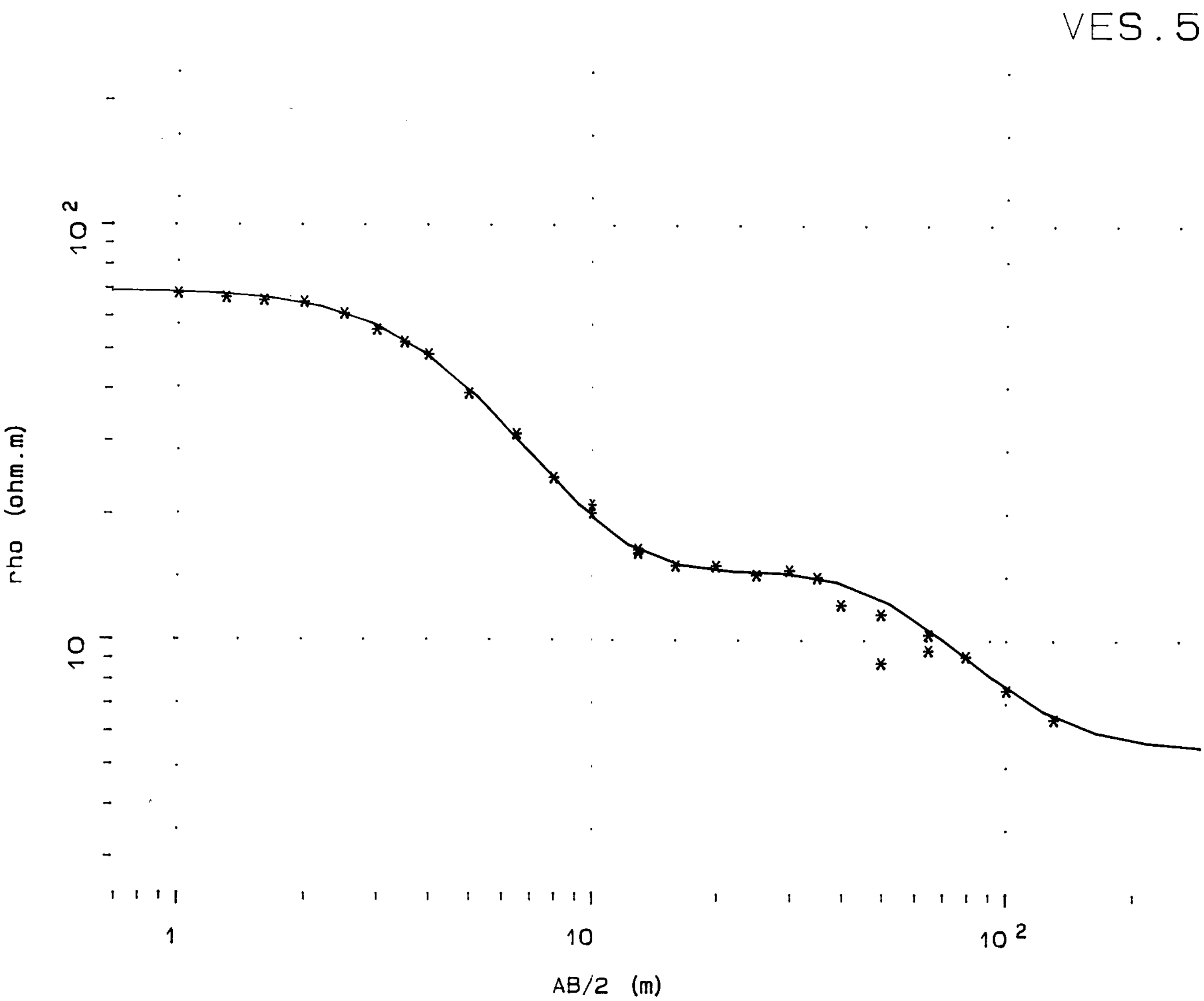
SADME S20991

S.A.D.M.E.

BORRIKA

Resistivity (ohm.m)	depth (m)
oo	
1---------------------	0.000
69.298	
2---------------------	2.365
15.315	
3---------------------	9.028
5.157	
4---------------------	11.930
92.146	
5---------------------	15.224
5.415	



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* BRGM/GPH * GRIVEL *

Schlumberger

Figure 20. Borrika Soil Salinity Study- VES 5 Data and Inversion

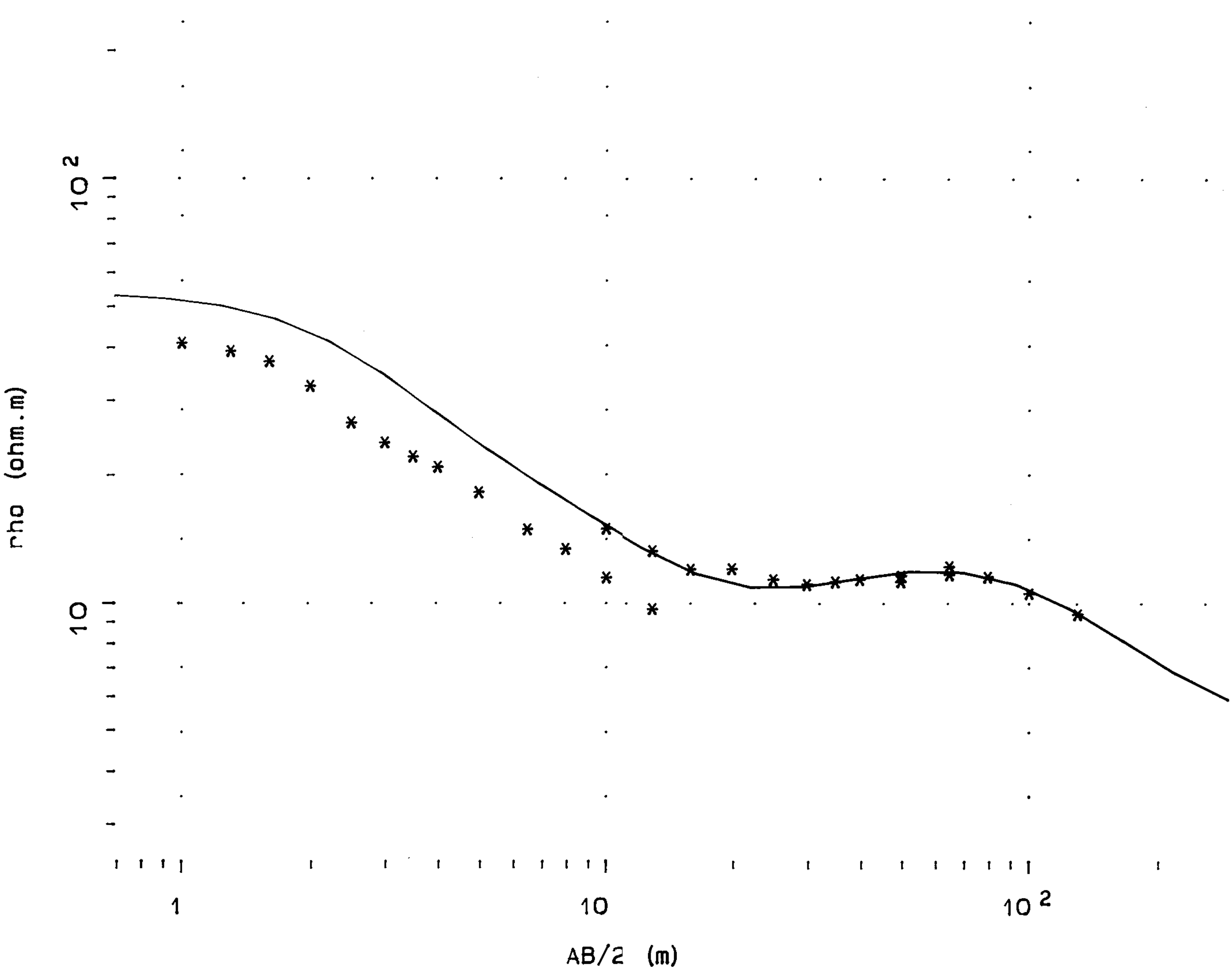
SADME S20992

S.A.D.M.E.

BORRIKA

	Resistivity (ohm.m)	depth (m)
	oo	
1----------------------		0.000
	54.296	
2----------------------		1.311
	19.547	
3----------------------		5.317
	8.820	
4----------------------		23.195
	83.579	
5----------------------		26.851
	9.070	
6----------------------		65.538
	5.000	

VES.6



4865

* BRGM/GPH * GRIVEL *

Schlumberger

Figure 21. Borrika Soil Salinity Study - VES 6 Data and Inversion

SADME S20993

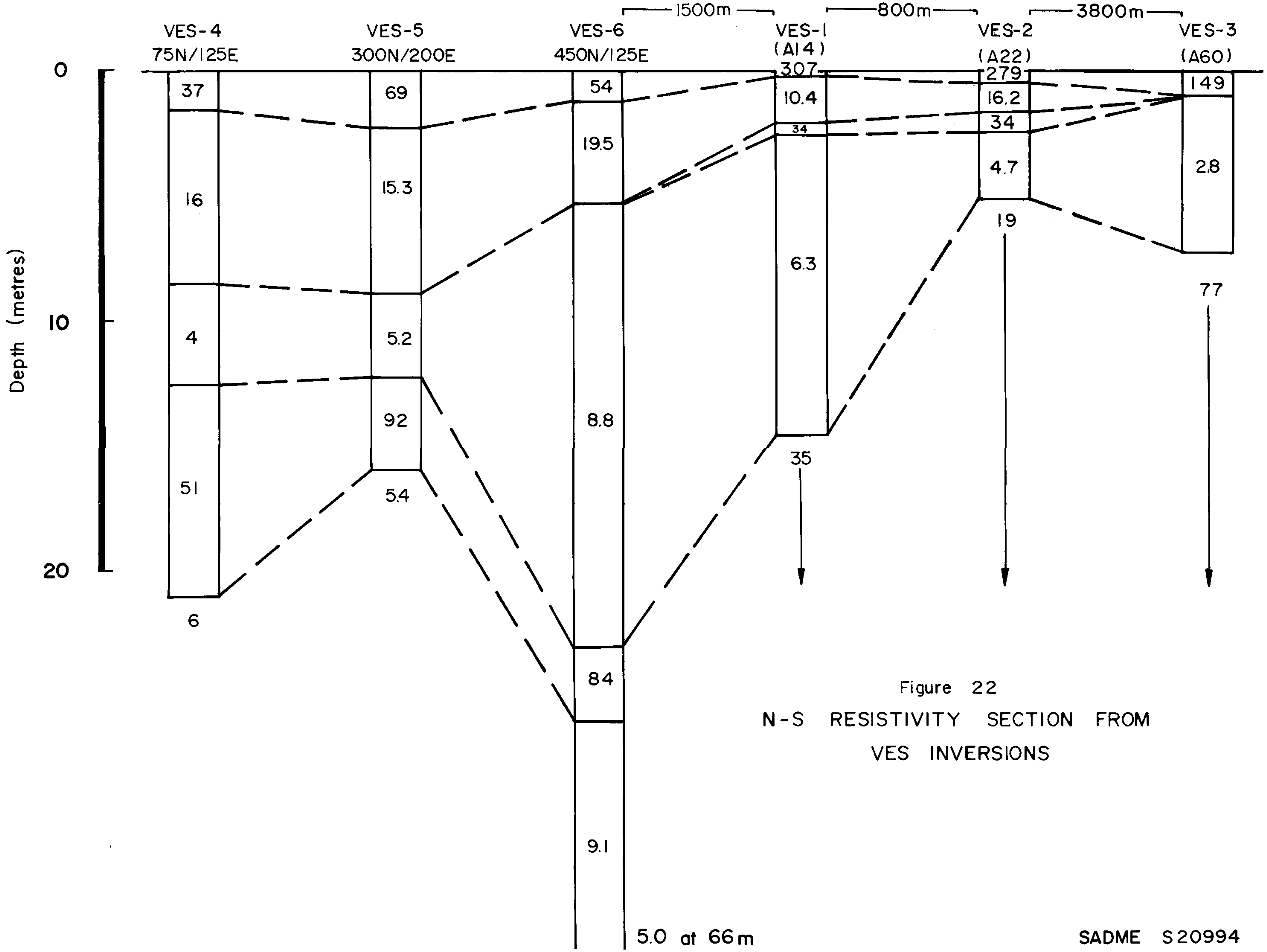


Figure 22
N-S RESISTIVITY SECTION FROM VES INVERSIONS

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