DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

REPT.BK.NO. 81/34
RESISTIVITY SURVEYS AT MIL-LEL
AND MILLICENT

NOVEMBER, 1980

GEOLOGICAL SURVEY

by

C.D. COCKSHELL

DME. No. 238/75

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DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

Rept.Bk.No.: 81/84
DME No.: 238/75

RESISTIVITY SURVEYS AT MIL-LEL AND MILLICENT, NOVEMBER, 1980

ABSTRACT

A detailed follow-up survey of vertical electrical soundings at Mil-Lel in the South East of South Australia has verified the existance of a plume of pollution within the shallow unconfined aquifer, previously investigated in December, 1979. The plume extended southwest from the Kraft cheese factory for approximately 1700 m, is ovoid in shape and up to 750 m wide. The contamination caused by disposing whey and liquid factory wastes into a sinkhole on the property has spread over a larger area than found in the previous survey, but its maximum thickness has reduced from 10 m to 6 m, giving rise to a constant contaminated water volume of approximately 380 Ml. Comparison of the plume geometry interpreted from the two surveys indicated a general southwest movement of approximately 50 m. The margins of the polluted zone are diffuse and difficult to map due to the resolution limits of the method used.

The salinity of the polluted zone appears to be variable, but a range 650-6500 mg/l could be expected. Salinities near the margins of the zone are expected to be less due to diffusion and dilution.

Reconnaissance vertical electrical soundings near the Millicent Saleyard effluent spray irrigation area indicate that this form of waste disposal has had no apparent effect on the underlying very shallow unconfined aquifer in this area.

INTRODUCTION

The disposal of industrial waste is a general problem in the South East of South Australia. Good quality groundwater occurs at shallow depth in an often cavernous limestone which is very susceptible to contamination.

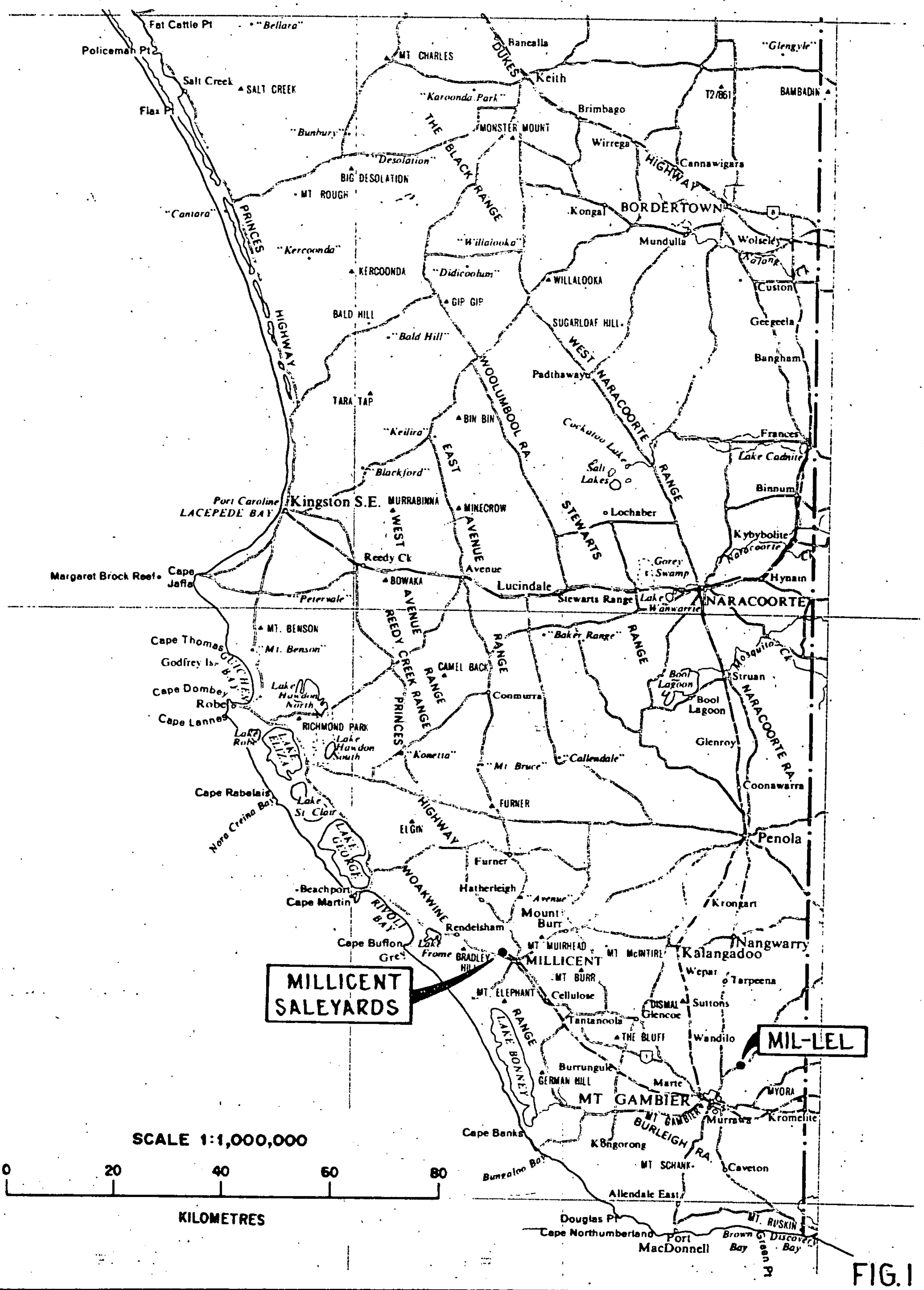

FIG.1

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED C.D.C.	C.D.O. 8.4.81 DATE
MIL-LEL AND MILLICENT RESISTIVITY SURVEYS NOVEMBER 1980	DRAWN R.H.	SCALE 1:1000000
LOCALITY PLAN	DATE JAN 1981	PLAN NUMBER
	CHECKED	S15299

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At the Kraft Mil-Lel cheese factory (Fig. 1) disposal of liquid wastes was accomplished for many years by direct discharge into a sinkhole on the property, which allowed rapid drainage to the limestone aquifer. In 1975 the problem of groundwater pollution became apparent and the method of waste disposal was changed to spray irrigation of perennial pastures (Barnett, Armstrong and Emmett, 1977). In 1979, at the request of the South East Water Resources Investigation Committee, the Geophysics Section of the Department of Mines and Energy conducted an electrical resistivity survey over the area to determine the extent and severity of the pollution in the aquifer. The results of the survey (Cockshell, 1980) indicated that a plume of pollution extended southwest from the factory for approximately 1600 m and was up to 650 m wide and 10 m thick.

It was suggested that a more intensive follow-up survey would define the pollution plume more accurately and provide information on the movement of pollution caused by the regional aquifer water flow. Detailed knowledge of direction and rate of movement was required to plan possible future decontamination action as the regional flow is in a southwesterly direction, straight toward Mt. Gambier, seven kilometres away (Waterhouse, 1977).

Whilst in the general area, the Hydrogeological Section of the department suggested that a brief reconnaissance survey over the Millicent Saleyards effluent spray irrigation area be carried out to investigate possible pollution of the very shallow aquifer in the area.

SURVEY PROCEDURE

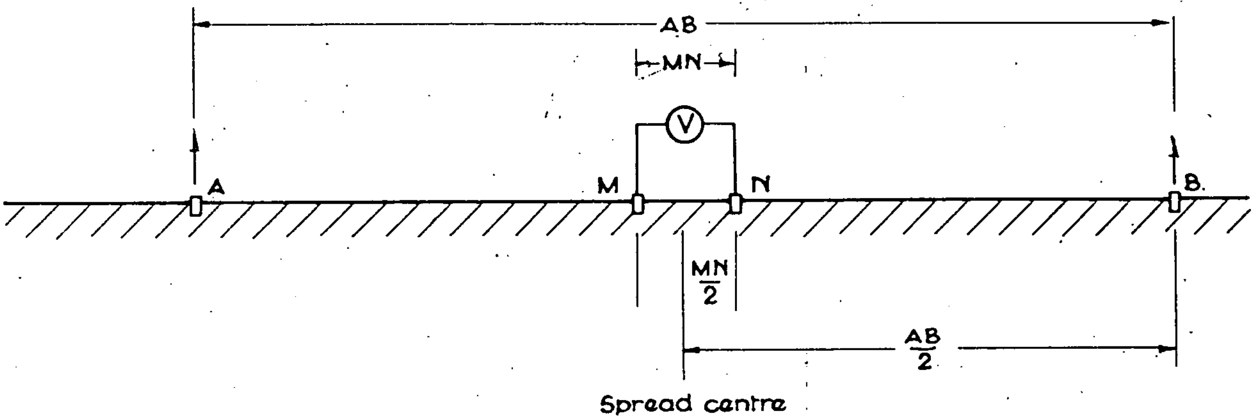
An eleven day survey was planned and commenced on 10th November 1980, incorporating six days in the Mil-Lel area and two days in the Millicent area. A series of Schlumberger vertical electrical soundings (VES) were planned to cover each area to explore the geometry of the more conductive polluted aquifer zone, located near the top of the moderately resistive unpolluted aquifer. Spreads were initially located along roads for easy access, but were later sited in paddocks for more intense coverage.

The equipment and technique used were the same as for the 1979 survey, the details of which can be found in the report by Cockshell, 1980. The Schlumberger array used is shown in Fig. 2 and comprises potential electrods (M and N) inside of and in line with the outer current electrodes (A and B). By increasing the electrode spacing the depth of investigation can be increased.

In the Mil-Lel area the maximum half-spread length (AB/2) required was generally 200 m and in the Millicent area it was generally 65 m.

From the measurement of potential and known transmitted current, the apparent resistivity for each value of MN/2 and AB/2 was calculated from the relationship shown in Fig. 2. The apparent resistivity was then plotted against the corresponding AB/2 value on bilogarithmic paper as shown in Fig. 3 for later interpretation.

SCHLUMBERGER VERTICAL
ELECTRICAL SOUNDING CONFIGURATION



$$\rho a = \pi \frac{V}{I} \frac{(AB/2 + MN/2)(AB/2 - MN/2)}{MN}$$

ρa = Apparent Resistivity

V = Measured Potential Difference

I = Input Current.

FIG. 2

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED C.D.C.	CDO 8.4.81 DATE
MIL-LEL RESISTIVITY SURVEY	DRAWN R.H.	SCALE ——
NOVEMBER 1980	DATE. Jan 1980	PLAN NUMBER
SCHLUMBERGER V.E.S. CONFIGURATION	CHECKED	S15300

2308

INTERPRETATION AND RESULTS - MIL-LEL

Intepretation was carried out initially by using Orellana and Mooney (1966) three layer curves, together with auxiliary curves to determine resisitivity and thickness for multiple layers (up to five). These results were then submitted to a Tektronix 4051 microcomputer for more detailed modelling. Models were accepted when a suitably good fit between the calculated and field curves was obtained (Fig. 3). The resolution limit placed on interpretation was that layers thinner than about 10% of their depth would not be detected.

At Mil-Lel, twenty nine soundings were carried out at locations as shown in Fig. 4. Several soundings produced poor apparent resistivity curves due to lateral variations in near surface resisitivity and, to a lesser extent, noisy reading conditions.

All the layers interpreted from the soundings in the Mil-Lel area have been placed into eight groups as shown in Table 1. Layer 1 represents the surface soil horizon which is up to 2.2 m thick and extremely variable in resistivity. The highly resistive layer 2 represents the dry sands of the Malanganee Formation which are up to 1.6 m thick. The low resistivity of layer 3 indicates a thin clay layer in some areas and a thicker, possibly clayey limestone zone elsewhere. This layer could be correlated to the top of the Pleistocene Bridgewater Formation. Layers 4 and 5 represent a thick zone of limestone which appears to vary in water content from dry in parts of layer 4 to completely saturated in parts of layer 5. These layers appear to form a transition zone between the near surface dry sediments and the underlying aquifer. Stratigraphic correlation of this zone is difficult but it is assumed to include part of the Bridgewater

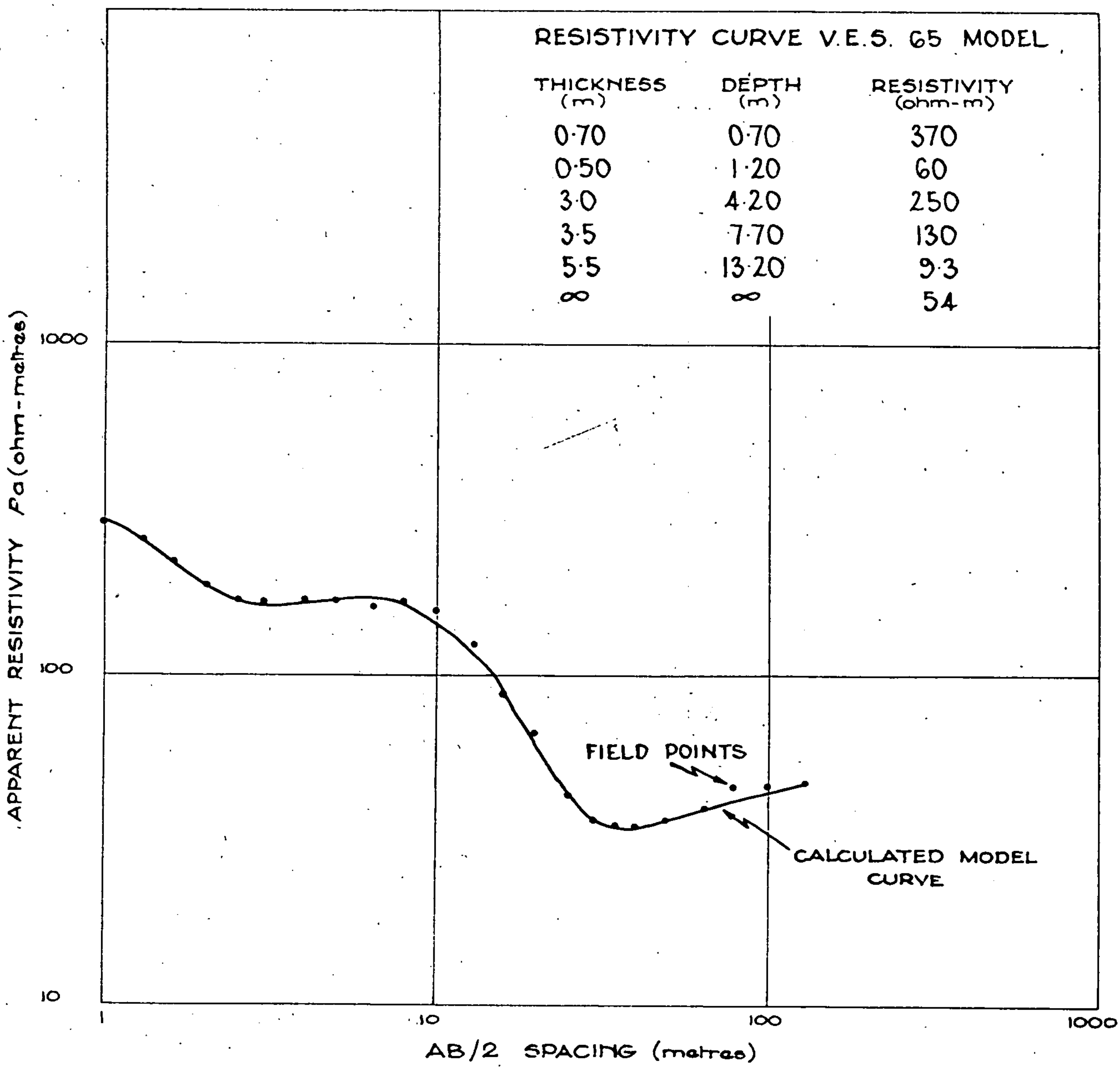


FIG. 3

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MIL-LEL RESISTIVITY SURVEY
NOVEMBER 1980

RESISTIVITY CURVE V.E.S. 65

COMPILED	C.D.C.	CDO	8·4·81 DATE
DRAWN	R.H.	SCALE	—
DATE	JAN 1981	PLAN NUMBER	
CHECKED		S15301	

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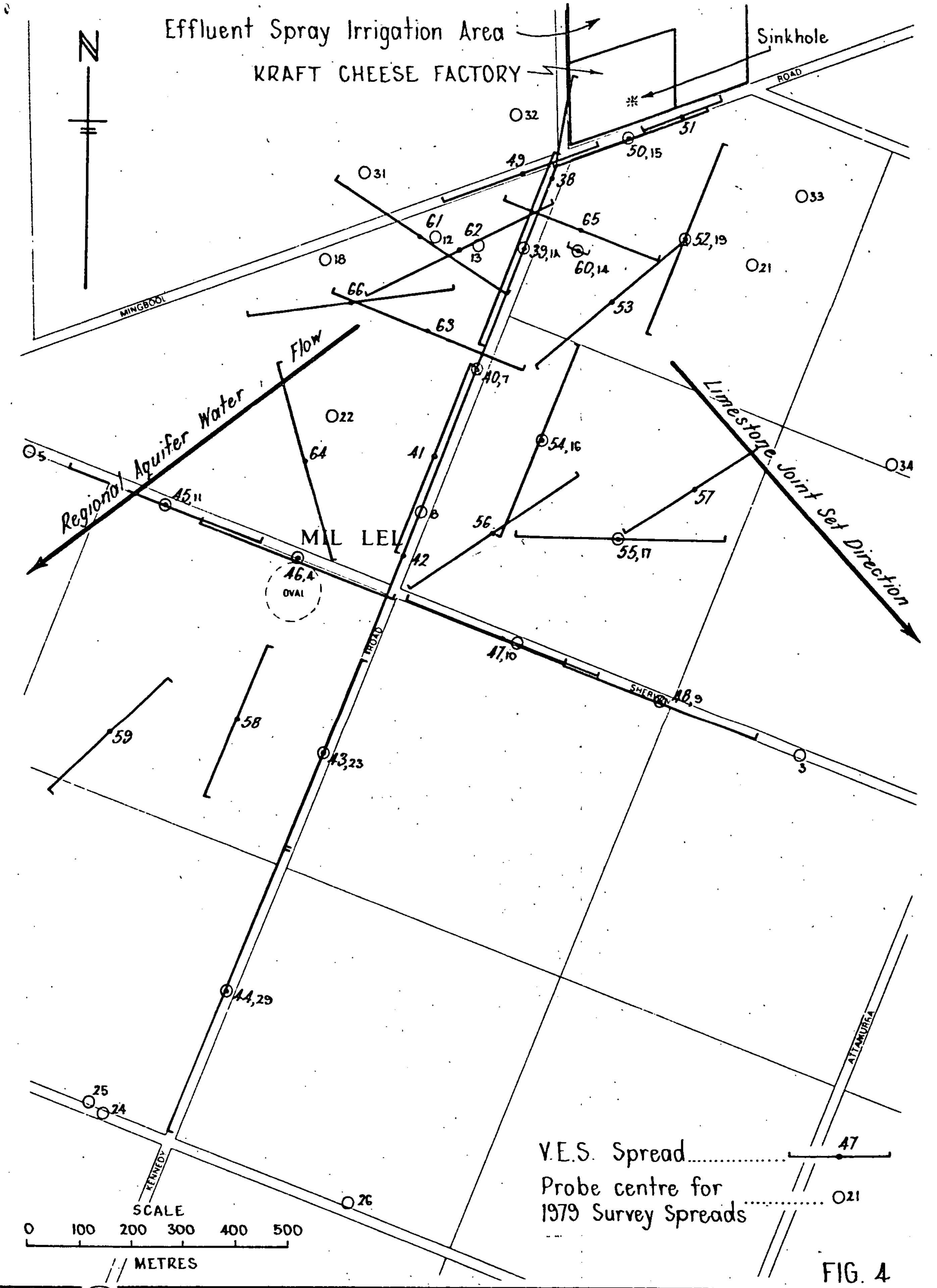

FIG. 4

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MIL-LEL RESISTIVITY SURVEY
NOVEMBER 1980
V.E.S. SPREAD PLAN

COMPILED C.D.C.	CDO 8.4.81 DATE
DRAWN R.H.	SCALE 1:10000
DATE Jan. 1981	PLAN NUMBER
CHECKED	S15302

2308

Formation where present and possibly part of the underlying Oligo-Miocene Gambier Limestone. The low resistivity of layer 6 indicates the presence of polluted groundwater in the Gambier Limestone aquifer. In several soundings a seventh layer of moderately high resistivity has been interpreted which may indicate a less permeable zone within the aquifer, which is represented by the very thick layer 8.

The distribution of polluted groundwater is shown by the isopach plan of layer 6 in Fig. 5. The pollution plume extends approximately 1700 m from the factory bearing 210°, and is up to 750 m wide. The plume attains a maximum thickness of just over 6 m approximately 200 m southwest of the factory. As stated by Cockshell (1980), the margins of the polluted zone are difficult to define due to the resolution limits of the method used and the probable existence of a transition zone between the polluted and the unpolluted aquifer. Therefore, little confidence can be placed on the accuracy of the zero isopach or "Assumed Limit of Pollution" shown in Fig. 5.

The average resistivity of the unpolluted aquifer is 51 ohm-metres which corresponds to a groundwater salinity of about 300-360 mg/l. The resisitivity of the polluted layer averages 11 ohm-metres but is quite variable. As resistivity and thickness are equivalent within certain limits, that is, a thin low resistivity layer will have a similar response to a slightly thicker, slightly more resistive layer, the interpreted resistivity of the polluted layer depends on its interpreted thickness. The interpretation of data in this survey has been biased toward producing a smooth isopach map at the cost of resistivity continuity. Even so, there is a significant increase in resisitivity away from the centre of the plume, indicating the

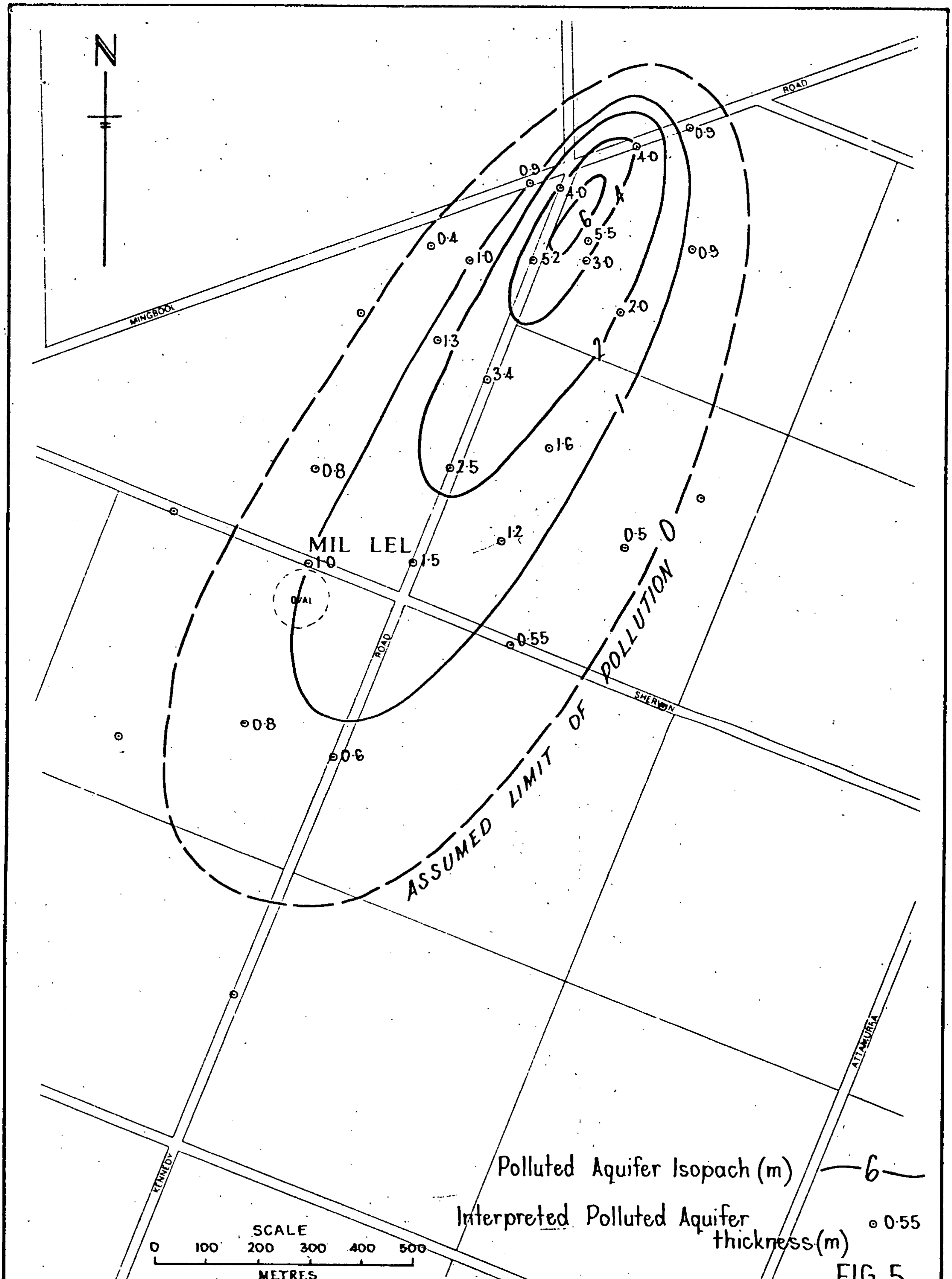

FIG. 5

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED C.D.C.	CDO 8.4.81 DATE
MIL-LEL RESISTIVITY SURVEY NOVEMBER 1980 POLLUTED AQUIFER ISOPACH PLAN 1980 DATA INTERPRETATION	DRAWN R.H.	SCALE 1:10000
	DATE Jan 1981	PLAN NUMBER
	CHECKED	S15303

2308

effect of dispersion and dilution. Outside the 2 m isopach the average resistivity is 13.0 ohm-metres, while within this line the average is 7.7 ohm-metres. Therefore, although an average groundwater salinity of approximately 1800 mg/l is indicated for the whole plume, a salinity range of 600-6500 mg/l could be expected.

The 1980 survey provided extra control for the interpretation of the 1979 survey data, and a number of 1979 soundings required reinterpretation to be consistent with this control. A complete list of 1979 VES interpreted layers, grouped into the same system as that for the 1980 survey, are shown in Table 2. This reinterpretation caused changes of layer 6 parameters in some soundings and a revised polluted aquifer isopach plan is shown in Fig. 6. The general features of this pollution plume are the same as those reported by Cockshell (1980) but some isopachs have been laterally displaced.

Comparison of the results of the two surveys is effected by the overlay of the 1980 polluted aquifer isopach plan on the revised 1979 isopach plan (Fig. 6). Comparison of the two plans shows that over the eleven month period between the two surveys there has been an increase in areal extent of the effected zone from 97 to 109 ha. This increase appears to be volumetrically balanced by the reduction of maximum plume thickness from nearly 10 m to just over 6 m. This change of distribution can be seen in Table 3 where polluted groundwater volumes have been estimated for each isopach interval. The estimated total contaminated water volume is approximately 380 Ml for both surveys.

The other main feature of this comparison is the general extension of the isopachs in a southwesterly direction. This extension averages 50 m which indicates an annual movement of

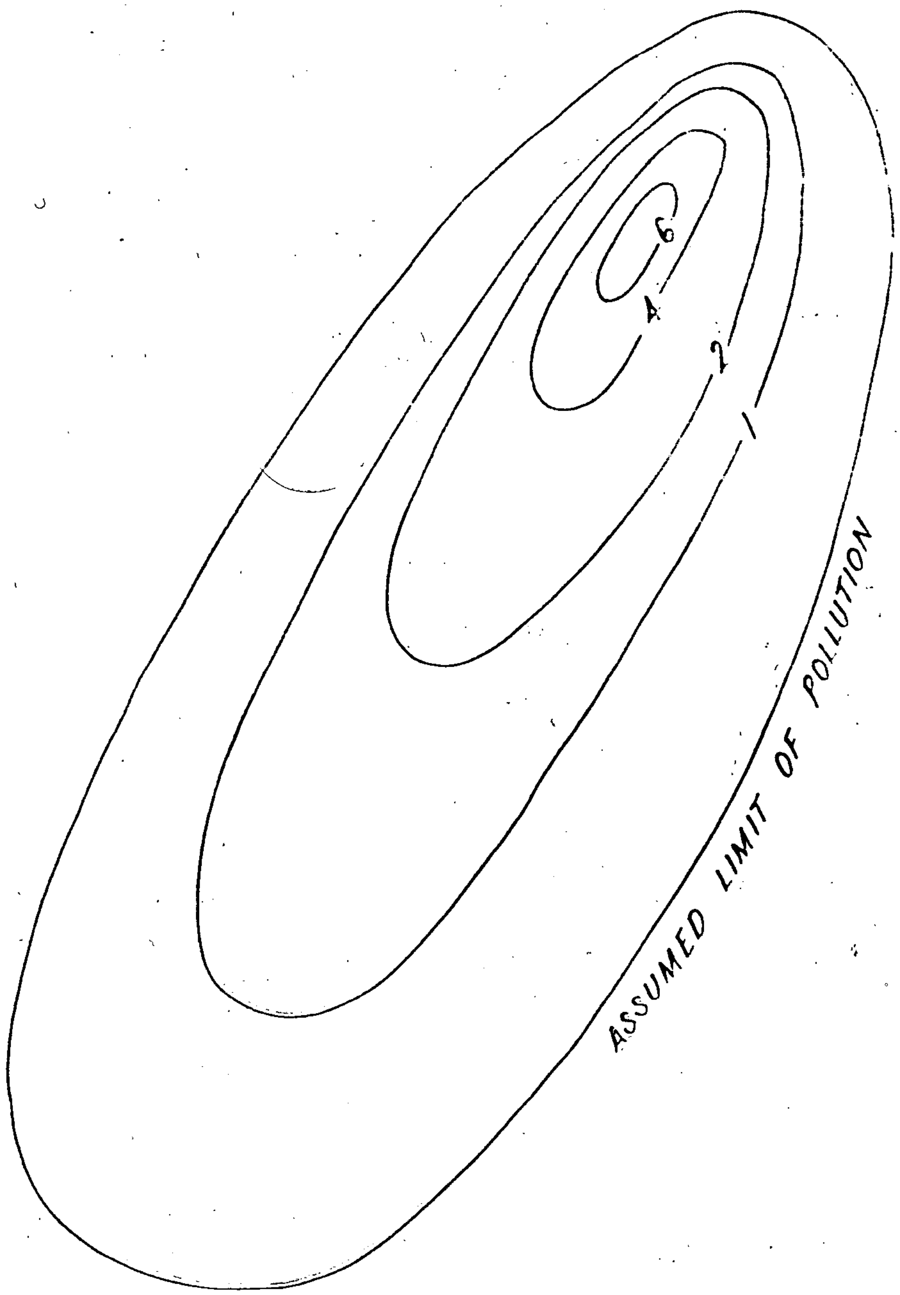

FIG. 6 overlay

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED C.D.C.	B 8.4.81 CDO DATE
MIL-LEL RESISTIVITY SURVEY NOVEMBER 1980	DRAWN R.H.	SCALE 1:10000
1979-1980 ISOPACH COMPARISON	DATE Jan. 1981 CHECKED	PLAN NUMBER S15304

2208

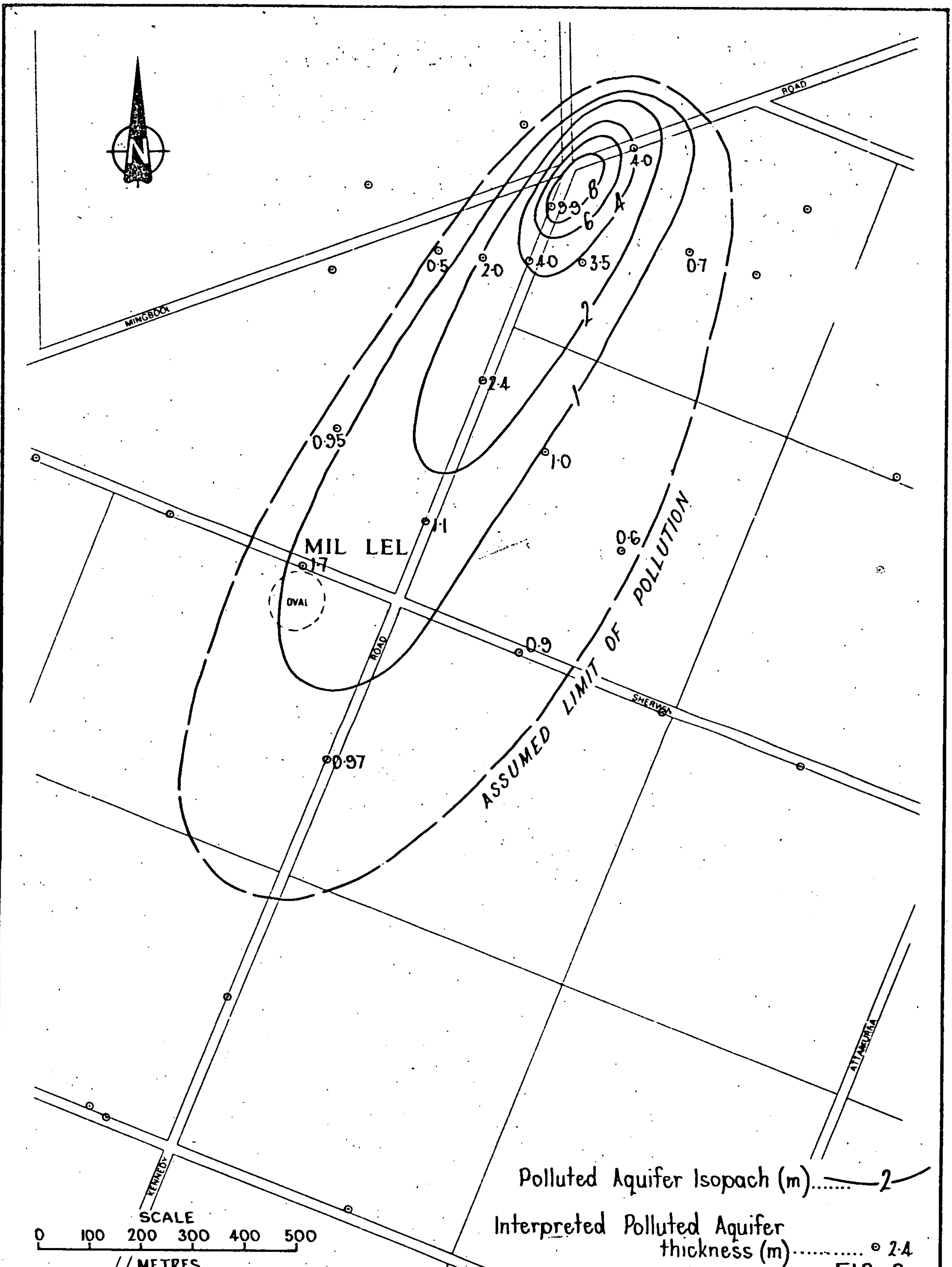

FIG. 6

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MIL-LEL RESISTIVITY SURVEY
NOVEMBER 1980
POLLUTED AQUIFER ISOPACH PLAN
REVISED 1979 DATA INTERPRETATION

COMPILED C.D.C.	CDO	DATE 6.4.81
DRAWN R.H.	SCALE 1:10000	
DATE Jan. 1981	PLAN NUMBER	
CHECKED	S15305	

approximately 55 m. This is consistent with the movement of maximum pollution thickness away from the factory at a rate of 200 m in four years, and it also agrees with regional water flow calculations. The rate of radial diffusion out from the plume is estimated to be 5 m per year.

INTERPRETATION AND RESULTS - MILLICENT

Seven reconnaissance Schlumberger VES probes were sited in and around the Millicent Saleyards spray irrigation area as indicated in Fig. 7. Although the spreads were much shorter than those at Mil-Lel, the interpretive procedure was the same as that noted in previous pages.

All the layers interpreted from the soundings have been placed into five groups as shown in Table 4. Layer 1 represents the surface sandy soil horizon which is up to 0.7 m thick and quite variable in resistivity. The more resistive layer 2 represents the dry to partly saturated sandy limestone of the Bridgewater Formation, while the water bearing part of this unit is represented by layer 3. Layer 4 is a zone of moderately high resistivity which is difficult to correlate stratigraphically, but it may represent a less permeable zone within the Bridgewater Formation overlying the thick Gambier Limestone (layer 5).

The average resistivity of layer 5 is 64 ohm-metres, which is very similar to that of layer 3. This indicates that there is little apparent pollution of the aquifer which is represented by layers 3, 4 and 5. It is further noted that although layer 3 resistivities are generally lower than corresponding layer 5 resistivities, which may indicate a salinity increase of approximately 30 mg/l, this variation in resistivity may reflect different rock lithologies and properties of the two layers. The

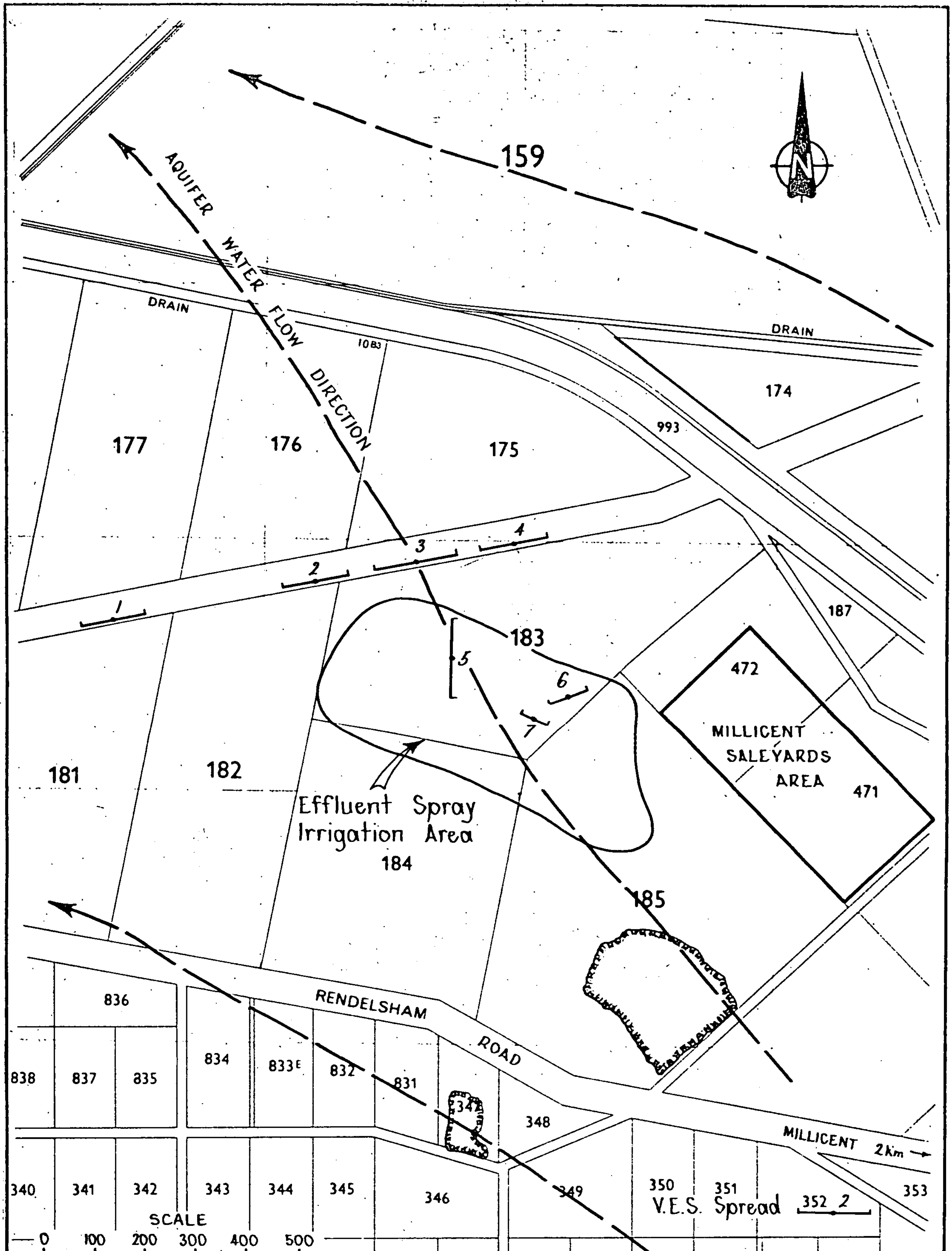

FIG. 7

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

MILLICENT RESISTIVITY SURVEY
NOVEMBER 1980
V.E.S. SPREAD PLAN

COMPILED C.D.C.	C.D.O. 8·4·81	DATE
DRAWN R.H.	SCALE 1:10000	
DATE Jan. 1981	PLAN NUMBER S15306	
CHECKED		

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number and accuracy of the soundings may also have an influence on this apparent variation.

CONCLUSIONS

The survey has confirmed the presence of a plume of pollution within the unconfined aquifer southwest of the Mil-lel cheese factory. The general shape of the plume is the same as that derived from the less detailed 1979 survey, but the plume has extended to approximately 1700 m southwest of the factory and is now up to 750 m wide. The maximum thickness of the plume has decreased to just over 6 m which volumetrically balances the increase in area. The total volume of the contaminated aquifer is estimated to be 1.25 million cubic metres, which contains approximately 380 Ml of contaminated water, assuming a porosity of 30%.

Regional aquifer water flow has caused a general extension of polluted layer isopachs to the southwest which indicates an annual movement of 55 m, which includes diffusion at a rate of about 5 m per year. This figure is consistent with the movement of the zone of thickest pollution away from the factory and regional water flow calculations.

The interpreted resisitivity of the polluted layer varies considerably and could not be used to indicate accurately aquifer salinity. However, it is expected that salinity may range from 600 mg/l near the edge of the polluted zone up to 6500 mg/l near its centre. Further VES surveys could be carried out to monitor the movement of the pollution plume and to provide better salinity estimates near its centre, but only drilling and careful water sampling could define its margins due to the resolution limits of the method used.

Reconnaissance soundings in the region of the Millicent Saleyard effluent spray irrigation area indicate no apparent pollution of the very shallow unconfined aquifer. Some soundings indicated a zone of lower resistivity at the very top of the aquifer but the method cannot define whether this is caused by slight changes in lithology, hydraulic parameters or groundwater salinity. It is recommended that no further VES surveys be carried out in this area due to the lack of resolution of the method compared to the definition required.

C.D. Cockshell

C.D. COCKSHELL
GEOPHYSICIST

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TABLE 1

	LAYER 1		LAYER 2		LAYER 3		LAYER 4	
MIL-LEL VES No.	Thick (m)	Resist. (ohm.m)	Thick (m)	Resist. (ohm.m)	Thick (m)	Resist. (ohm.m)	Thick (m)	Resist. (ohm.m)
38	0.06	240	0.6	4000				
39	0.03	25	0.15	1400	4.0	40	0.7	450
40	1.3	90					2.0	200
41	0.04	39	0.23	2700	0.25	12	3.3	260
42	0.14	170	0.50	980			1.3	200
43	0.30	190	0.40	1100	0.10	25	5.5	180
44	0.30	160	1.1	900			7.5	95
45	0.50	180			0.07	7.9	2.7	380
46	2.2	330			0.25	9.0	1.0	500
47	0.48	230	0.30	1800	0.10	10	1.0	470
48	0.04	38	0.85	670	0.10	9.0	1.5	600
49	0.75	630	0.65	2900				
50	0.12	330	0.90	2000			5.0	110
51	1.2	170			1.4	39	1.2	870
52	0.70	370	1.5	980			3.2	340
53	0.03	75	0.30	2600	0.20	14		
54	0.17	140	0.83	1000				
55	0.09	430			0.15	13		
56	0.10	170	1.0	2100	0.10	9.0	6.0	270
57	0.05	200	1.6	1950				
58	0.04	100	0.90	3400	0.19	25	8.0	380
59	0.05	58	0.60	1300				
60	0.80	540			0.10	16	3.0	240
61	0.95	230			0.15	6.3	0.30	1000
62	0.80	500			0.20	4.9		
63	0.05	150	0.50	2600	0.30	7.9		
64			1.4	730	0.50	50	2.9	580
65	0.70	360					3.0	260
66	0.10	170	1.3	1550	1.6	60		
					2.6	30		

TABLE 1 (cont.)

MIL-LEL VES No.	LAYER 5 Thick (m)	LAYER 5 Resis. (ohm.m)	LAYER 6 Thick (m)	LAYER 6 Resist. (ohm.m)	LAYER 7 Thick (m)	LAYER 7 Resist. (ohm.m)	LAYER 8 Resist. (ohm.m)	ELEV-ATION (m) AHD
38	3.9	70	4.0	4.8			49	61
39			5.2	8.5			50	59
40	4.2	30	3.4	4.5			63	57
41			2.5	3.9			54	61
42	5.5	93	1.5	10.5			48	59
43			0.60	25			43	55
44	1.8	160					40	55
45	1.0	60			4.0	280	45	58
46	7.0	68	1.0	15	1.0	280	40	60
47	5.3	150	0.55	30			50	58
48	3.0	80			5.0	140	49	56
	5.0	35						
49	6.3	110	0.90	11			54	63
50	5.0	130	4.0	5.0			37	65
51	5.3	170	0.90	20			34	64
52			0.90	13			50	60
53	4.5	130	2.0	12			73	59
54	2.1	80	1.6	8.1			64	58
55	3.0	140	0.50	7.0	2.0	240	56	58
56			1.2	25			53	59
57	2.1	120					65	59
58			0.80	3.5			66	59
59	8.0	130					47	55
60			3.0	18			69	60
61	2.8	250	0.40	5.0			44	59
62	4.6	150	1.0	14			49	59
63	4.6	160	1.3	6.9			46	59
64			0.80	2.6			57	59
65	3.5	100	5.5	9.3			54	62
66	8.0	42			1.5	450	44	60

TABLE 2

MIL-LEL VES No.	LAYER 1 Thick (m)	LAYER 1 Resist. (ohm.m)	LAYER 2 Thick (m)	LAYER 2 Resist. (ohm.m)	LAYER 3 Thick (m)	LAYER 3 Resist. (ohm.m)	LAYER 4 Thick (m)	LAYER 4 Resist. (ohm.m)
1	.07	81	.52	3050				
1A*	.05	35	.15	3200	1.0	14	0.4	700
2	.05	120	.25	2500	.43	10	2.52	500
3	1.0	362	.20	1650	.20	9.0	2.8	165
4*	1.0	395	.14	1700	.25	10	1.5	400
5	1.2	241			.15	15		
6	.42	205			.50	28	12	335
7	1.0	212			.15	10	2.7	162
8	.30	780	1.1	2200			7.0	195
9	1.4	344			.08	16	6.4	174
10	1.5	205					4.0	188
11	.55	158			.10	11	2.0	451
12*	1.0	305			.11	9.5		
13	.15	142	.29	3650				
14*	.70	385			.10	13	.60	900
15*			2.4	1250	.30	7.0	.30	200
16	.20	600	.70	4550				
17	.05	140	.50	2050				
18	.15	1100	1.5	3400				
19*	.10	280	2.8	1800				
20	.10	250	.70	2900	.15	5.0		
21			1.8	4100	.35	5.0	1.8	200
22*	.02	350	1.5	5100	.10	25		
23	.06	300	1.25	930	.15	12		
24	ABANDONED							
25			1.5	1500	.15	10	2.0	350
26	.03	70	1.8	4000	.22	6.5	2.0	450
27			1.7	2300	1.0	55	20	560
28	.18	80	.27	800			.50	200
29*			1.6	2000	.10	30		
30	.80	450			.15	5.8	7.7	1200
31			.78	2900				
32	.08	600	1.6	3650	.08	3.7	6.0	230
33	.02	200	1.2	3700			6.0	170
34	ABANDONED							
35			.50	1100	.60	22		
36			1.2	4200	.60	14		
37*	ABANDONED							

(* denotes reinterpretation of 1979 data)

TABLE 2 (cont.)

MIL-LEL VES No.	LAYER 5 Thick (m)	Resis. (ohm.m)	LAYER 6 Thick (m)	Resist. (ohm.m)	LAYER 7* Thick (m)	Resist. (ohm.m)	LAYER 8 Resist. (ohm.m)	ELEV-ATION (m)AHD
1	5.3	41	9.9	9.7			62	60
1A*			4.0	5.5			60	59
2							60	60
3							61	59
4*	10.5	98	1.7	11			52	60
5	10.8	150					41	60
6							64	56
7			2.4	3.8			61	57
8			1.1	4.7			50	59
9							53	56
10	5.0	135	.90	3.5			53	58
11	7.9	140					45	58
12*	8.0	120	0.5	30			51	58
13	7.0	44	2.0	6.3			54	60
14*	6.0	68	3.5	12			59	60
15*	8.5	100	4.0	5.2			48	65
16	2.7	34	1.0	13			62	58
17	6.0	92	.60	10			63	58
18	8.0	140					64	63
19*	3.0	120	.70	3.2			60	60
20	3.0	135					48	63
21							53	61
22*	12	110	0.95	10	2.0	320	60	62
23	9.0	63	.97	2.6			48	55
24	ABANDONED							53
25	13	125					56	53
26	11	125					64	60
27							58	67
28	15	142					59	54
29*	6.0	85					46	55
30							60	49
31	8.0	95					60	59
32							63	66
33							51	62
34	ABANDONED							60
35	4.0	52					48	64
36	1.0	80					48	64
37*	ABANDONED							

TABLE 3

POLLUTED AQUIFER VOLUME CALCULATIONS

1979 SURVEY

POLLUTED AQUIFER ISOPACH INTERVAL (m)	AREA (m^2)	AVERAGE THICK.(m)	ROCK VOLUME (m^3)	WATER VOLUME* (Ml)
8–10	9 200	9.20	84 660	25
6–8	12 300	7.04	86 600	26
4–6	21 700	4.86	105 500	32
2–4	124 300	2.88	358 000	108
1–2	234 200	1.46	342 000	103
0–1	567 000	0.49	277 800	84
TOTALS	968 700		1 254 500	378

1980 SURVEY

POLLUTED AQUIFER ISOPACH INTERVAL (m)	AREA (m^2)	AVERAGE THICK.(m)	ROCK VOLUME (m^3)	WATER VOLUME* (Ml)
6–8	6 800	6.20	42 200	13
4–6	34 700	4.96	172 200	52
2–4	138 500	2.72	376 100	113
1–2	270 000	1.43	386 100	116
0–1	639 500	0.44	281 400	85
TOTALS	1 089 500		1 258 000	379

*ASSUMING POROSITY OF 30%

TABLE 4

MILLICENT SALEYARD VES No.	ELEVATION (m, AHD)	LAYER 1 Thick (m)	LAYER 1 Resist. (ohm.m)	LAYER 2 Thick (m)	LAYER 2 Resist. (ohm.m)	LAYER 3 Thick (m)	LAYER 3 Resist. (ohm.m)	LAYER 4 Thick (m)	LAYER 4 Resist. (ohm.m)	LAYER 5 Resist. (ohm.m)
1	15	0.45	640	0.50	3400	0.70	64	0.70	430	69
2	15	0.65	260	0.65	530	2.0	40	2.3	340	47
3	15	0.40	125	0.70	550	2.8	42	0.80	580	52
4	15	0.70	120	0.70	230	1.0	70	3.3	140	59
5	16	0.13	1600	0.65	2500	0.80	150	0.16	270	61
6	16	0.25	350	0.30	750	0.35	78	0.15	100	83
7	16	0.17	760	0.23	3500	0.40	70	0.30	300	80