J. DREXEL.

DEPARTMENT OF MINES AND ENERGY
GEOLOGICAL SURVEY OF SOUTH AUSTRALIA

Groundwater Resources of the Barossa Valley

M.A. Cobb

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HOME PAGE

Aerial view of Tanunda taken in January 1985 showing patchwork of vineyards irrigated by groundwater (*Dept. Lands. SVY 3189/000*).

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SUMMARY

The Barossa Valley in South Australia is the second largest single area in Australia planted to vines. About 8600 ha are currently planted of which about 2400 ha are irrigated. Smaller areas of irrigated vegetables and fruit trees also exist. Irrigation water is mainly groundwater which is also used in several wineries for washing and cooling purposes. Groundwater withdrawal during 1979 was estimated to be 1.6 x 10^6 m^3.

Groundwater is stored in a complex series of sediments of Cainozoic age. The aquifers are sands and gravels occupying an asymmetric trough, fault controlled, and the maximum thickness of sediments is approximately 140 m. The complex fluviatile, deltaic and lacustrine depositional environment is reflected in rapid lateral and vertical facies changes, making aquifer definition difficult.

The North Para River and its tributaries traverse the Valley floor and are important, depending on location, either as sources of recharge or as groundwater drains. Water quality in the North Para River is of marginal to poor quality except during peak flow, whereas Tanunda and Jacob Creeks are of much better quality.

Groundwater quality is variable and generally approaches the recommended limit for vine irrigation but some irrigation with higher salinities is practised. Any increase in groundwater salinity would limit its usefulness for irrigation. Chemical composition of the groundwater does not so far appear to have had any effect on soil permeability. There is now some evidence that salinity is rising on a regional scale but recorded rises in certain wells are probably attributable to poor construction or casing corrosion.

A trial water budget for 1979-80 showed a near balance but, because of the assumptions, budget components are approximate only. Observation well hydrographs to that time indicate complete or nearly complete annual recovery of water levels, except in the Dorrien-Tanunda area where increased pumping in the years up to 1979/80 has reduced groundwater storage. After 1980, water level observations show small water level declines in most areas but particularly in the Tanunda region.

INTRODUCTION

'Agricola' (1849) in his treatise Description of the Barossa Range and its Neighbourhood in South Australia eloquently described the Barossa Valley, then Angas Park:

> . . .Angas Park, between the ranges of the Belvedere and the Barossa Range, which is a delightful spot of fertile land, in the shape of level meadows, with very large gum-trees (Eucalypti), and partly a mere grassy plain, without even the least shrub. This park is moistened by chains of ponds from the Gawler River, running from Light's Pass, and from a brook issuing out of a valley between the Kaiserstool and Hochenstauffen, and joining the Gawler; is about seven miles long, and four miles broad. . .
> The salubrity of the climate in New Silesia, in connection with the fertility of the soil and the splendid panorama of its hills, renders the country fit for a town with a seat of learning. More than 30,000 acres may be chosen with a frontage of fresh water, and in all the rest of the fertile land fresh water is found by sinking wells from twenty to thirty feet deep.

Whilst no exception can be taken to his description of the delights of the area, comments on the water resources are over generous. Surface and groundwater resources of the region vary widely in volume and quality both spatially and temporally. Stream flow is intermittent with quality deteriorating as flow recedes. Well yields and groundwater salinities vary considerably.

The Department of Mines undertook an assessment of the groundwater resources of the Barossa Valley in the early 1950s, results of which were summarised by Chugg (1955). Subsequently, only infrequent measurement of water level was undertaken in observation wells until the mid 1970s. This work showed that the groundwater was being increasingly exploited and that a more detailed hydrogeological investigation was required.

The Gawler River is one of the Australian Water Resources Council's representative basins, hence the surface water resources are under investigation by the Engineering and Water Supply Department (E&WS Dept). In addition, a North Para Water Resources Advisory Committee (NPWRAC) has been formed to advise the South Australian Water Resources Council - an advisory body to the Minister of Water Resources - on matters relating to waste disposal into, and water quality of, the North Para River. Its charter has recently been expanded to cover the groundwater resources of the area.

Groundwater is the dominant source of water for the irrigation of vines, vegetables, orchards and pasture. Farm dams (natural catchment) and pumping from rivers and creeks are the next major source, with reticulated water last. The increasing cost of reticulated water is making it less attractive for irrigation and development of the area's groundwater resources is increasing annually.

For this report the Barossa Valley is defined by the limits of Cainozoic sedimentation as shown on Figure 1.

PHYSICAL FEATURES

The Barossa Valley lies about 60 km northeast of Adelaide in the Mount Lofty Ranges. It is arcuate in plan with a north-south length of about 25 km and an average width of from 6 to 8 km, narrowing in a southerly direction (Fig. 1).

Topography

The valley proper is a relatively flat plain about 270 m above mean sea level, which passes into a region of subdued relief in the Tanunda-Lyndoch area. To the east lie the Angaston Hills and Barossa Ranges while to the west are the lower Greenock Hills which are a series of low roughly north-south ridges.

Despite its relatively small area the valley is characterised by a great variety of soil types (Northcote et al. 1954, 1957, 1959).

Climate

The area has a typical Mediterranean climate with hot dry summers and cool moist winters. Most rain falls between April and October, with summer thunderstorms providing an erratic but sometimes significant contribution to the annual rainfall (Table 1). Topography influences rainfall: for example average annual rainfall is 503 mm at Stockwell increasing to 771 mm at Pewsey Vale in the upper catchment of the North Para River (Fig. 2).

The Department of Agriculture operates a climatological station at the Nuriootpa Viticulture Research Sta-

Table 1. Average monthly and annual rainfall for selected recording stations

Bureau of Met. Station and Number	Years of Record	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Year Total
							(mm)							
Stockwell 023317	88	20	22	21	40	56	62	61	64	54	46	31	26	503
Nuriootpa 023312	92	20	21	22	41	58	65	64	67	56	47	31	27	519
Tanunda 023318	107	22	21	23	45	64	73	68	70	60	50	31	26	553
Angaston 023300	92	21	23	23	44	64	71	70	72	61	51	33	27	560
Pewsey Vale 023313	90	26	26	29	61	90	111	106	105	82	64	40	31	771

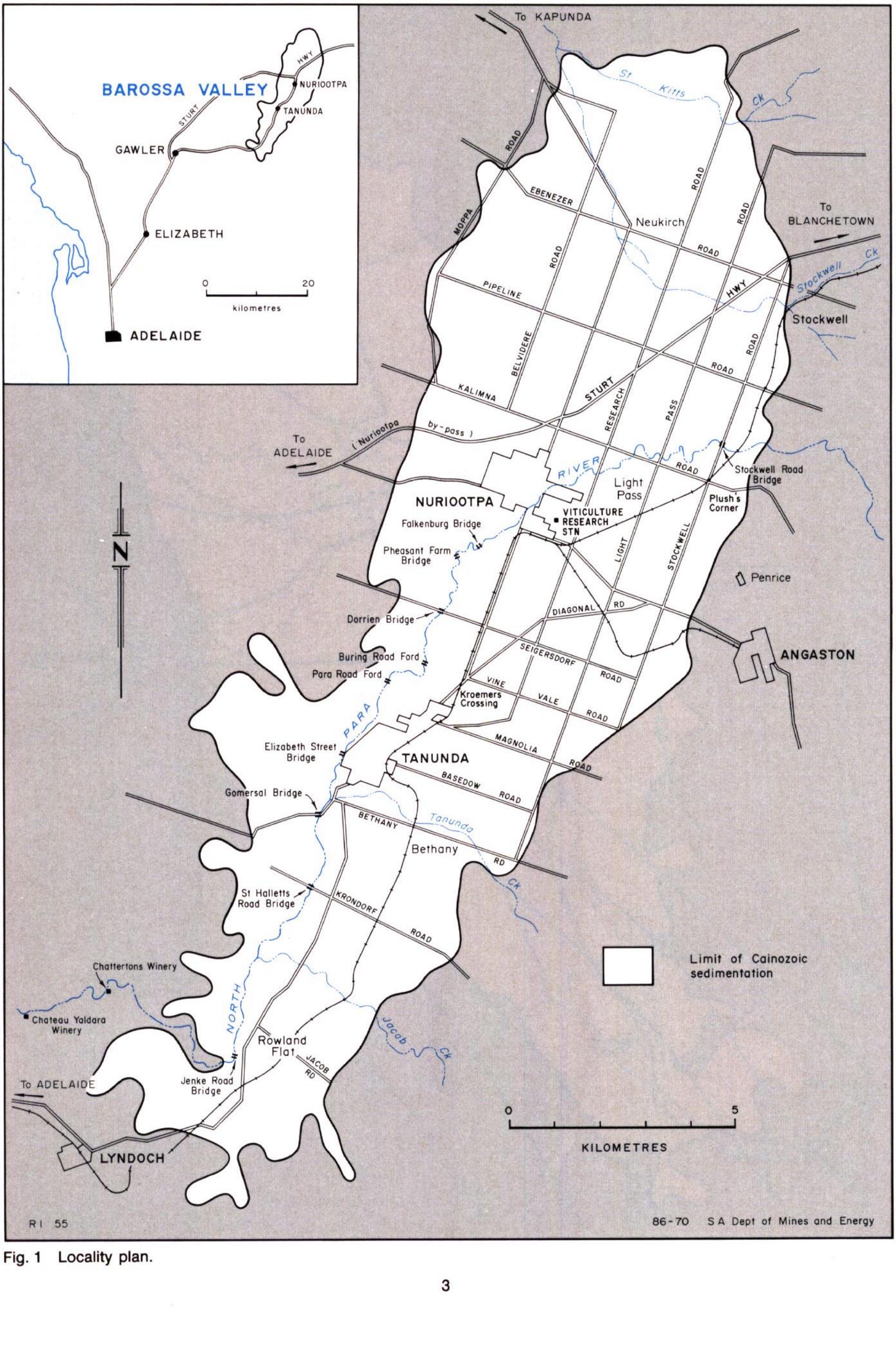


Fig. 1 Locality plan.

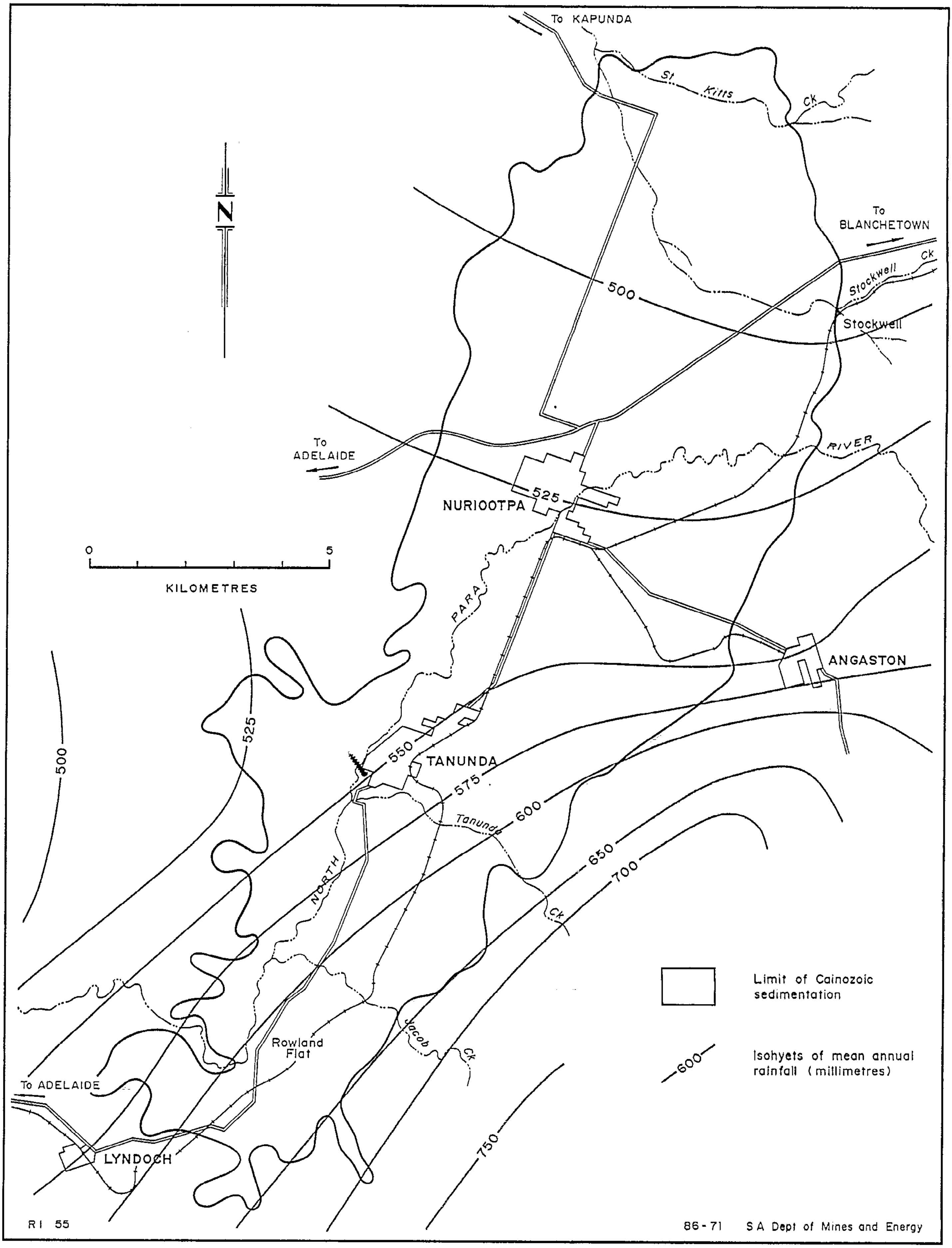


Fig. 2 Mean annual rainfall isohyets.

Table 2. Meteorological data for Nuriootpa and Turretfield

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
NURIOOTPA:													
Solar Radiation ($Jcm^{-2}day^{-1}$)	2 635.0	2 340.0	1 920.0	1 380.0	1 025.0	795.0	880.0	1 190.0	1 160.0	1 985.0	2 445.0	2 615.0	
Sunshine (hrs)	9.6	9.5	8.6	6.7	4.8	4.9	4.6	5.1	6.3	7.5	8.5	8.8	
Max. Air Temp. (°C)	28.9	27.8	25.8	21.0	16.6	14.3	12.7	13.9	16.6	19.9	23.6	25.8	
Absolute Max. Air Temp. (°C)	42.8	40.7	38.3	34.1	26.2	24.9	19.0	25.3	31.9	34.0	40.7	40.6	
Mean Air Temp. (°C)	21.1	20.5	18.6	14.8	11.6	9.6	8.5	9.3	11.1	13.8	16.5	18.6	
Min. Air Temp. (°C)	13.3	13.2	11.4	8.7	6.5	5.0	4.2	4.6	5.6	7.8	9.3	11.4	
Absolute Min. Air Temp. (°C)	2.3	4.4	0.8	0.2	−1.1	−5.4	−4.7	−2.8	−1.8	−0.2	−1.0	0.7	
Relative Humidity 9 am	45.0	51.0	54.0	63.0	78.0	80.0	85.0	83.0	70.0	59.0	50.0	48.0	
Evaporation (mm)	220.0	190.0	155.0	107.0	59.0	41.0	42.0	56.0	87.0	134.0	173.0	205.0	1 469
Rainfall (mm)	20.0	20.0	21.0	41.0	58.0	66.0	63.0	67.0	56.0	46.0	31.0	28.0	517
TURRETFIELD:													
Max. Air Temp. (°C)	30.2	29.4	27.0	23.1	17.8	15.8	14.2	15.0	17.5	21.7	24.5	26.6	
Mean Air Temp. (°C)	22.8	22.4	20.1	16.9	12.8	10.8	9.7	10.2	11.8	15.0	18.0	19.6	
Min. Air Temp. (°C)	15.3	15.3	13.2	10.6	7.7	5.8	5.2	5.3	6.1	8.2	11.5	12.5	
Relative Humidity 9 am	41.0	46.0	52.0	57.0	80.0	87.0	93.0	87.0	75.0	56.0	46.0	47.0	
Evaporation (mm)	299.0	212.0	203.0	118.0	66.0	50.0	49.0	63.0	93.0	131.0	196.0	282.0	1 759
Rainfall (mm)	17.0	21.0	18.0	33.0	58.0	52.0	56.0	58.0	52.0	43.0	27.0	25.0	458

Data from Department of Agriculture and Fisheries

tion and selected meteorological data are given in Table 2.

Figure 3 summarises average monthly data at Nuriootpa for rainfall, Class A pan evaporation, and potential evapo-transpiration calculated by the method of Thornthwaite (Appendix 4). The actual monthly rainfalls for the period February 1979 to January 1980 inclusive, the period used for a trial water budget, are also plotted and show variations from the average.

For average data the rainfall excess is 57 mm over the pan evaporation and 165 mm over potential evapotranspiration.

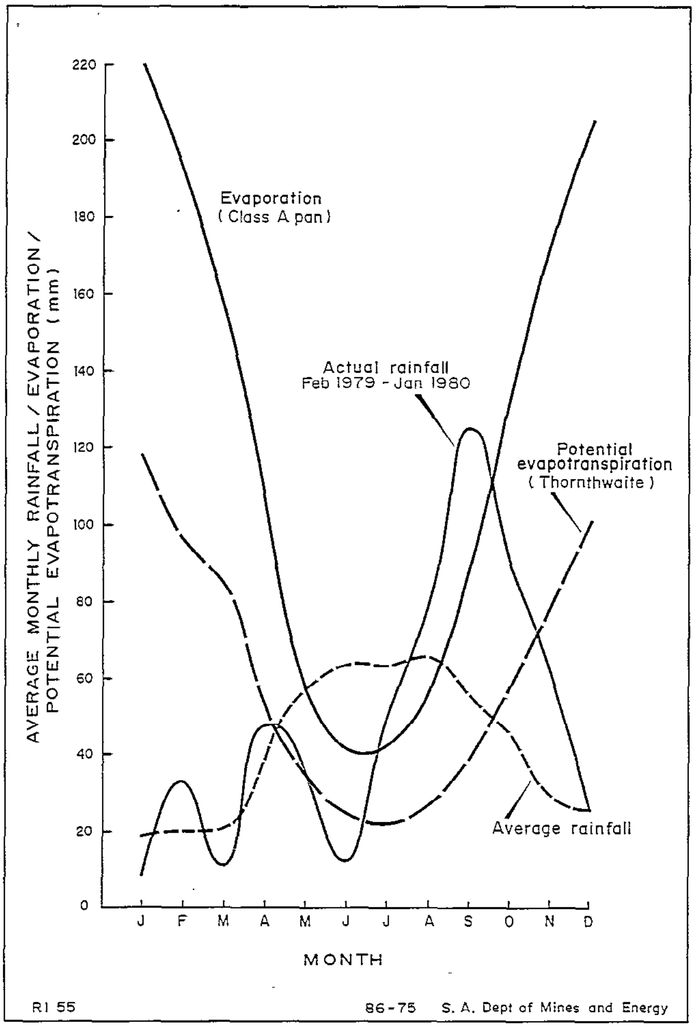


Fig. 3 Rainfall and evaporation statistics, Nuriootpa.

Land Use

The first settlers in 1837 found a scrub covered plain dissected by creeks supporting stands of tall eucalypts. Within a very short time the townships of Tanunda, Langmeil, Bethany, Lights Pass, Nuriootpa and Angaston were established. By 1851 the Tanunda and surrounding areas supported a population of 5000 (Yelland, 1970). Large areas of scrub were cleared and planted to wheat and vineyards with orchards and vegetable gardens surrounding farmhouses. Forty years later in a census of vineyards in South Australia it was found that the principle centres of viticulture were in the Angaston, Tanunda, Nuriootpa, Adelaide, Barossa, Clare, Clarendon and Willunga districts.

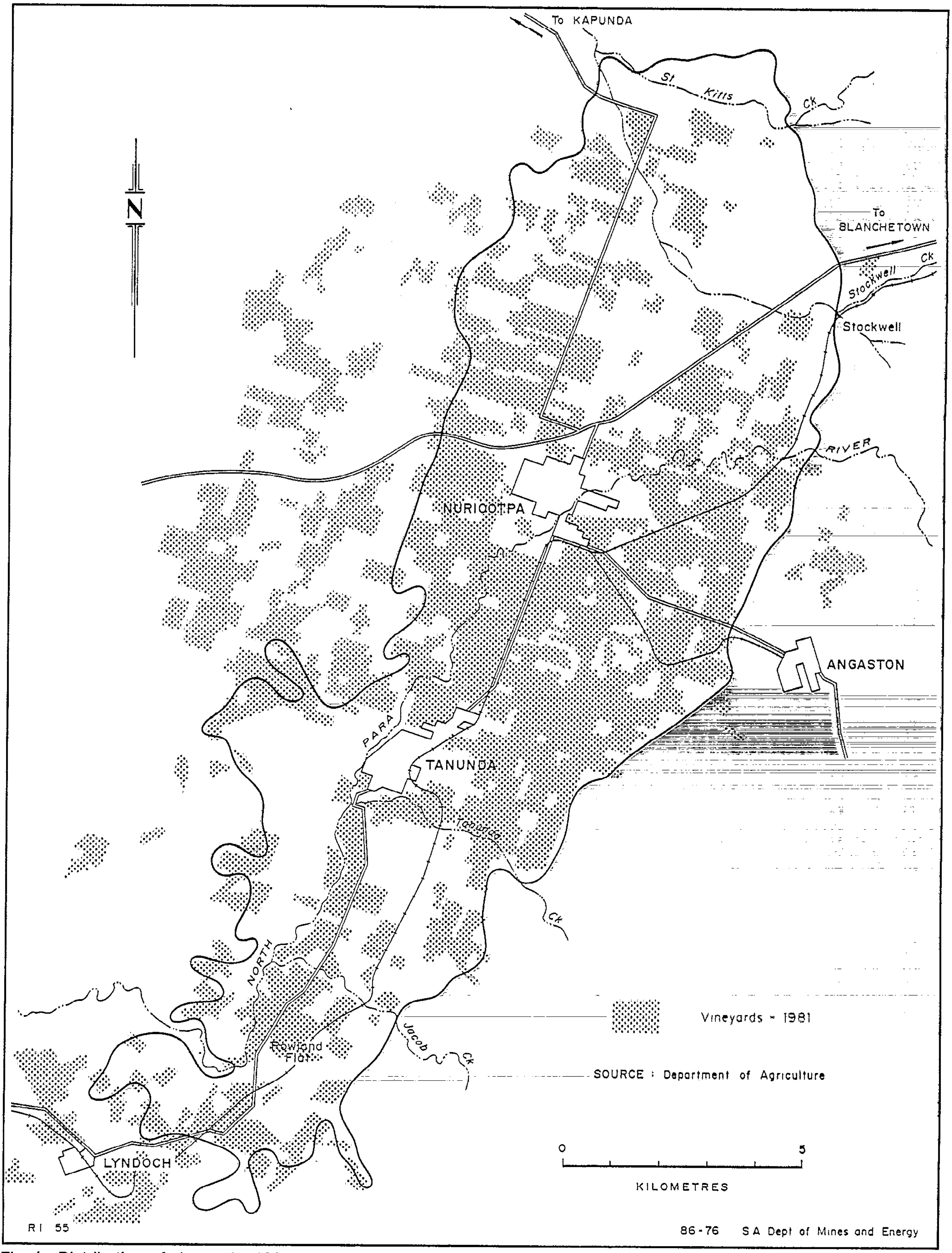


Fig. 4 Distribution of vineyards, 1981.

The importance of the wine industry is shown by the fact that the area supports 8640 ha of vines, producing about 40 000 t of grapes a year. This is about 20 per cent of the total production in South Australia (French et al., 1978).

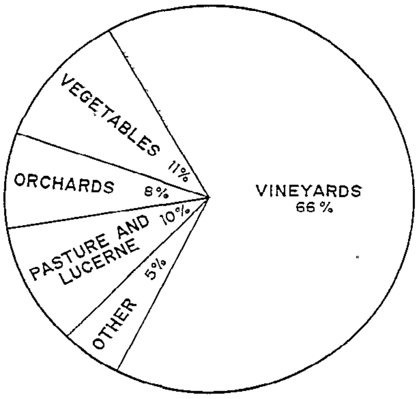
Holdings are generally small with 30 per cent of the 790 grape growers having less than 8 ha and only 11 per cent having greater than 24 ha. The present day distribution of vineyards is shown on Figure 4. In the District Councils of Angaston, Tanunda and Barossa, which cover most of the Barossa Valley proper, around 28 per cent of vineyards (2400 ha) are irrigated (Figs. 5 and 6). A variety of irrigation methods are used including furrow, spray, trickle, flooding and combinations of these. The relatively low well yields favour trickle irrigation especially for new plantings (Fig. 5).

The present area planted to orchards and irrigated is 104 ha (Fig. 6) but this area changes year by year. Apricots for drying are dominant but prunes, pears and almonds are also grown. Furrow and soak-hose irrigation is universal with most orchards located along the flood plain of the North Para River.

Vegetable growing is important but total irrigated area is only about 71 ha (Fig. 6). The vegetables (dominantly carrots, onions and, increasingly, leaf crops) are grown on sandy soils with low water holding

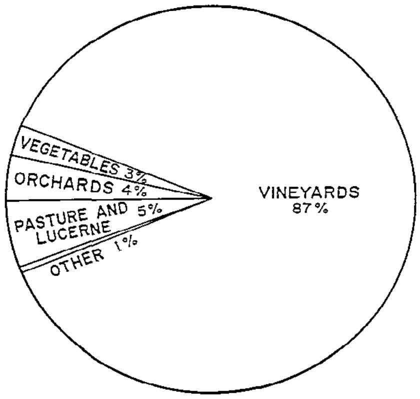
CROPS

1969-70



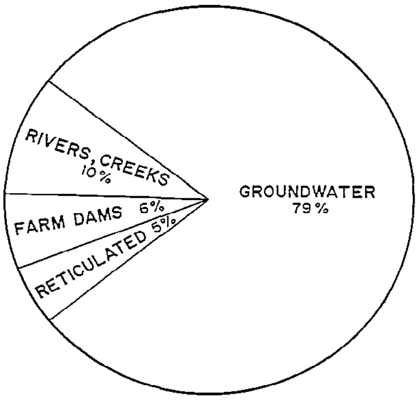
Crops	Total number of hectares 1969-70	1983-84
Vegetables	128	71
Orchards	95	104
Vineyards	782	2381
Pasture and lucerne	112	144
Other	61	10
Total	1178	2710

1983-84



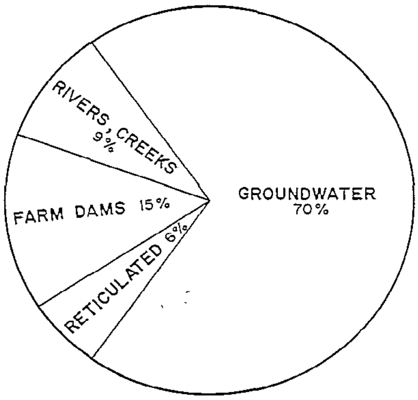
WATER SOURCES

1969-70



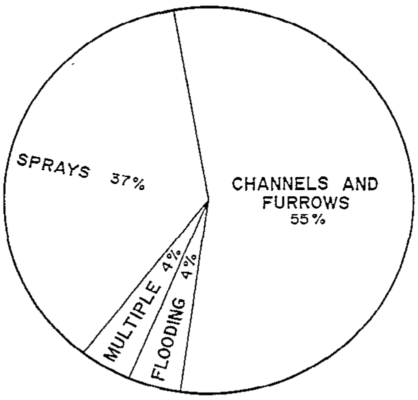
Source	Total number of hectares 1969-70	1983-84
Rivers and creeks	120	257
Farm dams	71	406
Groundwater	933	1889
Reticulated	54	158
Total	1178	2710

1983-84



IRRIGATION TYPE

1969-70



Irrigation type	Total number of hectares 1969-70	1983-84
Sprays	439	360
Channels and furrows	647	518
Flooding	43	
Multiple types	49	614
Trickle		1217
Total	1178	2710

1983-84

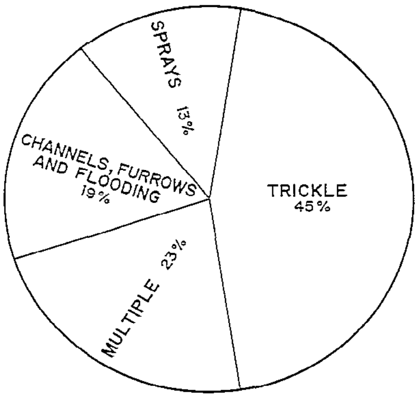


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Fig. 5 Crops grown, water sources and irrigation methods.

capacity; irrigation application rates are higher than for other crops. Spraying is the dominant method of application.

In addition to grape, fruit or vegetable growing most holdings are also involved in other enterprises, mostly fat lambs, dairying and poultry raising.

Graphs showing the changes in areas of crops irrigated and the source of the irrigation water for the District Council areas of Angaston, Tanunda and Barossa are given in Figures 6 and 7. It is obvious from the latter that the area irrigated is on the increase despite annual variations. An increase in irrigation from dams has resulted from development of vineyards in the ranges east of the valley. In areas of low well yields, such as northeast of Bethany, it is common practice to pump from a well into a dam for later irrigation.

The distribution of irrigation wells is shown on Figure 8 along with other well uses.

The three largest towns of Angaston (pop. 1730), Nuriootpa (pop. 2800) and Tanunda (pop. 2250), have common effluent or sewage treatment schemes for disposal of domestic wastes.

Little natural vegetation remains apart from isolated stands of eucalypts left for shade or along drainage lines, mainly on Kaiserstuhl and in the Kalimna district.

SURFACE WATER RESOURCES

Surface water resources of the Barossa Valley are dominated by the North Para River and its main tributaries, Duck Ponds, Angaston, Tanunda and Jacob Creeks (Fig. 1). A low water divide occurs in the northern third of the valley with drainage north of it leading to the Light River. This low watershed is poorly drained and the low-lying areas are generally waterlogged after heavy rain. The main drainage lines in this area are the Stockwell and St Kitts Creeks. All surface drainage is intermittent.

Flow in the creeks is important as a source of recharge to groundwater resources. Reductions in surface flows are apparent where they discharge from the eastern hills and traverse the valley floor.

The North Para River, just south of Nuriootpa, in a normal year acts as a drain for groundwater. During the 1979-80 summer, flow was maintained in the River through Tanunda, whilst in years with relatively dry winters base flow is generally maintained only into early January (Appendix 2).

Water quality is flow-dependent (compare daily discharge and water conductivity figures for each site in Appendix 2). Initial flows tend to be of poor quality because of admixture with saline springs, groundwater discharge as the water table rises, and the rapid solution of surface salts accumulated over summer. As flow increases water quality improves rapidly, but as flow diminishes during spring and early summer water quality gradually worsens as groundwater base flow becomes dominant. The disposal of winery and distillery wastes by dumping into the creeks during periods of adequate flow also leads to short-term increases in water salinity.

Surface water is used extensively for vine irrigation especially in the Bethany area where water is pumped from the creek into large storage dams. To the west of the North Para River, from Nuriootpa south, only limited areas are served by reticulated water and the river is an important source of domestic (non-drinking)

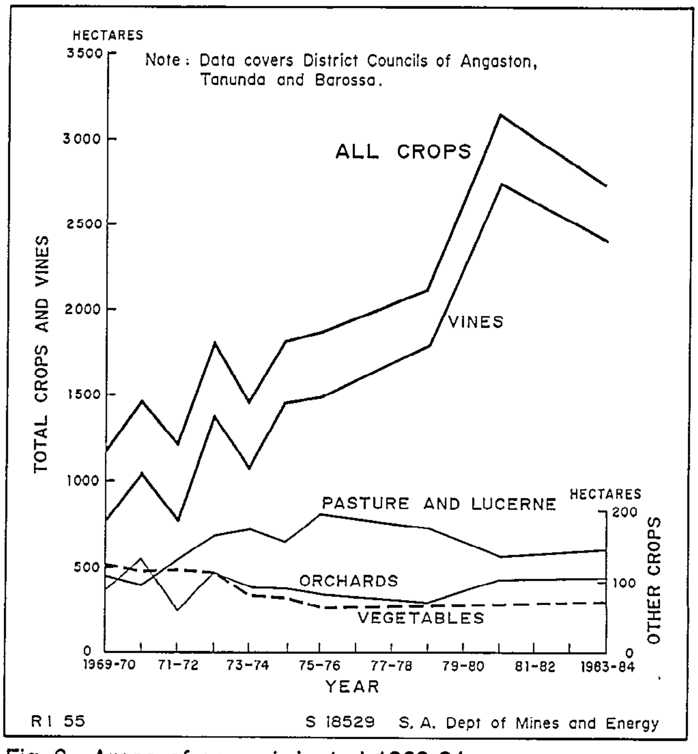


Fig. 6 Areas of crops irrigated 1969-84.

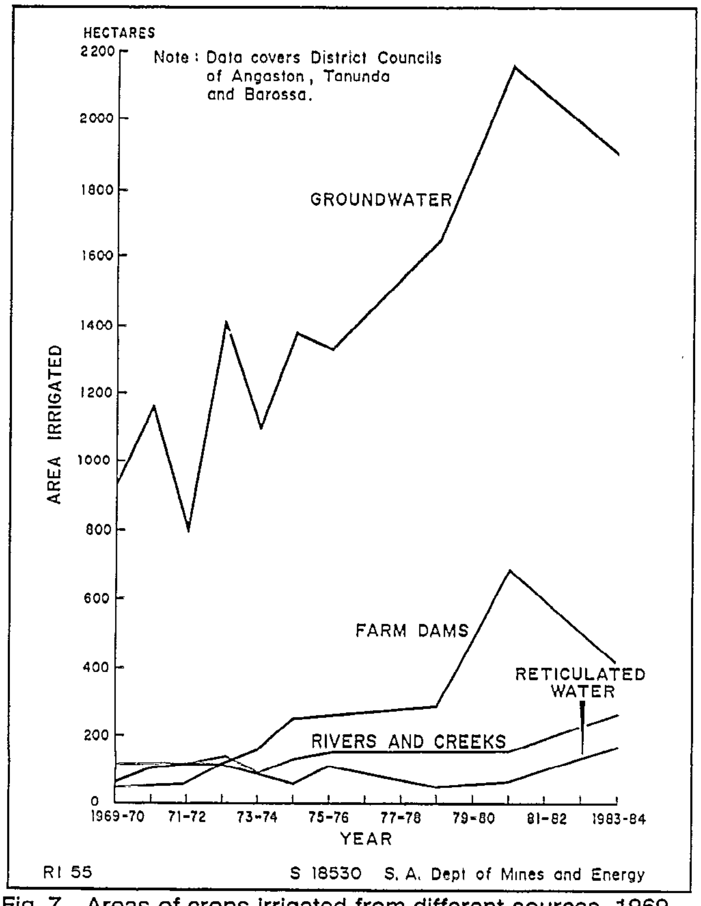


Fig. 7 Areas of crops irrigated from different sources, 1969-84.

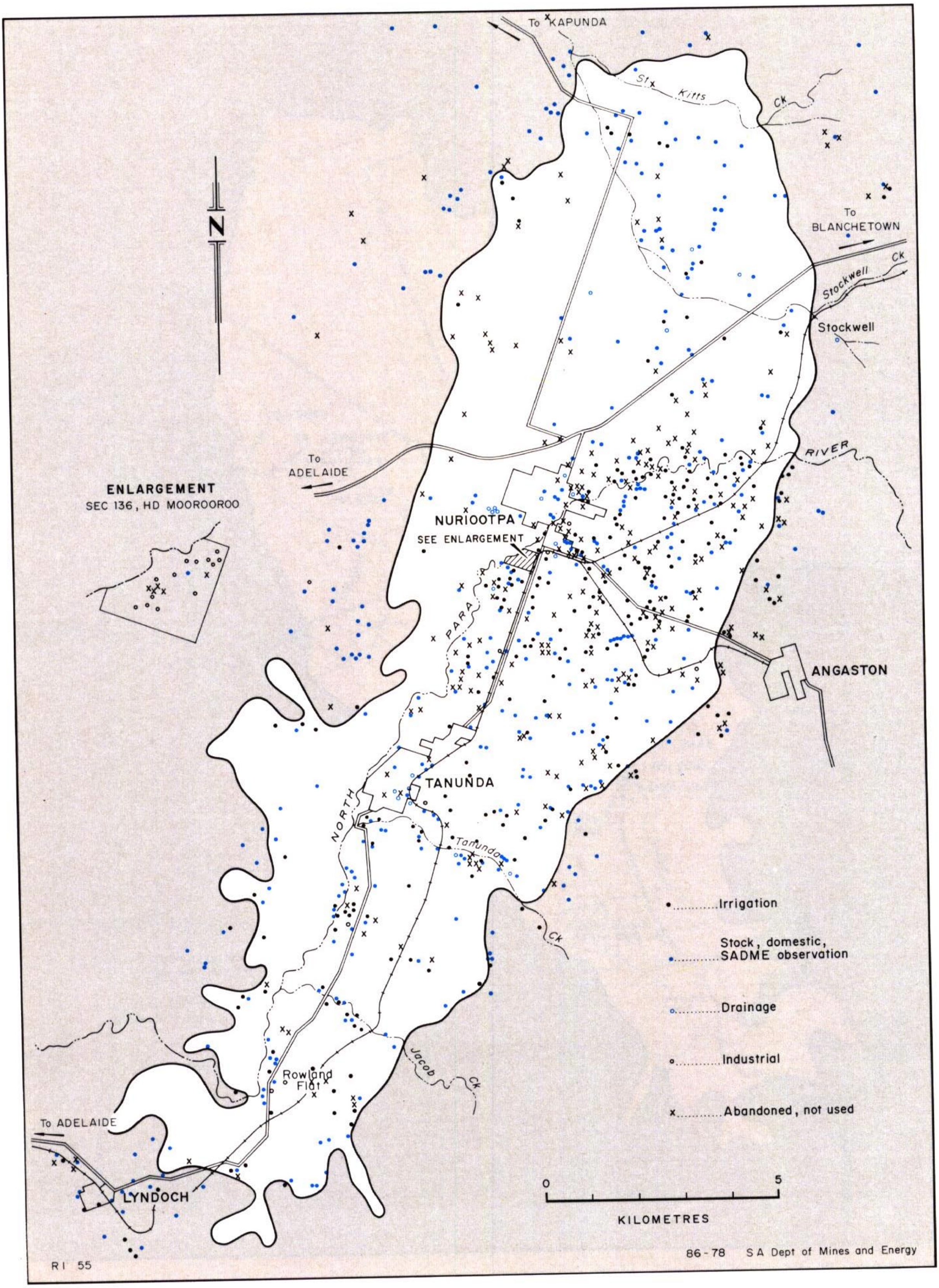
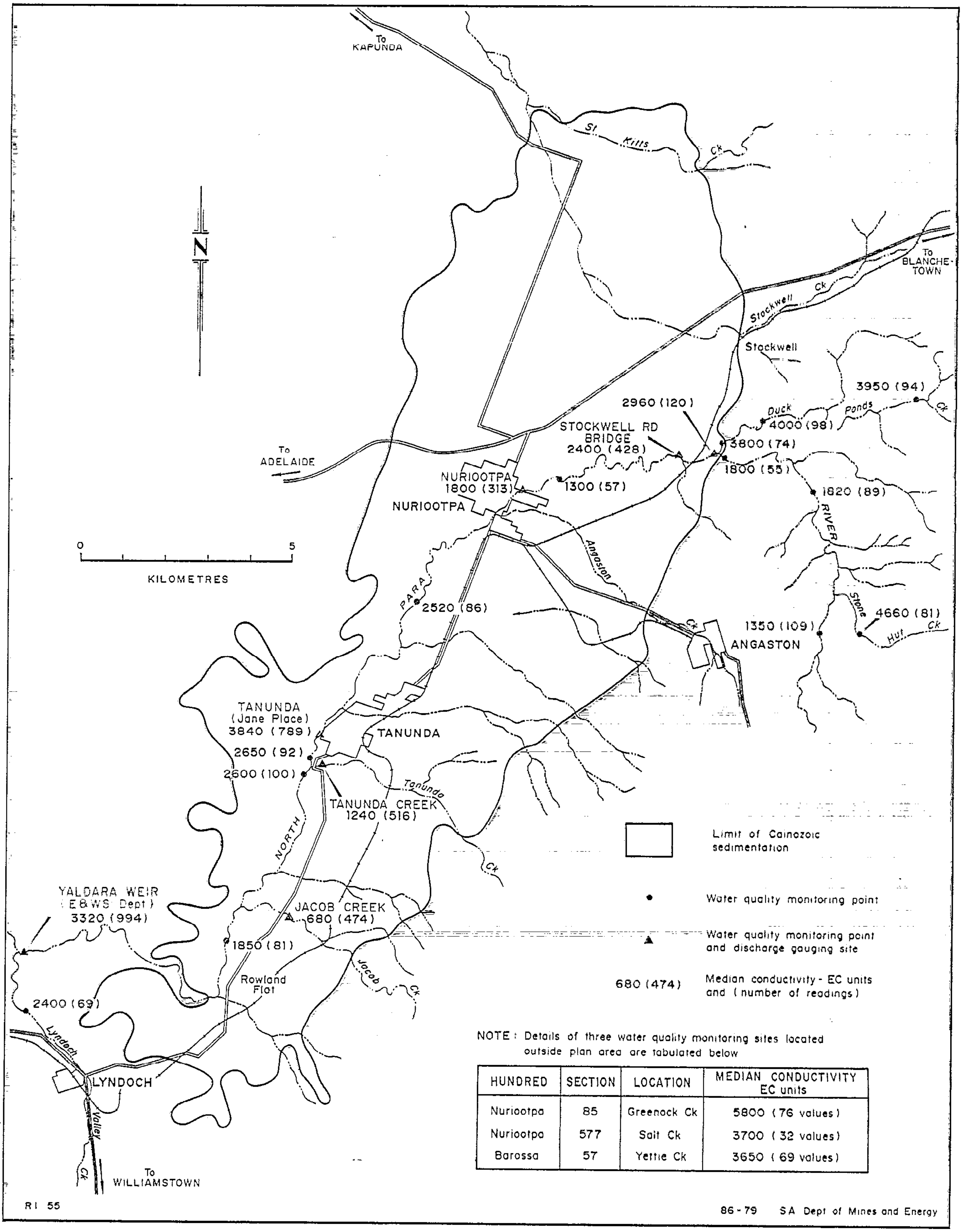


Fig. 8 Well use plan.



HUNDRED	SECTION	LOCATION	MEDIAN CONDUCTIVITY EC units
Nuriootpa	85	Greenock Ck	5800 (76 values)
Nuriootpa	577	Salt Ck	3700 (32 values)
Barossa	57	Yettie Ck	3650 (69 values)

Fig. 9 River discharge gauging sites, quality monitoring sites and median conductivities.

water. River water is used for washing quarry sand at Rowland Flat.

Because of the interaction between surface water and groundwater the quantity and the quality of water in the creeks is important. In early 1975 six staff gauges were installed on North Para River and on its tributaries, Jacob Creek and Tanunda (Bethany) Creek (Fig. 9), in an attempt to quantify stream losses to groundwater and groundwater discharge to the creeks, where applicable. An attempt was made to monitor river water level and salinity daily but only 1979-80 records are complete. Results of two programs are given in Appendix 2.

GEOLOGY

The oldest rocks in the area are Precambrian siltstones and shales, from 750 to 1000 million years (Ma) old (Table 3). These were originally deposited in the Adelaide Geosyncline and were succeeded by marbles, shales and dolomitic siltstones of Cambrian age. Together these rocks form the basement and margins to the Cainozoic sediments of the valley.

By early Permian times (about 270 Ma ago) the older rocks had been elevated to a mountain range and were being eroded. During the Mesozoic Era further erosion resulted in an area of low relief with deeply weathered rocks. In the early Tertiary Period, tectonic activity in the form of basement block subsidence along faults was occurring (Taylor *et al.*, 1974) with uplift of the ancestral Mount Lofty Ranges. However, Goode and Williams (1980) suggest that the Mount Lofty-Flinders block north of the intersecting Padthaway Ridge did not begin its uplift history until later in the Tertiary.

Table 3. Geological time scale

Era		Period	Epoch	Age (Ma)
				0
CAINOZOIC		QUATERNARY (approx. 1-2 m.y.)	HOLOCENE (approx 10000yrs)	0·01
			PLEISTOCENE (approx. 1-2 m.y.)	2
		TERTIARY (approx. 63 m.y.)	PLIOCENE (approx. 5 m.y.)	7
			MIOCENE (approx. 19 m.y.)	26
			OLIGOCENE (approx 12 m.y.)	38
			EOCENE (approx. 16 m.y.)	54
			PALAEOCENE (approx. 11 m.y.)	65
MESOZOIC		CRETACEOUS (approx. 70 m.y.)		135
		JURASSIC (approx. 60 m.y.)		195
		TRIASSIC (approx. 30 m.y.)		225
PALAEOZOIC	Upper	PERMIAN (approx. 55 m.y.)		280
		CARBONIFEROUS (approx. 65 m.y.)		345
		DEVONIAN (approx. 50 m.y.)		395
	Lower	SILURIAN (approx. 40 m.y.)		435
		ORDOVICIAN (approx. 65 m.y.)		500
		CAMBRIAN (approx. 100 m.y.)		600
		PRE-CAMBRIAN		

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Daily *et al.* (1976) support early Tertiary block faulting as does Twidale (1976). However, it is not clear whether the Barossa Valley is a fault-angle depression or a large fault-line valley scoured out by a precursor to the North Para drainage system. The existence of a thick section of weathered basement underlying the Valley sediments does not support the latter contention.

Thus it is considered that in early Tertiary time the Stockwell Fault (Fig. 12), which presently defines the eastern margin of the Barossa Valley, came into existence. Subsidence on the western side of this fault resulted in an arcuate asymmetric trough with its deepest portion against the eastern margin (Fig. 11).

This trough rapidly filled with coarse sands, gravels and discontinuous clay layers to a maximum thickness of 140 m. As the trough filled, finer grained sediments were deposited; carbonaceous and lignitic material indicate shoreline and swamp conditions and stable tectonics. Well preserved wood fragments and fossil fruits characterise the finer sands and silts.

In the Middle Miocene, about 17 Ma ago, renewed uplift of the basement rocks along faults led to erosion of high areas and deposition of a variety of fluviatile and lacustrine sediments, coarse sands, gravels and white clays. These sediments are typically non-carbonaceous apart from erratic reworked clay balls and wood fragments, especially near the base. The sediments are here correlated with the deltaic sands, gravels and sandy clays exposed in the Rowland Flat quarries which have been dated as Miocene or possibly early Pliocene (Harris and Olliver, 1965).

The lower carbonaceous sediments are not considered to be contemporaneous with the sands quarried at Rowland flat, for the following reasons:

- The basal sediments overlie deeply weathered basement whereas basal units in the sand quarries rest on fresh eroded basement. It is considered that the western areas, and the ranges to the east of the valley, were the source areas for these lower sediments.
- It is difficult to see how an early Tertiary fault-initiated topographic low would not become an area of deposition until the Oligo-Miocene as proposed by Twidale (1976). He states elsewhere in the same paper that, at the end of the Eocene, the Barossa Valley was still an area of deposition. It is even more difficult to imagine it maintaining its integrity until the Miocene or even early Pliocene (Harris and Olliver, 1965).
- The basal units in the Rowland Flat sand quarries contain abundant large staurolite crystals whereas none have been recognised in drilling the deeper portions of the Valley. Dalgarno (1961) considers the source of these staurolites as Marinoan schists outcropping to the north of the Barossa Valley. Indeed, similar staurolites can be found in Quater-

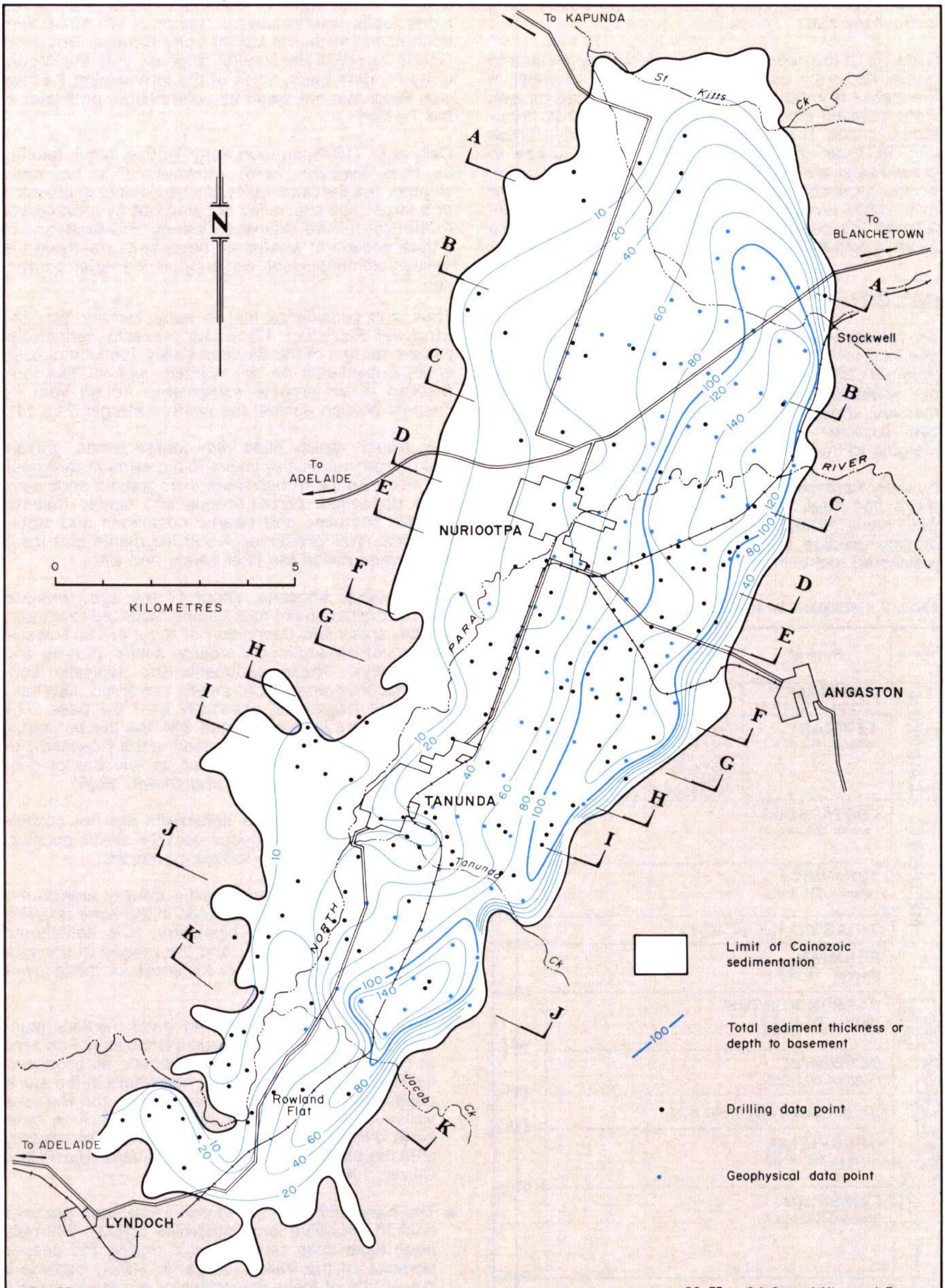

Fig. 10 Total sediment thickness or depth to basement.

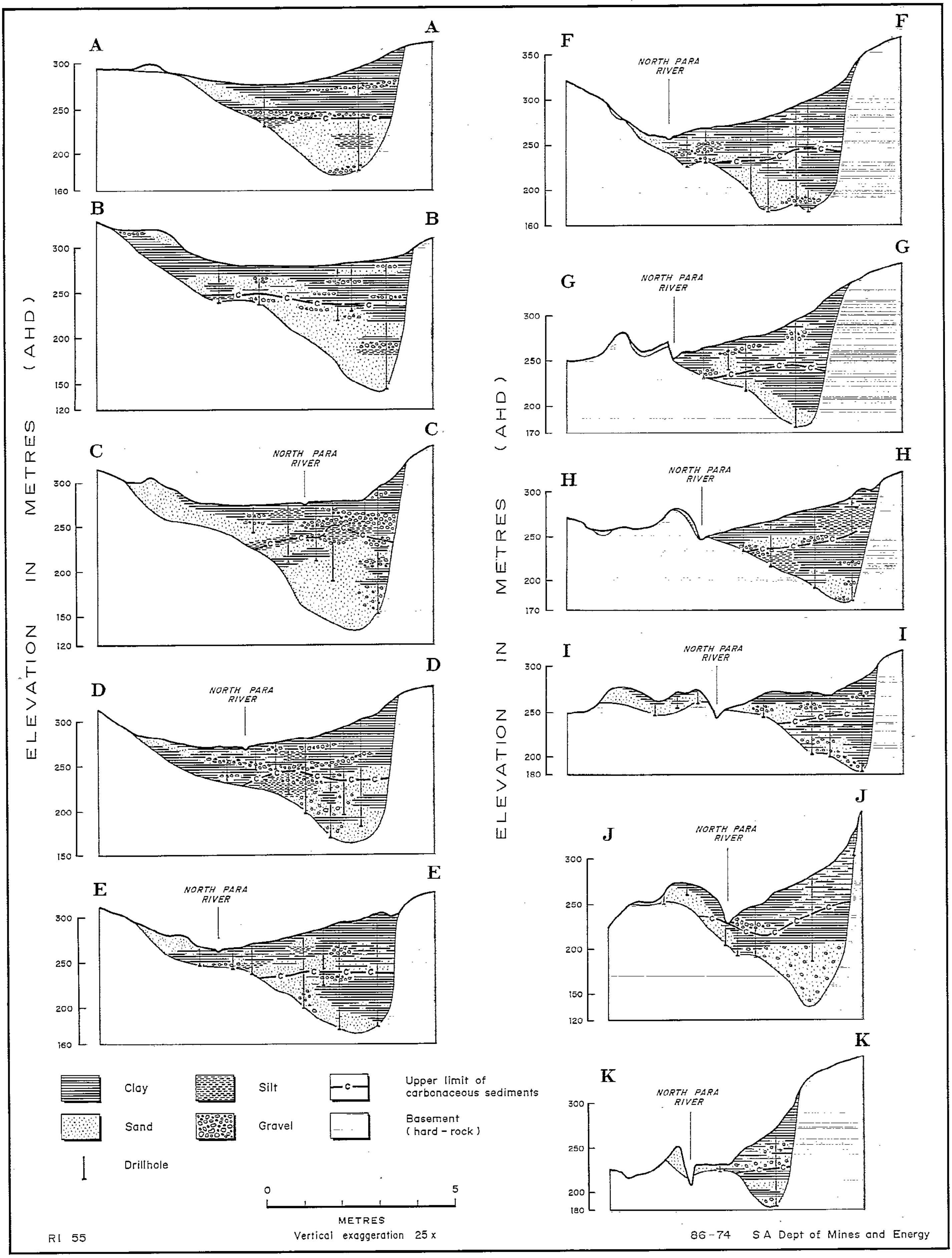

Fig. 11 Geological cross sections.

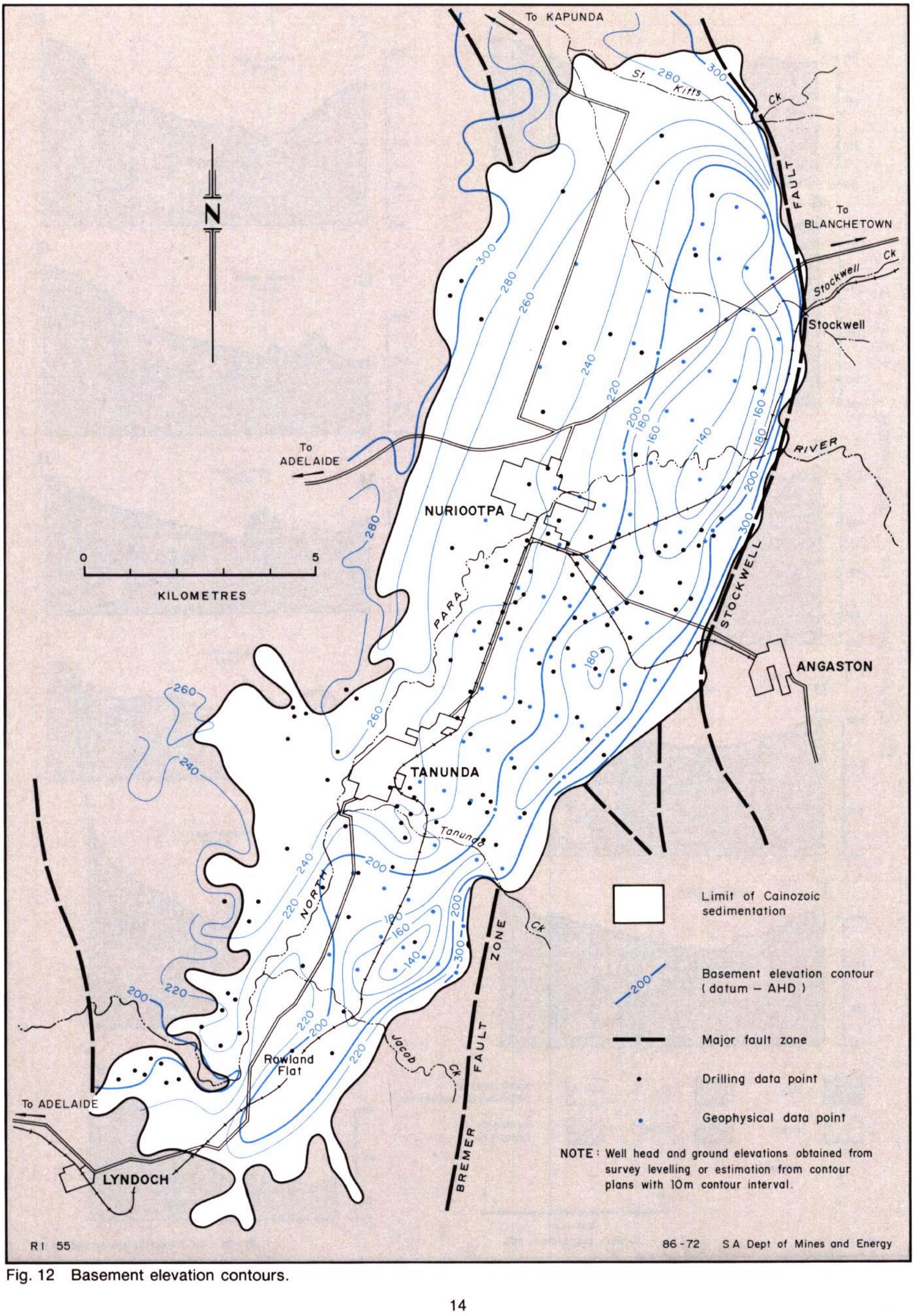

Fig. 12 Basement elevation contours.

nary to Recent creek sediments along the northwestern portion of the valley. These could be derived from reworking of local Tertiary sediments or from outcropping Marinoan sediments in the Moppa-Koonunga area.

Consideration of the above places the age of the carbonaceous sands as either Eocene, and hence equivalent in age to the coal and carbonaceous sands at Port Wakefield, or Miocene-Pliocence but older than the Rowland Flat sands. The latter age is supported by a Pliocene age having been given to fossil fruits collected from a depth of approximately 100 m in the deeper portion of the valley southeast of Tanunda (Hossfeld, 1949).

Tertiary sediments are overlain by relatively thin but variable Quaternary outwash material, generally dark red-brown clays and silts with erratic interbedded clayey sand and gravel lenses.

Basement elevation contours are given in Figure 12 and total sediment thickness on Figure 10. Geological cross-sections are given in Figure 11 and geological logs and composite well logs in Appendix 1.

HYDROGEOLOGY

Groundwater mainly is stored in, and moves through, unconsolidated sediments ranging from coarse clean gravels to dense clays. The many facies variations in the sediments caused by the ever changing depositional environment has led to a complex aquifer system. The aquifer systems are not easily described, except generally as follows:

- *hard rock aquifer:* shale and marble
- *lower aquifer:* carbonaceous quartz sands and gravels.
- *middle aquifer:* carbonaceous and non-carbonaceous quartz sands.
- *upper aquifer:* gravels.
- *water-table aquifer:* mainly alluvium

Hard rock aquifer

The Barossa Valley is surrounded and underlain by Cambrian and Pre-Cambrian rocks, ranging from carbonaceous shales to coarse crystalline marbles. Groundwater in such an environment is stored in, and moves through, openings in the rocks (joints, cleavages, faults). The wide range of rock types and past tectonic stresses has resulted in a wide range of well yields and salinities. For example, two wells approximately 200 m apart in essentially the same rock type realised individual yields of 100 m^3day^{-1} and 1300 m^3day^{-1}, respectively. The hard rocks underlying the valley have a relatively deep weathering profile of up to 20 m. This clay profile acts as a confining layer between fresh rock and overlying sediments.

Within the valley, hard rock aquifers have been little used until recently. Wells are concentrated along the main Nuriootpa-Tanunda Road and in the Tanunda area where basement is relatively shallow and overlying sediments seldom include useful aquifers.

Three hard rock wells were tested to define hydraulic properties (Appendix 3) with results summarised below. Hydraulic conductivities have been calculated assuming aquifer thickness is equal to open hole depth. These results do not reflect the wide range in hydraulic properties which could be expected from hard rocks as indicated by well yields. From inspection of cuttings from wells drilled in the Tanunda-Nuriootpa area it appears that the degree of quartz veining plays an important part in well yield: the more veining the higher the yield.

Hydraulic properties, hard rock aquifer

Well No.	Transmisivity (t) $m^3day^{-1}m^{-1}$	Hydraulic Conductivity (k) $m^3day^{-1}m^{-2}$	Comments
6629-460-00008	33.0	1	Dorrien area; open hole section 32 m.
6728-100-01690	0.3	3.0×10^{-3}	Mt McKenzie area (south of Angaston); open hole assumed to be 100 m.
6629-460-00018	2.6	2.3×10^{-2}	Tanunda-Nuriootpa road near Dorrien; open hole 111 m.

Potentiometric Contours

Potentiometric contours for hard rock aquifers are given in Figure 13. In areas where hard rocks are exposed outside the area of sedimentation, the contours are equivalent to the water table contours. As with the other aquifer systems a groundwater divide exists in the Neukirch area, but because of limited data it cannot be accurately located. North of the divide, groundwater flow is northerly and, south of the divide, it is southwesterly, similar to the other aquifers. The water table contours outside the valley are generalised but in detail they would be very intricate because of the more complex topography. Seasonal fluctuations of water levels marginal to the valley tend to be small, generally less than 1 m whereas along the Nuriootpa-Tanunda Road, seasonal fluctuation is up to 6 m, and 3 m in the Tanunda-Bethany area.

Lower Aquifer

This aquifer occupies the deep eastern half of the Valley and consists of a basal coarse clean sand and gravel that generally fines upwards. Maximum thickness is 100 m in the Plushs Corner area but it thins to 30 m east of Tanunda. Clay and silt lenses occur within the sequence and become dominant in the Tanunda area (Fig. 11). It is probable that the basement high in this area resulted in quieter water conditions allowing fines to settle out. The gradual facies change from sand to silt and clay in a southeasterly direction north of Tanunda suggests a northerly source area with a quiet lacustrine environment against the Tanunda basement high. Drilling data are sparse south of Tanunda but the aquifer appears to thicken initially, and then thins in a southerly direction, with increasing clay content (Fig. 11).

This aquifer was little used until recently since it was assumed that white or grey clays intersected in drilling represented weathered basement. Increased interest in irrigation and the relativley low yields obtained from the overlying sands has led to deeper exploratory drilling especially in the Vine Vale-Tanunda area (Fig. 1).

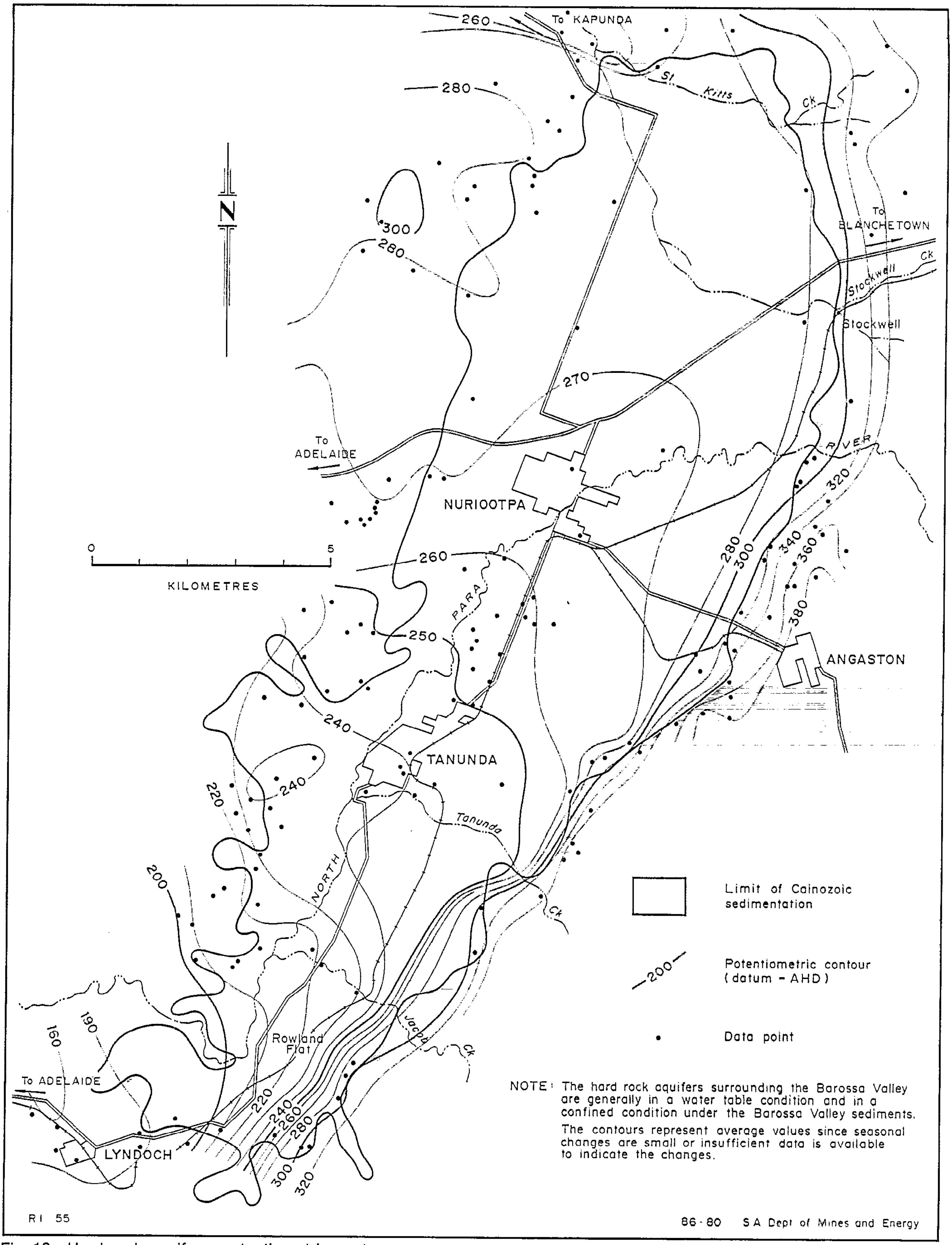

Fig. 13 Hard rock aquifers: potentiometric contours.

Hydraulic characteristics, lower aquifer

Well No.	Transmissivity(T) $m^3day^{-1}m^{-1}$	Storage Coefficient (S)	Hydraulic Conductivity(K) $m^3day^{-1}m^{-2}$	Comments
6729-500-00781	60.0 (range 51-70)	2.35×10^{-3}	1.55	Observation well MOR92; no evidence of leakage.
6729-500-00988	7.3	—	0.61	Aquifer thickness 12 m.
6628-050-11156	26.0	—	6.50	Aquifer thickness 4 m in Tanunda area.
6729-500-00680	10.3	—	1.37	Aquifer thickness 7.5 m in Stockwell/Penrice Road area.

With an appropriate selection and development of well screen, yields range from 400 to 1000 m^3 day^{-1}. A controlled aquifer test adjacent to Section 90 hundred Moorooroo and several tests on private irrigation wells (Appendix 3) yielded results as above:

Potentiometric Contours

Potentiometric contours for this aquifer are given in Figures 14 and 15 and selected hydrographs in Figure 70. Groundwater movement is in a southerly direction (Fig. 15). A significant cone of depression forms in the summer irrigation season with water levels in the central portion often falling by more than 40 m. Recovery is relatively rapid and appears to be complete towards the end of winter in most areas. In the northern part of the Valley, where minor irrigation takes place, there has been a small but definite decline in water levels since 1981/82 (see observation well MOR100). This trend is also observed in the Lights Pass area. In the central area where the extreme annual fluctuations occur, water levels appear to recover each year (see MOR92). In the Bethany area where expansion of irrigation resulted in water level declines from 1975 to 1983 a return to higher levels has now occurred as irrigation expansion has stabilized (see MOR 59).

Middle aquifer

The generally non-carbonaceous sand and gravel ('middle') aquifer shows a wide range of facies from coarse sands and gravels through silts and occasionally to clays, commonly white, pale brown to pale grey in colour. This aquifer was the first to be developed, in the Lights Pass-Nuriootpa area. The aquifer overlies the basal carbonaceous aquifer (Fig. 11), and is either hydraulically connected to it or separated by a silt/clay aquitard. It is commonly discontinuous and quite variable in thickness, from less than 5 m to 20 m.

Well yields vary widely, from less than 100 m^3day^{-1} to over 1300 m^3day^{-1}. Many wells were abandoned due to sand problems prior to availability of well screens and some show signs of casing collapse due to corrosion. Wells drilled since July 1976 are required to have pressure cemented casing to overcome this problem.

A controlled aquifer test was performed adjacent to Section 90 hundred Moororoo and two tests on private irrigation wells with results as below.

Potentiometric Contours

Selected potentiometric contours for this aquifer are given in Figures 17 and 18 and selected observation well hydrographs in Figure 70. In the central portion of the valley groundwater flows are in a southerly to westerly direction (Fig. 18) and converge on the North Para River. East and south of Tanunda the flow appears to be in a general southerly direction, though observation points are limited. North of Nuriootpa, beneath the Belvidere plain, a groundwater divide exists with flow north of it being in a northerly direction towards St Kitts Creek. The location of the divide is uncertain and potentiometric contours ill defined because of limited data.

Seasonal fluctuations are less extreme than for the basal aquifer with a maximum of about 6 m in the Lights Pass-Diagonal Road area, where maximum drawdown occurs in the basal aquifer, and in the Bethany area (Fig. 19). In general seasonal fluctuations range from 1 to 3 m (Fig. 70) but in the Bethany-Tanunda area a general decline in potential has been noted. This is apparently caused by increased groundwater usage since 1975-76, but stabilisation is apparent since 1983 (see MOR60). Water levels in the northern Lights Pass (see MOR32), central (see MOR 75) and Tanunda-Dorrien areas (see MOR 7,68) show a downward trend at least since 1981/82.

Withdrawals from this aquifer have not led to the development of a regional cone of depression but to

Hydraulic characteristics, middle aquifer

Well No.	Transmissivity(T) $m^3day^{-1}m^{-1}$	Storage Coefficient (S)	Hydraulic Conductivity(K) $m^3day^{-1}m^{-2}$	Comments
6729-500-00782	10.5 (average)	3.6×10^{-4}	0.44 (average)	Observation well MOR93; aquifer consists of clayey sand.
6629-460-00053	500.0	—	125.00	Near Nuriootpa; aquifer is gravel, slightly clayey; well was screened.
6729-500-00675	18.0	—	6.00	Stockwell Rd, Plushs Corner; slotted casing, installed; salinity rises significantly during pumping; aquifer possibly not fully penetrated.

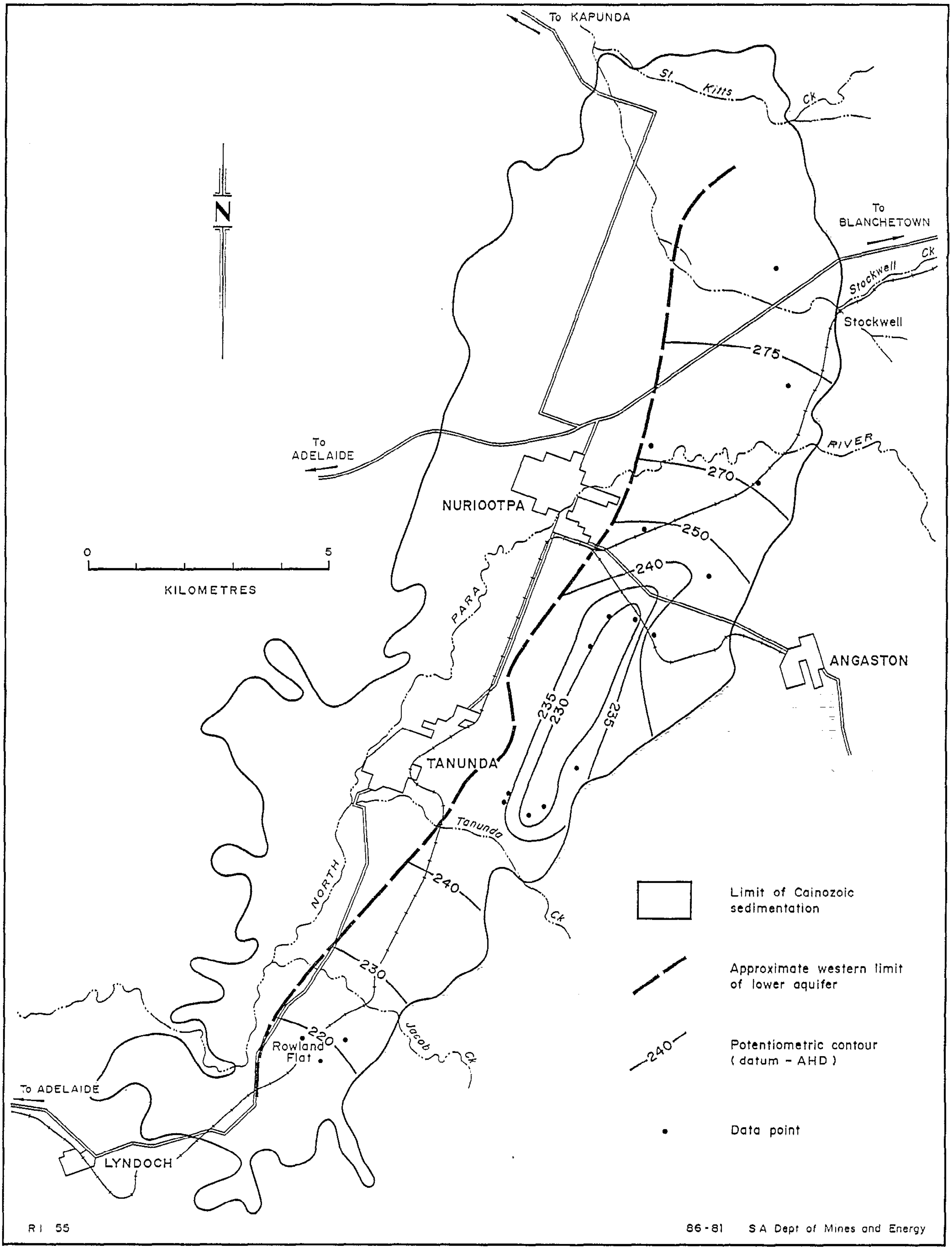

Fig. 14 Lower aquifer: potentiometric contours (February 1980).

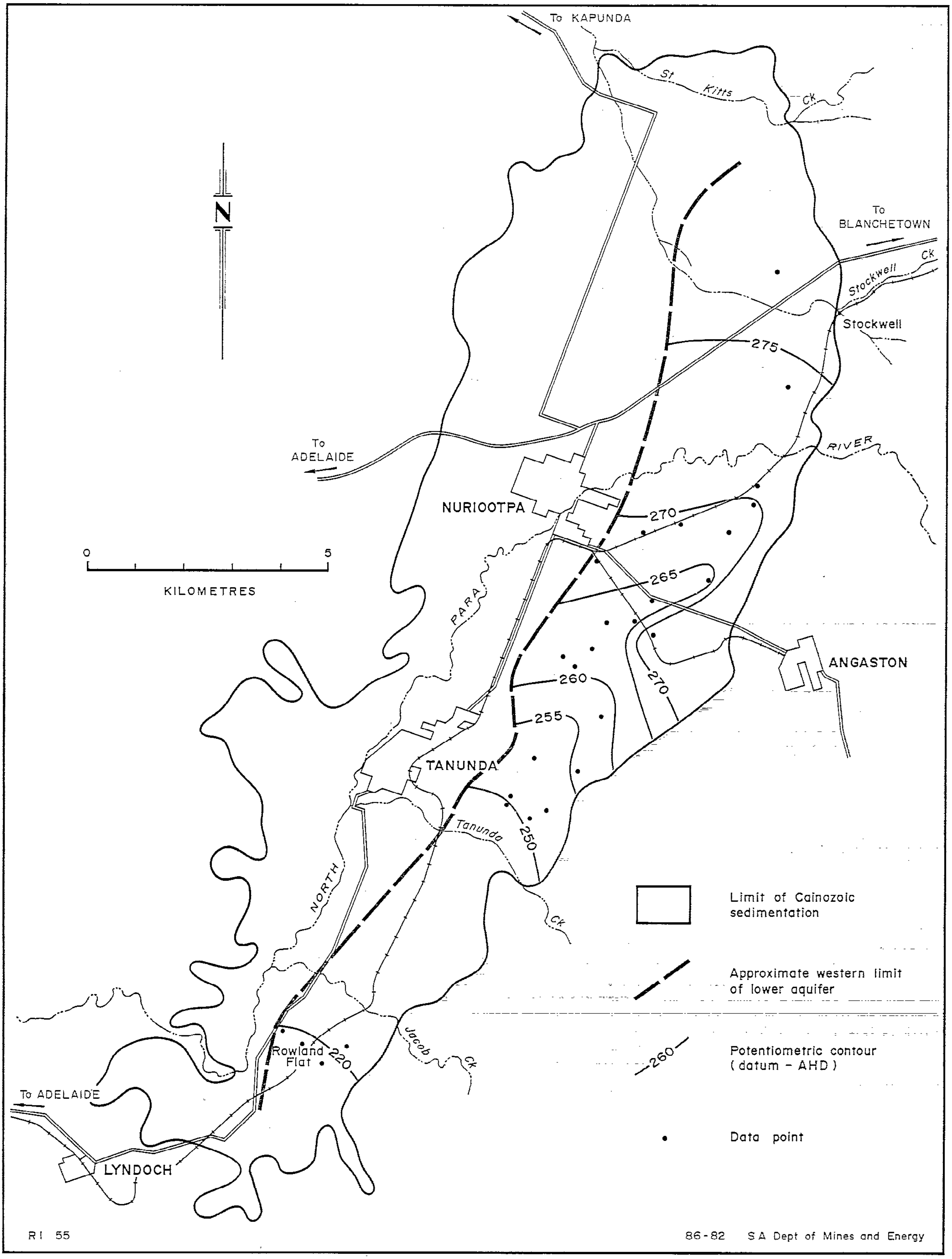

Fig. 15 Lower aquifer: potentiometric contours (August 1980).

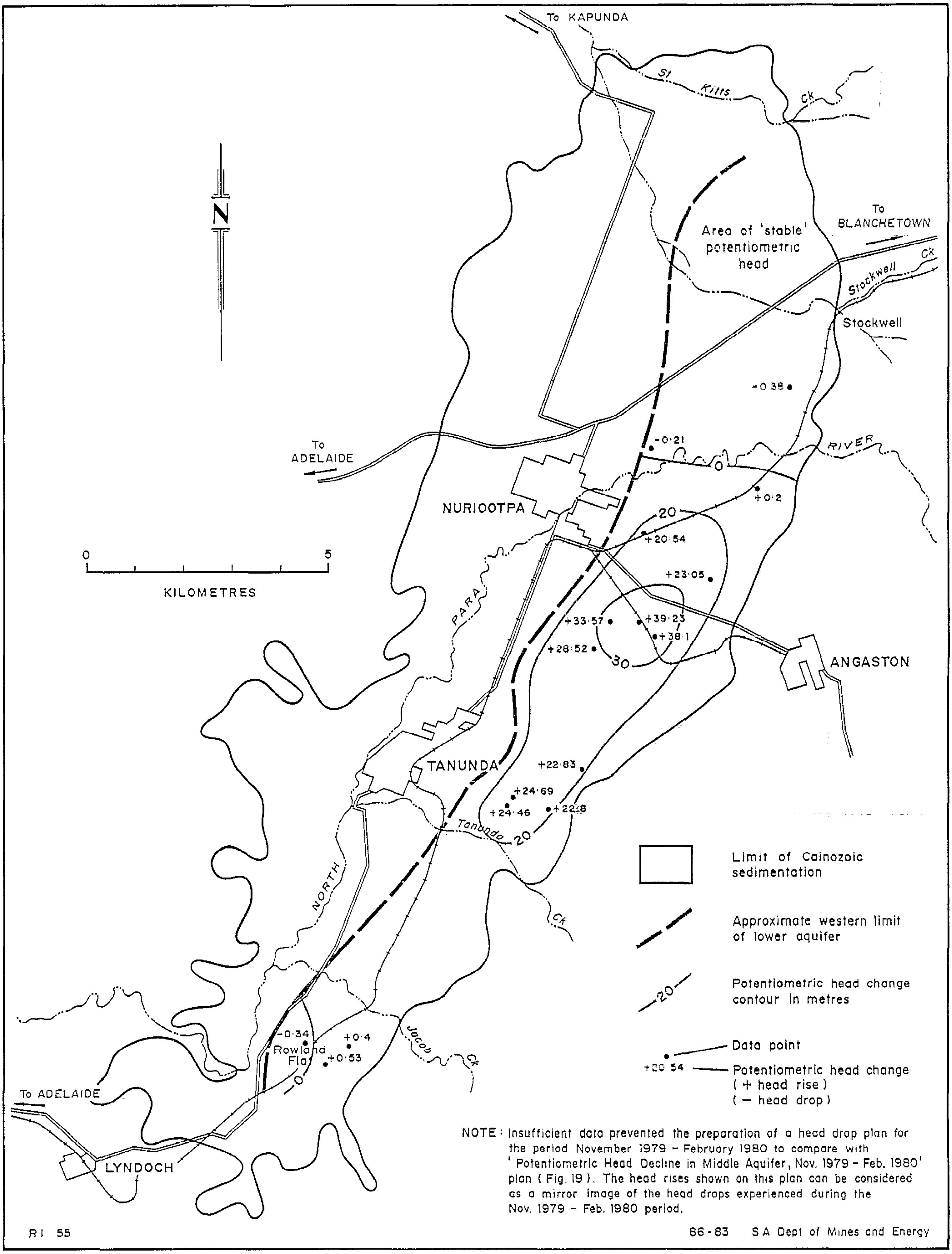

Fig. 16 Lower aquifer: potentiometric head rise after end of pumping (February to August 1980).

a shift in the upgradient direction of contours in the area of pumping influence.

Typical regional seasonal changes in water levels from spring to late summer are given on Figures 17 and 18. The period for these fluctuations differs from the lower aquifer (Fig. 16) where insufficient data were available. A slight increase in head in the extreme northern portion of the valley over the same period is unexplained.

Upper aquifer

This generally clayey or silty gravel appears to be discontinuous and restricted to the flood plain of the North Para and its tributaries. It is unclear whether it is associated geologically and hydraulically with the relatively thin ferruginous gravels (outwash gravels) found closer to the eastern ranges.

Thickness of these beds ranges from less than half a metre up to 10 m, but is commonly 4 to 5 m. Clay interbeds of from 1 to 2 m in thickness are common within the gravel but are discontinuous. Well yields are variable ranging from 400 to 1200 m^3day^{-1}, but quality of the water restricts its use to cooling and make-up water in the winery complex at Nuriootpa and to limited irrigation elsewhere.

A well test performed on aquifers south of Nuriootpa disclosed hydraulic conductivities of 168 $m^3day^{-1}m^{-2}$ on drawdown and 95 $m^3day^{-1}m^{-2}$ for recovery (Appendix 3).

Fluctuations in water levels for observation wells are shown by hydrographs in Figure 70 (MOR 10,39,74). Most withdrawals take place close to the North Para River from the vicinity of Lights Pass through Nuriootpa to Dorrien. A small decline in water levels has been noted.

Water table aquifer

The water table is contained within sediments ranging from clays to coarse clean gravels. The latter tend to be restricted in occurrence and thickness being associated mainly with creek flood deposits and with the upper parts of alluvial fans abutting the eastern ranges. The most common lithology of the unconfined aquifer is a silt or a sandy silt. Near Tanunda the middle aquifer is at or approaches the surface and is unconfined.

Early settlers dug shallow wells to develop the unconfined aquifer for household and stock use, though most of these are now abandoned or used for septic tank overflow disposal. Most were located adjacent to the North Para River or its tributaries.

Several features should be noted regarding water table contours (Fig. 20):

- There is hydraulic continuity between the water table in the sediments and the water table in the adjacent hard rocks.
- An east-west groundwater divide exists in the northern part of the Valley in the Neukirch area. North of this, groundwater flow is to the north towards St Kitts Creek. South of the divide, flow is towards an area of internal drainage south of Neukirch and, further south, flow is in a general southwesterly direction.
- A mound in the water table exists where the North Para River enters the valley, indicating that the river is an influent or losing stream in this area. Downstream the mound attenuates, the water table is quite flat, and near Nuriootpa a trough develops indicating that the North Para has become an effluent or gaining stream, acquiring water by groundwater discharge. A similar effluent characteristic is indicated for Bethany Creek.
- Gradients on the water table along the eastern face of the valley are steep, reflecting the steep topography and relatively low hydraulic conductivity of the hard rocks.
- A groundwater divide exists along the axis of the sand quarries west of Rowland Flat.

The depth to water table varies with topography (Fig. 21) being deepest in the ranges to the east and northwest of the valley. Within the sediments of the valley it is deepest close to the eastern edge where it is up to 25 m below ground level. The water table is shallowest adjacent to lines of surface drainage, particularly the North Para south of Nuriootpa, and adjacent to Bethany Creek. The water table reaches the surface from winter to early midsummer along the North Para river from Dorrien southwards, providing base flow for the river. A relatively shallow water table occurs under the Belvidere Plains in the vicinity of Dimchurch, at a depth of from 2 to 3 m. Such shallow depths allow groundwater transpiration by phreatophytes and direct evaporation of groundwater occurs where the water table is within 2 m of the land surface.

Recorded fluctuations in the water table are given in Figure 70.

Gradual declines in water levels since the early 1960s are evident in most areas of the Valley.

Groundwater chemistry

Salinity

Groundwater salinity in sediments of the Barossa Valley varies over a wide range, from less than 1000 to over 14 000 mg/L. The erratic distribution of the upper gravels and the small number of sampling points vitiates preparation of a salinity plan for that aquifer.

LOWER AQUIFER: The best quality water in this aquifer occurs southeast of Tanunda and east of Rowland Flat where salinities of less than 800 mg/L are recorded (Fig. 22). In the Nuriootpa-Vine Vale area salinities are in the range 1000-1400 mg/L, increasing towards the ranges and northwards towards Neukirch Plain. Increase in salinity towards the east is probably a reflection of subsurface recharge to the basal aquifer by higher salinity deep groundwater from the hard rock aquifers of the ranges. Experience with recently drilled wells close to the ranges, with screens set immediately above the hard rocks (basement), shows anomalously high salinities compared with similarly constructed wells a few hundred metres further west.

MIDDLE AQUIFER: There are similarities in the salinity pattern for the non-carbonaceous and upper carbonaceous sands. Figure 24 shows the generalised salinity pattern for the latter with areas of lowest salinity southeast of the Nuriootpa-Vine Vale area and in the Rowland Flat area (although data in this area are scarce).

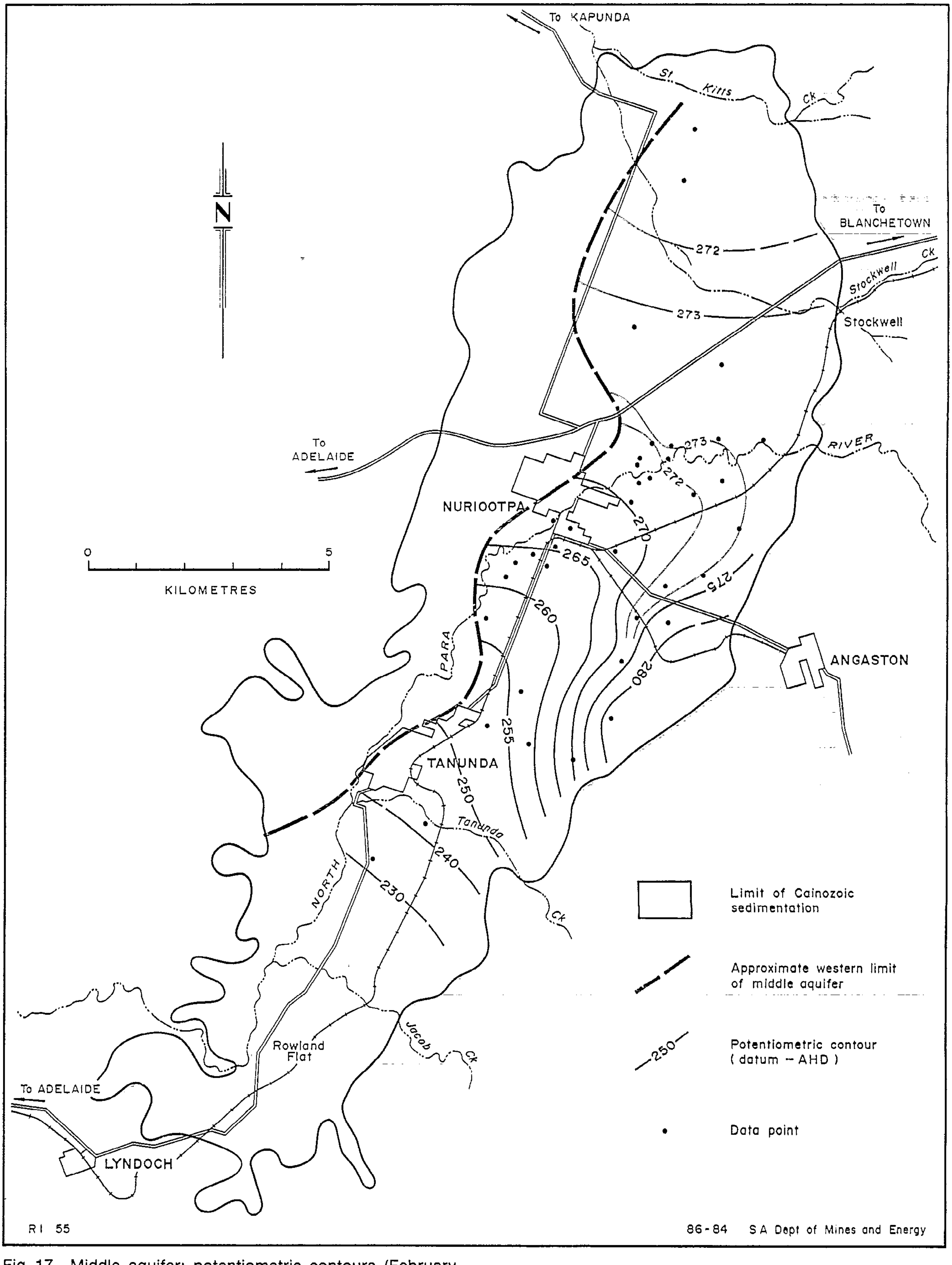

Fig. 17 Middle aquifer: potentiometric contours (February 1980).

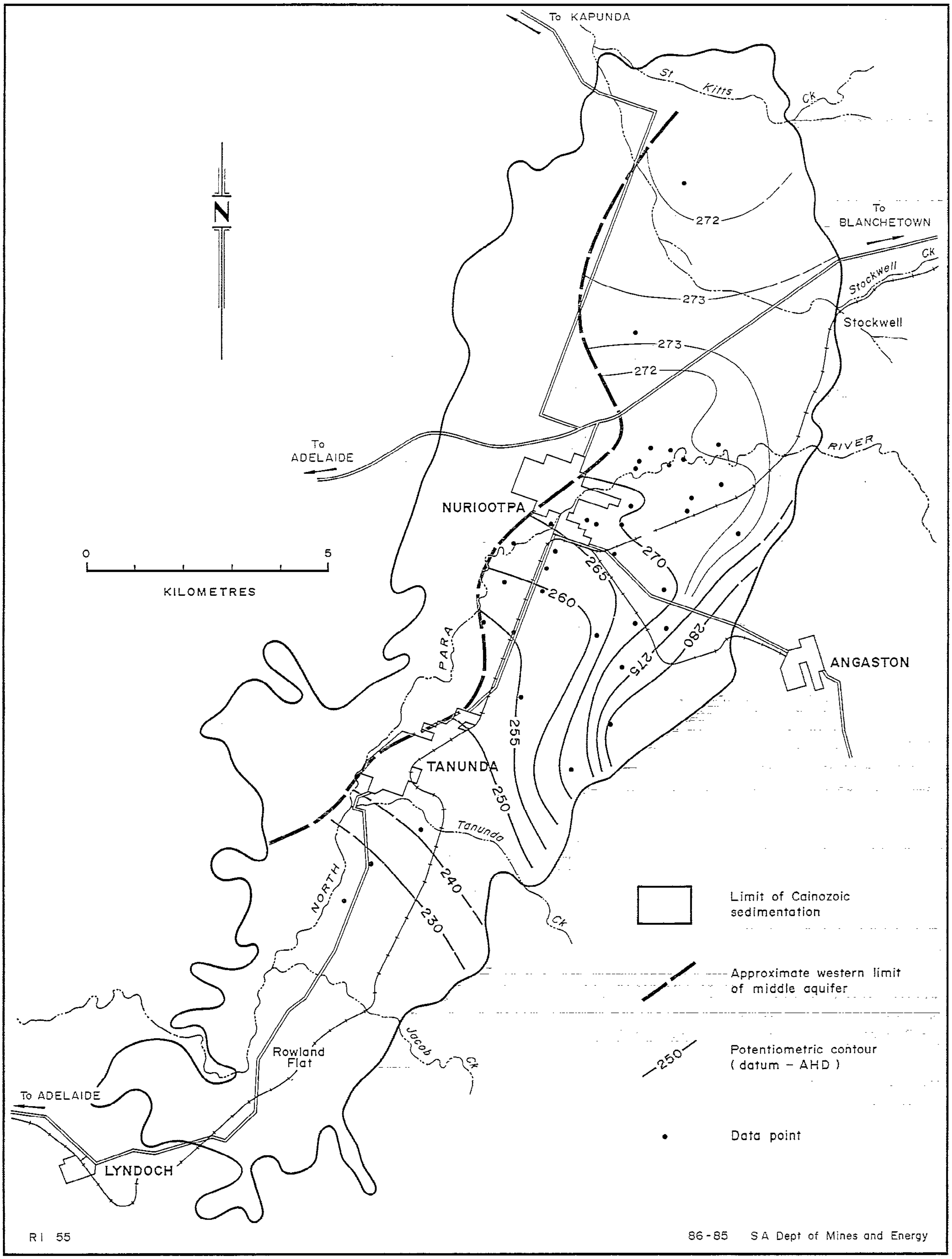

Fig. 18 Middle aquifer: potentiometric contours (August 1980).

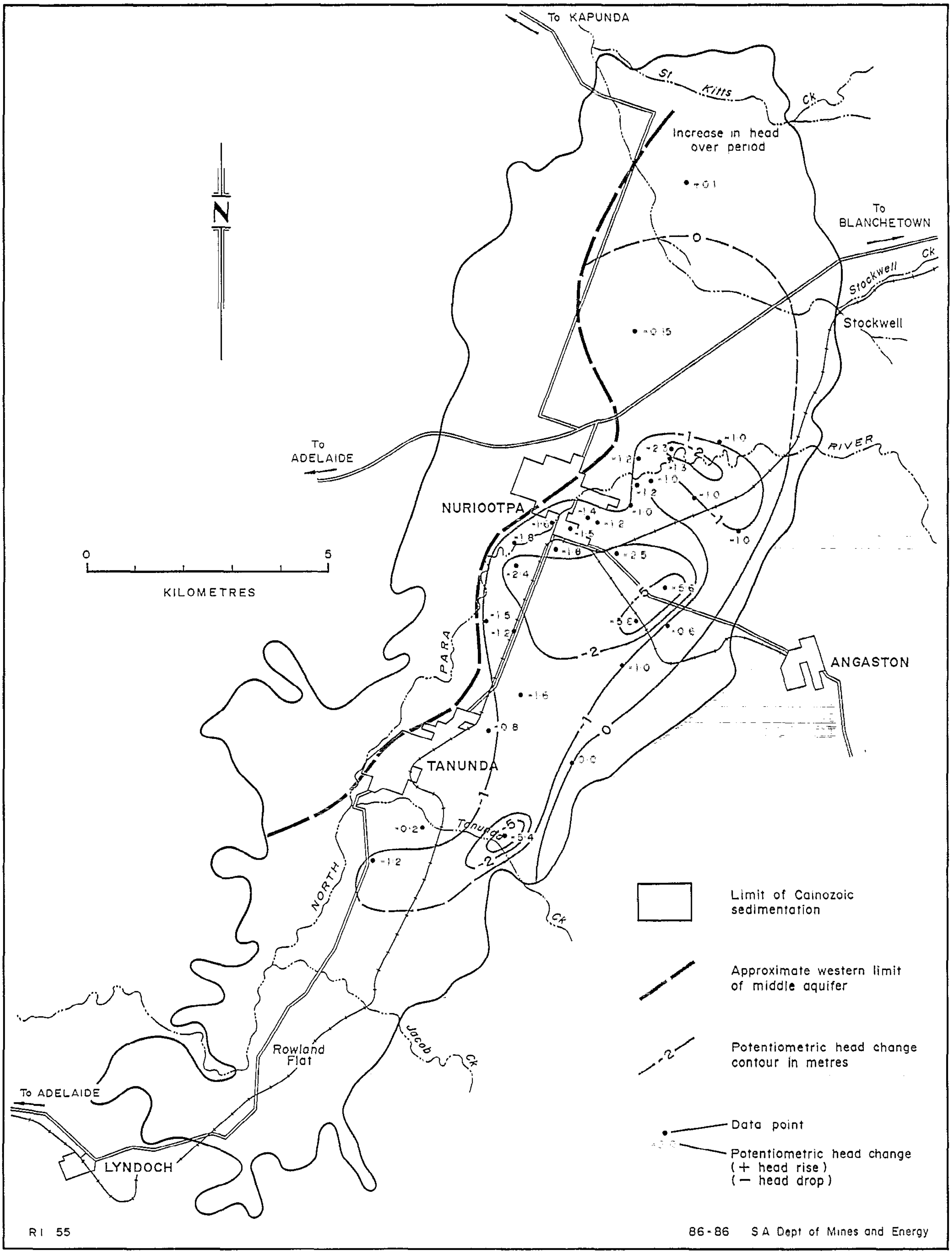

Fig. 19 Middle aquifer: potentiometric head decline (November 1979 to February 1980).

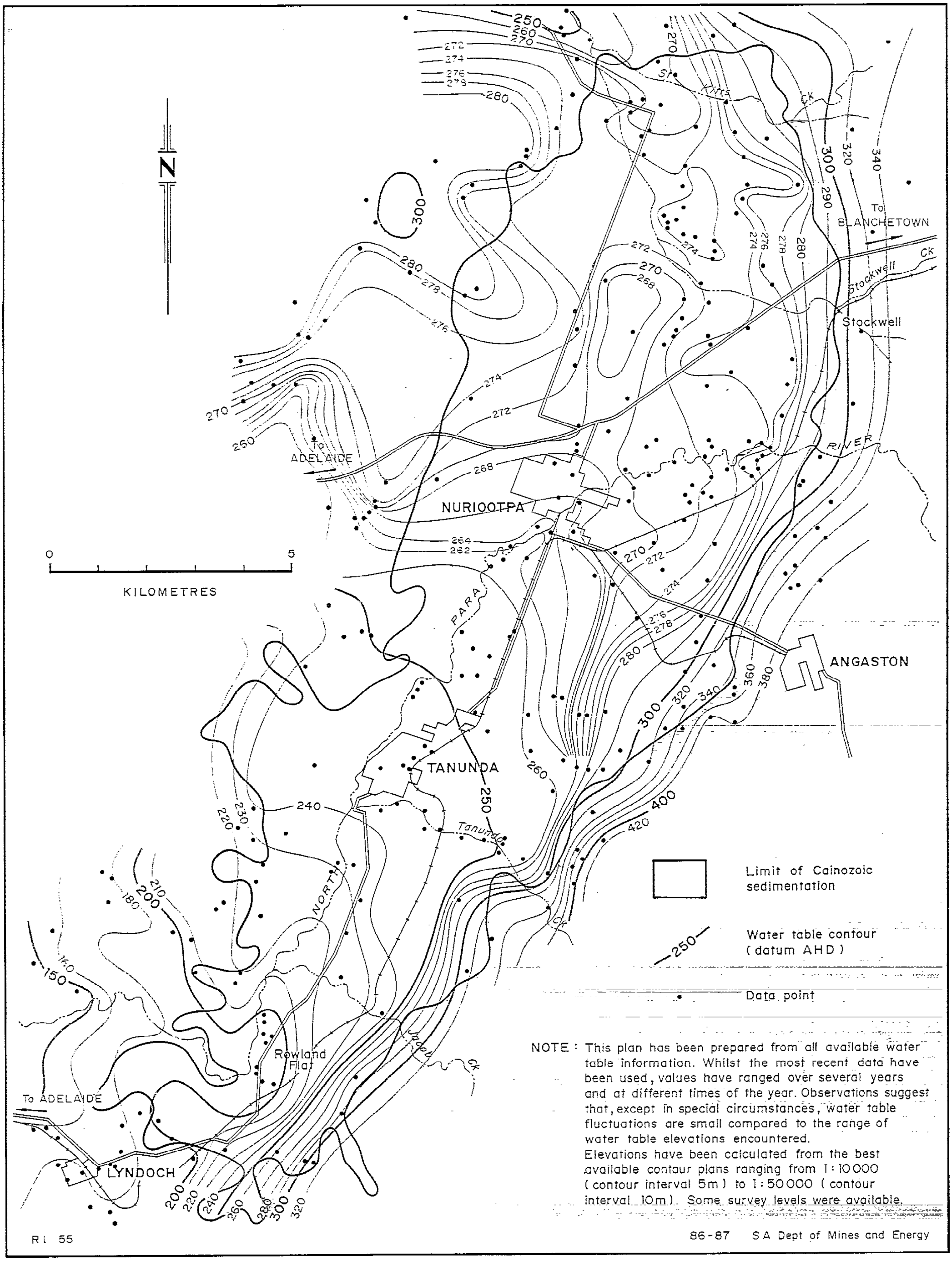

Fig. 20 Water table contours.

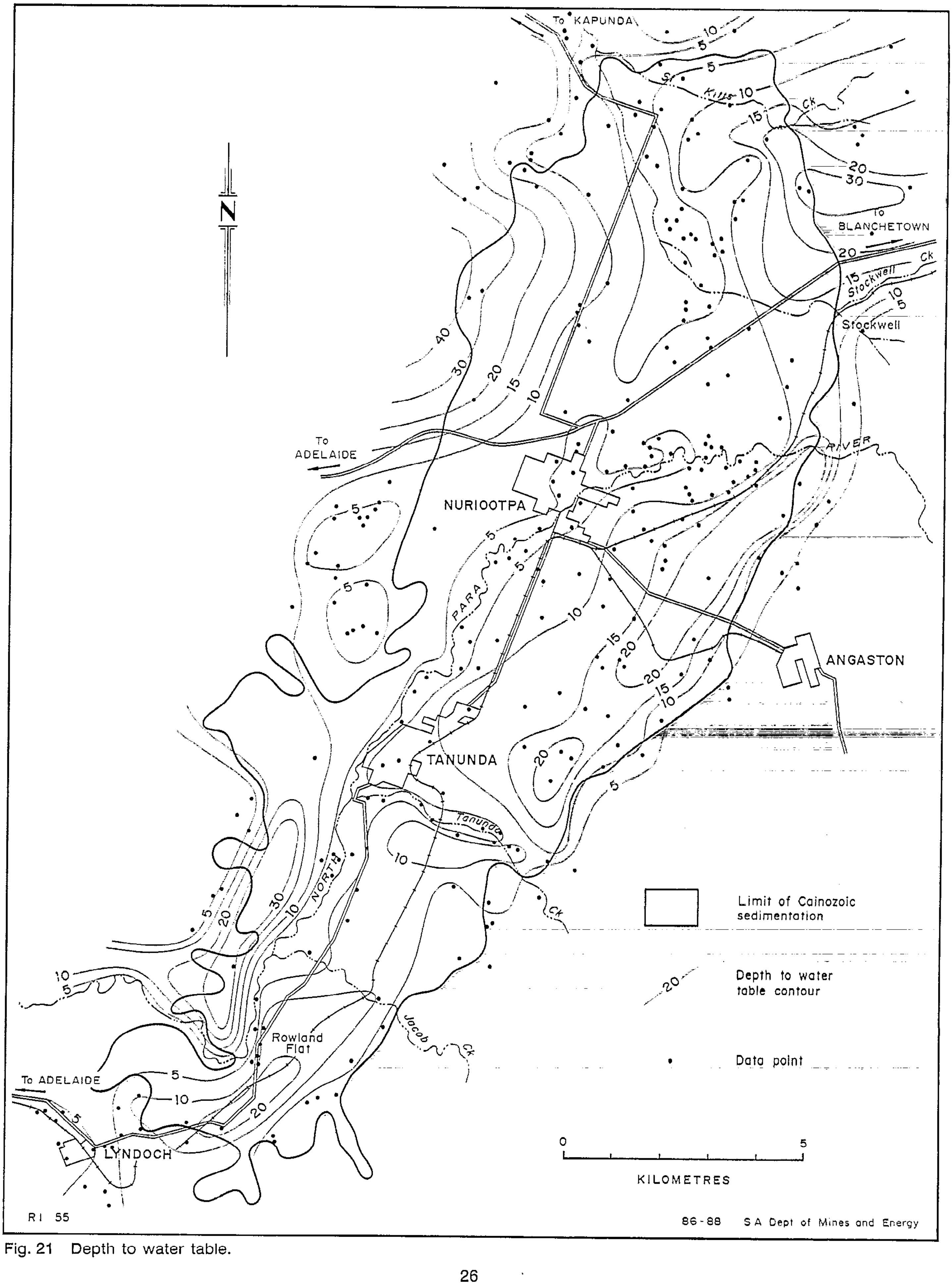

Fig. 21 Depth to water table.

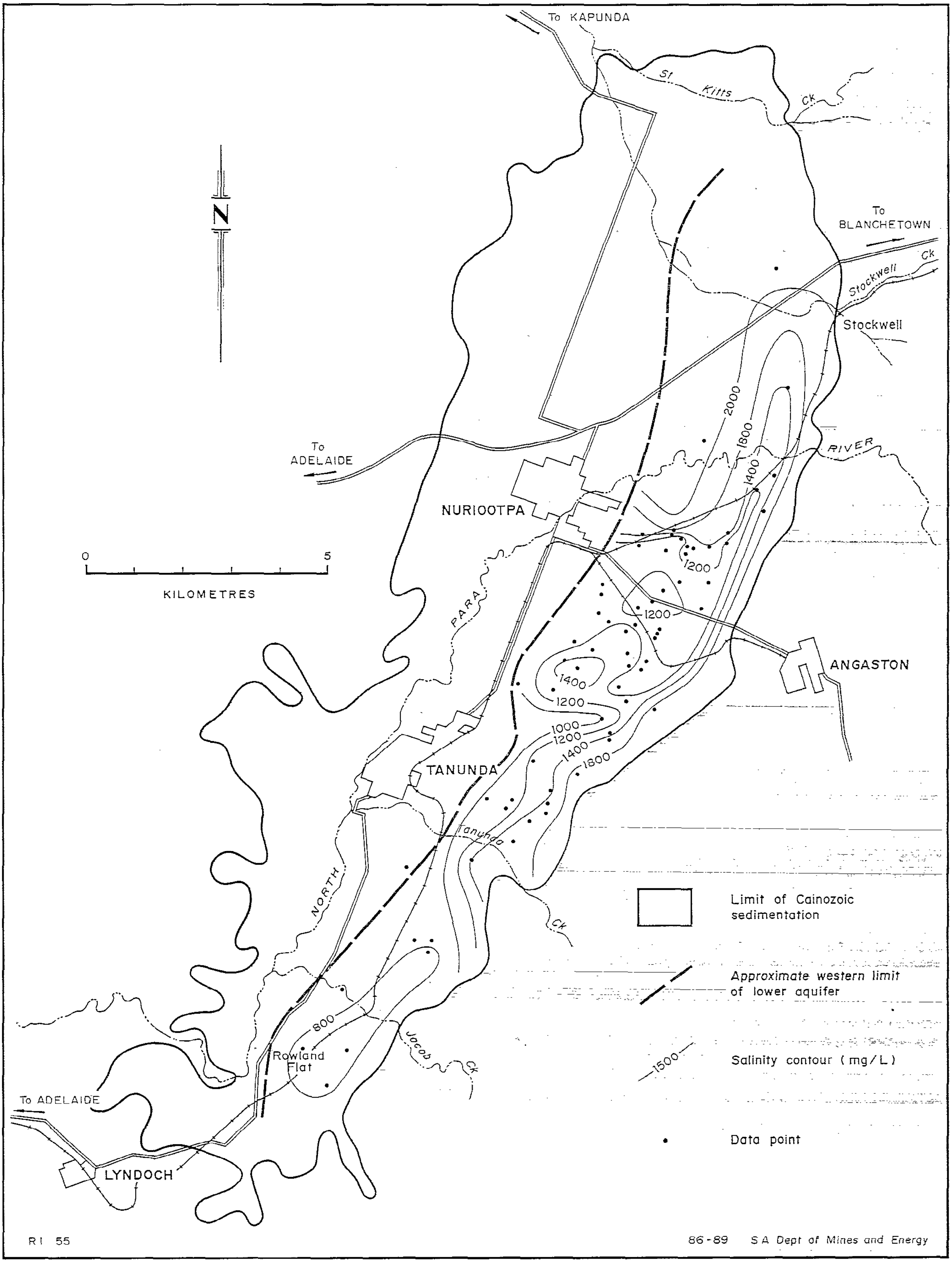

Fig. 22 Lower aquifer: salinity contours.

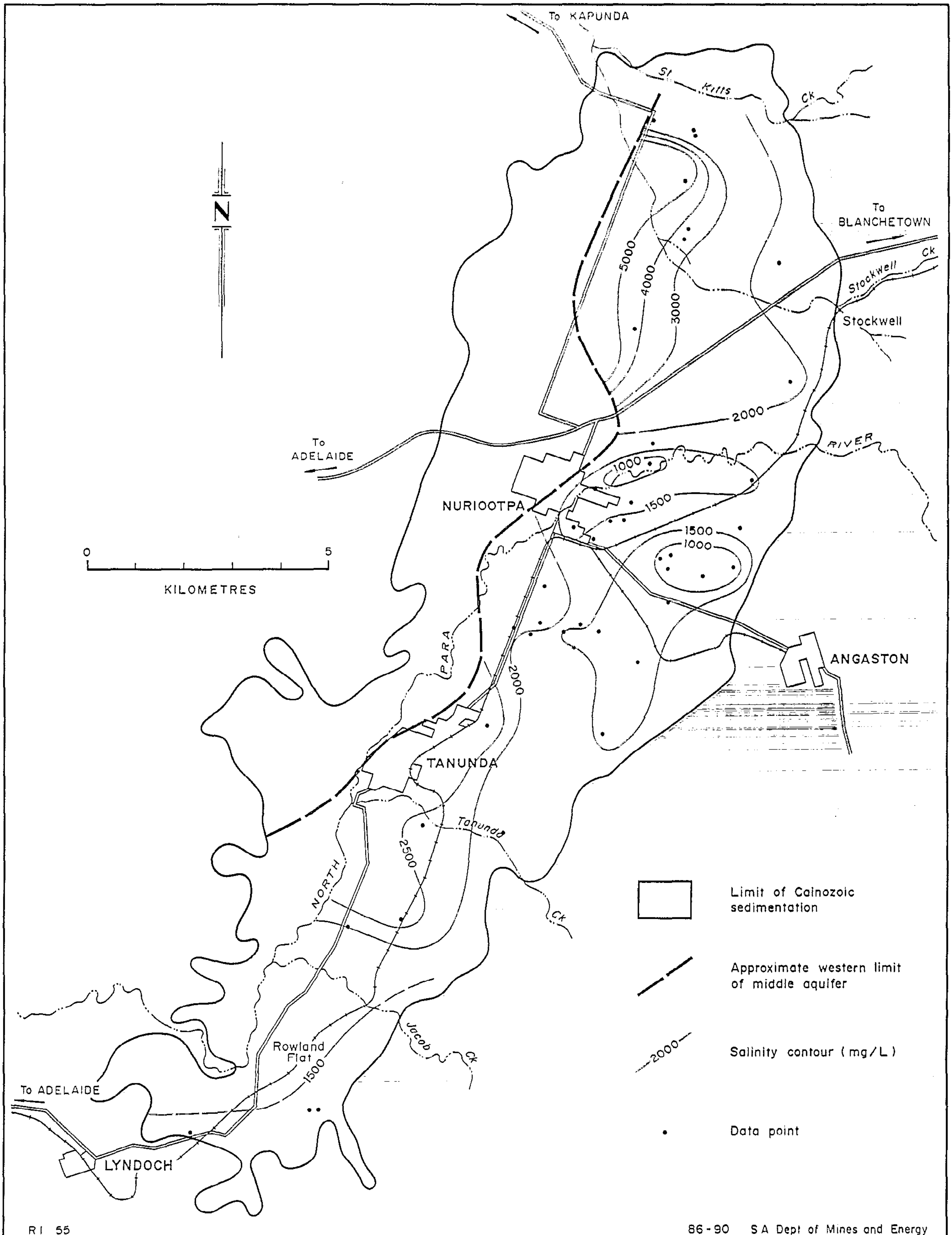

Fig. 23 Middle aquifer: salinity contours of non-carbonaceous sands.

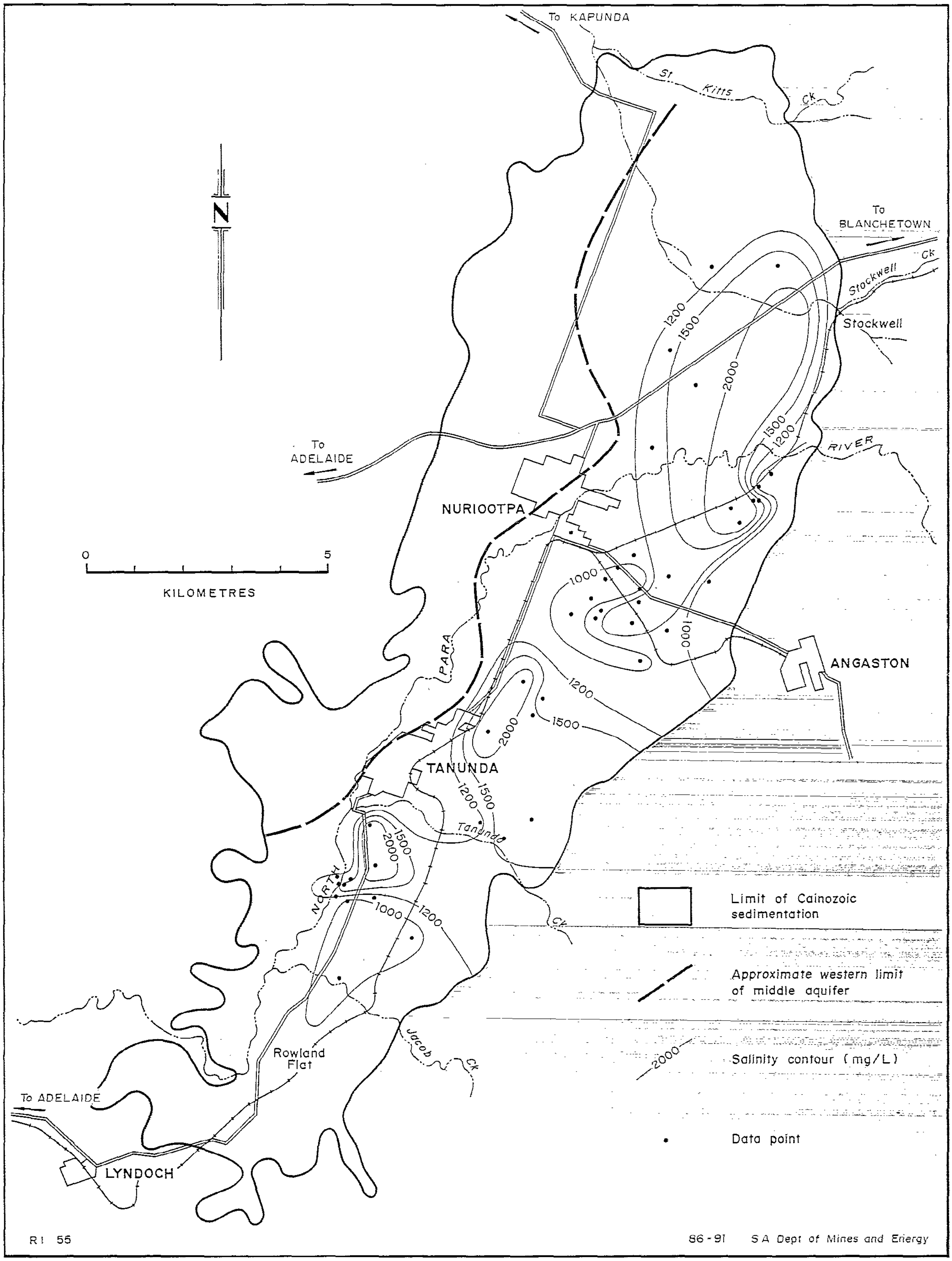

Fig. 24 Middle aquifer: salinity contours of carbonaceous sands.

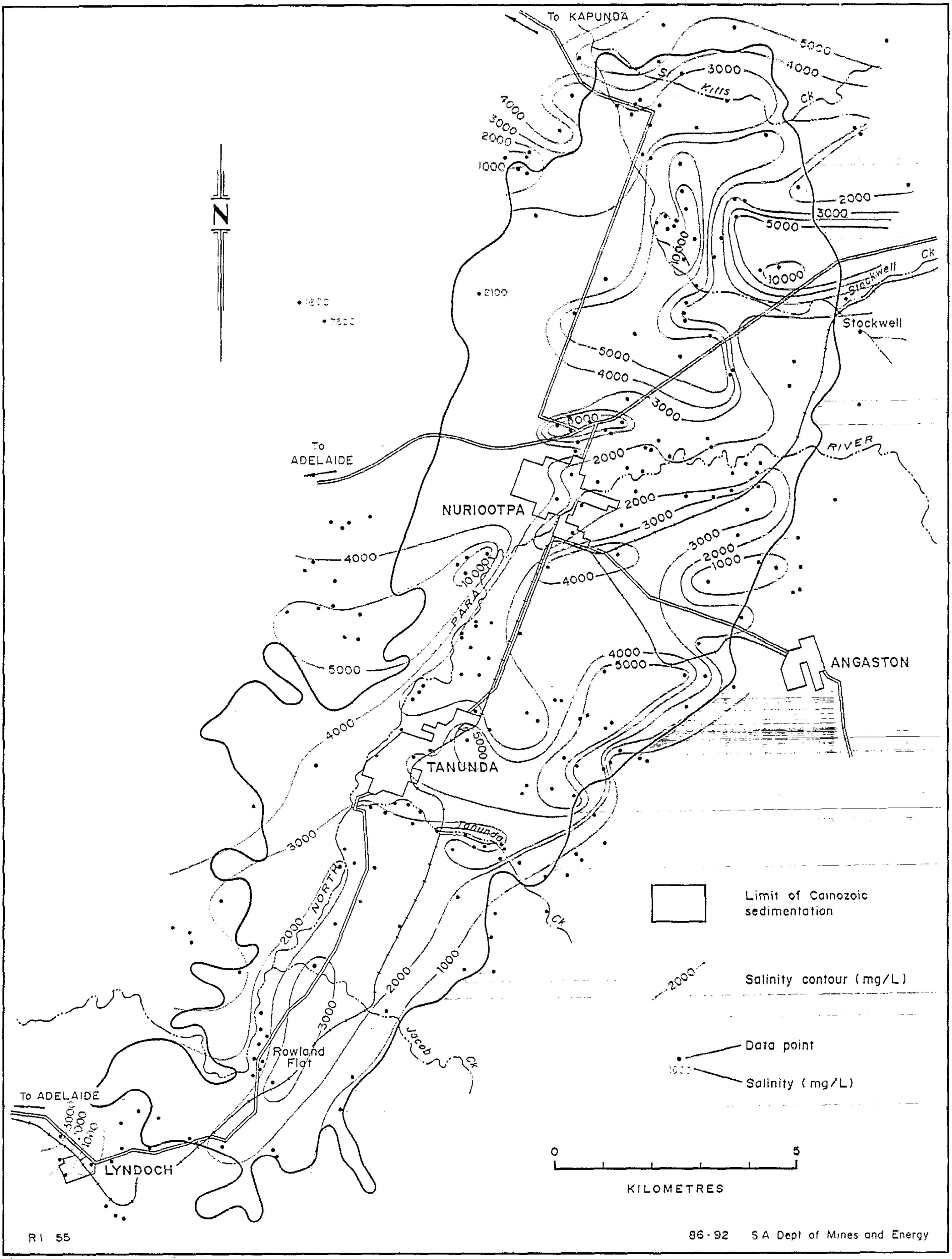

Fig. 25 Water table aquifer: generalised salinity zones.

The most obvious difference between the two aquifers is the existence in the upper carbonaceous sands of salinity highs (greater than 2000 mg/L) in the Stockwell-Plushs Corner and Kroemers Crossing areas and south of Tanunda, and the decrease in salinity towards both the western and eastern ranges. This is compared with the lower aquifer where salinities generally increase towards the eastern ranges.

The salinity highs in the Kroemers Crossing and south of Tanunda regions may be related to areas of near-stagnation caused by shallow and variable bedrock topography.

Figure 23 shows the salinity distribution for the non-carbonaceous sands and on a regional scale indicates opposite trends to the lower aquifer, that is highest salinities are in the west. The middle aquifer is unconfined in the west and the water table contour plan (Fig. 20) indicates groundwater inflow from the western ranges in this area. The lowest salinities (less than 1500 mg/L) are found adjacent to, and south of, the North Para River in the Lights Pass-Nuriootpa area, in the Penrice-Vine Vale area and southeast of Rowland Flat abutting the Barossa Ranges.

UPPER AQUIFER: These gravels contain groundwater with a salinity range of from 1600 to 2700 mg/L; the water is used for vine irrigation where soils have a high drainage capacity and excess volumes of water can be applied.

WATER-TABLE AQUIFERS: The water table shows a very wide range in salinities, from less than 1000 mg/L immediately adjacent the eastern ranges near Penrice, to over 10 000 mg/L north of Nuriootpa and in the Neukirch area (Fig. 25).

A complex salinity pattern is related to a number of factors including: spatial distribution of recharge from percolating rainfall; infiltration of stream flow in certain reaches of the creek system; evaporation directly from the water table; spatial distribution of evapotranspiration; underflow from the hard rock aquifers; and the wide range in sediments forming the unconfined aquifer, leading to a significant variation in residence time.

Active corrosion of steel casing is a possibility with such high salinities and there is a need for pressure cementing of casing during drilling.

Ionic Composition

MAJOR IONS: The major ionic constituents of groundwaters in the Barossa Valley are sodium (Na), calcium (Ca) and magnesium (Mg) as cations, and chloride (Cl), sulphate (SO_4) and bicarbonate (HCO_3) as anions. Potassium (K) as a cation is generally less than 20 mg/L.

Ratios of major ions (Fig. 26) presented for portion of the hundreds of Belvidere and Moorooroo and for the hundreds of Barossa and Nuriootpa show that the groundwaters are dominantly a sodium chloride (Na-Cl) type and, to a lesser extent, a sodium-calcium/chloride-bicarbonate (Na, Ca-Cl, HCO_3) type. Whilst both cations and anions appear to show trends away from the Na+K and Cl corners this does not appear to be related to the aquifer from which the sample was taken or well location: that is, there are no obvious chemical trends related to groundwater flow patterns.

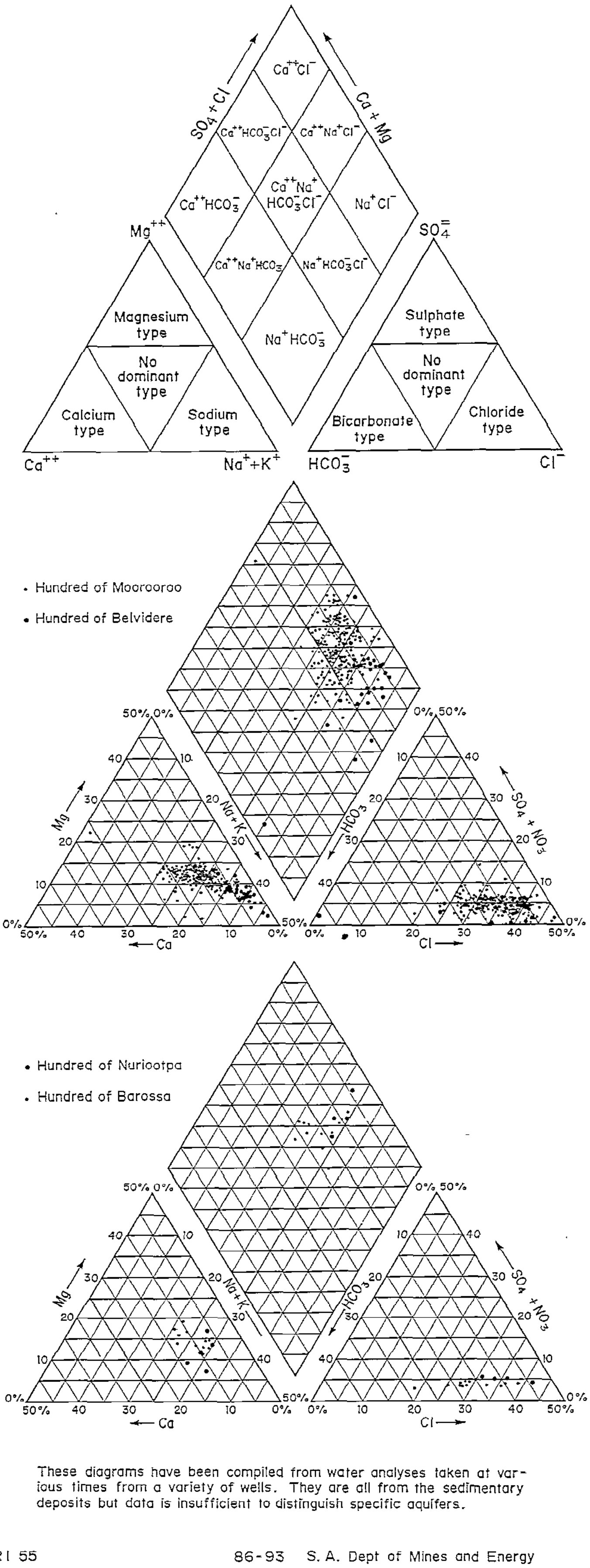

Fig. 26 Groundwater chemistry: modified Piper diagrams.

MINOR IONS: Groundwaters contain a variety of ions in concentrations generally measured in micrograms per litre or ug/L (l mg/L = 1000 ug/L).

Under the State water quality sampling programme (Cobb, 1979), several wells in the Barossa Valley and vicinity were sampled for minor ions, including heavy metals. The results are given in Table 4 and show the level of concentration to be expected for the various aquifers. Table 5 lists, where applicable, the recommended upper limit for each ion for various uses (Hart, 1974 and US Public Health Service, 1962).

Concentrations of heavy metals are very low and impose no limitations on use. Boron concentrations are lower than upper recommended limits. While fluoride commonly rises above the limit set for human consumption it is considered not to pose a problem as well water is rarely used for human consumption.

Dissolved Gases

Many wells which penetrate carbonaceous sediments produce water containing hydrogen sulphide (H_2S), which even in concentrations of less than 1 mg/L imparts a foul smell. In solution it causes casing corrosion and can lead to the growth of bacterial slimes from the action of sulphur-oxidizing bacteria; only one example of the latter problem has been noted.

The H_2S is formed by conversion of sulphur in the original protein of woody material found within the basal sediments (Krauskopf, 1967). Some of the sulphur is combined with iron to produce pyrite (FeS_2), a mineral commonly forming nodules in the basal sands.

Suitability for irrigation

Groundwater usage is mainly for the irrigation of vines with lesser amounts for fruit trees and vegetables (Fig. 8). Quality of the water is important in its effects on plants and possible long-term effects on soil structure.

The Department of Agriculture recommends that the salinity of irrigation water for use on vines should not exceed 1300 mg/L; for stone fruits, 850 mg/L; and for vegetable species grown in the area, 1300 mg/L. However, in the Valley these values are commonly exceeded and irrigation of vines with water of salinity up to 2400 mg/L is practiced on areas of sandy soil. Most vegetables are grown on the sandier soils of the area and irrigation with water of salinity from 1500 to 1700 mg/L is common. Thus, even with sophisticated land management techniques, groundwater salinities are marginal and any increase will have deleterious results.

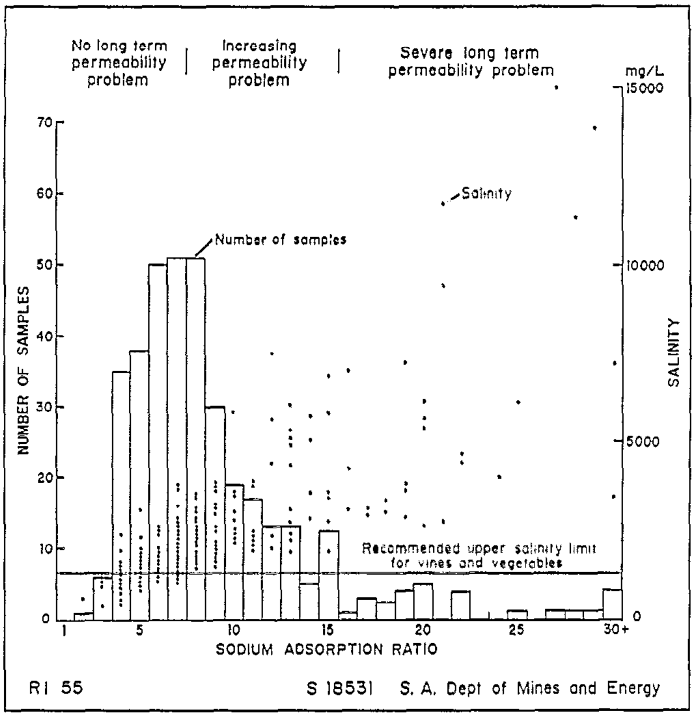

Fig. 27 Sodium adsorption ratio and salinity.

Specific ions are also important for their effects on plant growth and soil properties. Chloride (Cl) limits for irrigation of vines have been given by Hart (1974) as 350 mg/L and for under tree sprinklers of stonefruit as 175 mg/L. Most irrigation waters in the Barossa Valley exceed these values.

Sodium (Na) concentrations are important not only in terms of toxicity to plants but also for deleterious effects on soil structure. Sodium can exchange with

Table 4. Minor ion concentrations, selected wells

	Observation Well No.						
	BRS4	MOR106	MOR108	MOR109	MOR110	MOR112	MOR113
	CONCENTRATIONS mg/L						
Phosphate	0.60	0.20	0.06	0.06	0.16	0.06	0.06
Fluoride	0.64	1.00	1.00	0.36	0.98	0.42	0.58
Boron	0.07	0.17	0.08	0.13	0.15	0.14	0.12
Silicon	24.70	19.90	26.70	16.50	19.40	20.40	19.20
Iron	0.29	0.07	0.75	0.76	2.13	1.63	0.13
	CONCENTRATIONS ug/L						
Copper	<0.50	75.00	<0.50	3.00	7.00	2.00	2.00
Lead	<0.50	4.00	<0.50	5.00	6.50	2.50	1.50
Zinc	48.00	30.00	55.00	12.50	235.00	12.50	1.00
Cadmium	0.75	1.80	1.10	6.50	0.55	1.40	2.80
Manganese	9.50	28.00	110.00	12.50	35.00	75.00	2.50
Silver	<0.50	<0.50	<0.50	0.50	<0.50	<0.50	0.50
Arsenic	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00
Selenium	1.00	<1.00	<1.00	<1.00	<1.00	<1.00	2.00
Mercury	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Aluminium	940.00	330.00	380.00	740.00	320.00	400.00	480.00
Barium	185.00	40.00	150.00	140.00	25.00	90.00	105.00
Nickel	1.00	1.00	<1.00	5.00	1.00	1.00	1.00

< Signifies less than detection limit for ion

Table 5. Recommended upper working level concentrations for various uses

Ion	Usage		
	Domestic	Irrigation	Livestock
Fluoride	0.6-1.7 mg/L Depends on average maximum daily air temperature	2 mg/L	2 mg/L
Boron	1 mg/L	0.75 mg/L Plant dependent: some are sensitive to 0.3 mg/L	
Iron	0.3 mg/L Impairs taste and causes staining	1 mg/L Precipitates on contact with air	10 mg/L For water used to irrigate pasture
Copper	1 000 ug/L Impairs taste	200 ug/L	500-2000 ug/L Animal and feed dependent
Lead	50 ug/L	5 000 ug/L	500 ug/L
Zinc	5 000 ug/L	2 000 ug/L	20 000 ug/L
Cadmium	10 ug/L Accumulative in man	10 ug/L	10 ug/L
Manganese	50-100 ug/L Affects taste and causes staining	500 ug/L	
Silver	50 ug/L		
Arsenic	50 ug/L Acutely and chronically toxic to man	100 ug/L	1 000 ug/L
Selenium	10 ug/L	20 ug/L	20 ug/L
Mercury	2 ug/L		2 ug/L
Aluminium		5 000 ug/L	
Barium	1 000 ug/L		
Nickel		200 ug/L	

calcium (Ca) and magnesium (Mg) on clay particles causing them to disperse with a resultant decrease in soil permeability. In relatively clean clay-free sands, Na presents no real threat to soil structure and hence permeability; but since most soils in the Barossa Valley contain clay in varying proportions, long term problems may exist. The measure most commonly used to characterise the problem is the Sodium Absorption Ratio (SAR) where concentrations are expressed in millequivalents per litre (meq/L).

For the Barossa Valley it is assumed that SAR values less than 8 will not lead to long term permeability problems; between 8 and 16 there will be an increasing problem; and for values greater than 16 there will be severe long term permeability problems (M. McCarthy, Department of Agriculture, pers. comm. 1982). The SAR values recorded for the groundwaters contained within sediments of the Barossa Valley and the variation of SAR with total salinity are shown on Figure 27. These indicate that waters with a potential long term soil-damaging SAR value also have a salinity that would generally preclude them as irrigation waters. Even if an upper salinity limit for irrigation was taken as 2000 mg/L, then no waters have SAR values greater than 16 and only a few occur between 8 and 16.

Tables 4 and 5 show that typical minor ion concentrations in groundwaters of the area fall well below recommended limits for irrigation. However, some well waters contain sufficient iron to cause problems with precipitation in distribution lines and especially in drippers. The problem can be overcome by either of two methods: firstly, by pre-aeration and settling, for example in a dam; and, secondly, by precipitation after making the water alkaline. Both methods involve extra costs and modification of irrigation systems.

Water Quality Changes

Salinity changes in a well may occur through the interaction of one or more factors including:

- Regional changes in salinity distribution through changes in lateral movement of groundwater and modification of inter-aquifer leakage under pumping stresses.
- Aquifer interconnection outside the well casing where it is not pressure cemented.
- Corroded and perforated casing where highly saline groundwaters are in direct contact with the steel casing through lack of pressure cementing.

All wells drilled before July 1976 were not pressure cemented and thus casing corrosion and/or inter-aquifer connection is possible. Regular sampling of irrigation wells that are not pressure-cemented show a typical increase in salinity over an irrigation season as upper saline waters mix with the developed aquifer water.

Figure 72 shows salinity trends in several routinely sampled pressure-cemented irrigation wells whose locations are shown on Figure 71. It is obvious that salinities are rising but at different rates depending on the area and the aquifer involved. Whilst the time period over which salinity monitoring has taken place is quite short, average annual rises of from 20 to 50 EC units (10-25 mg/L) have been noted.

Recharge

Recharge to the unconfined aquifers of the Barossa Valley can take place through infiltration of rainfall and excess irrigation water through the soil profile and from surface (creek) flows.

Climatological and water chemistry data suggest long term recharge rates of 1 to 3 mm a year, despite an annual rainfall of from 500 to 650 mm. Fluctuations of water levels in shallow piezometers were used to estimate recharge for the year of the trial water budget and results are given in Appendix 4.

Loss of river flow to the unconfined aquifer during the trial water budget year was investigated by means of daily flow measurements at selected gauging sites (Appendix 2) and by analysis of water level fluctuations in shallow piezometers drilled adjacent to the North Para River. Results are given in Appendix 4 and in the subsequent water budget section.

Recharge to the confined aquifers is by induced vertical leakage from the unconfined aquifer and by lateral and vertical flow from adjacent and underlying hard rocks (Appendix 5).

Groundwater Pollution Potential

Groundwater in the Barossa Valley can be polluted by infiltration of contaminated surface water, infiltration of septic tank overflows, by direct discharge of wastes to the water table or other aquifers through drainage wells, from fertilisers, pesticides, weedicides, animal wastes, fruit processing and winery wastes.

No systematic sampling of wells in the Barossa Valley has been undertaken to establish whether pollution of groundwater has taken place.

The thirty wineries in the Barossa Valley produce 226 000 m^3 of wastes each year of which 164 000 m^3 is considered as low concentration wastes, and 62 000 m^3 as high. Low concentration wastes are produced by storage and fermentation tank washing, grape crusher cleaning etc., whilst high concentration wastes are produced from continuous and pot-still distillation processes. Wastes are stored in dams adjacent to the North Para River or its tributaries to await disposal into these watercourses during peak flows. Leakage from dams is likely as some were excavated into the water table. However, seepage to the water table would contribute to stream base flow. Whilst disposal of winery waste to the creeks in the Barossa Valley will have little effect on groundwaters there, the North Para River contributes to recharge of aquifers in the Northern Adelaide Plains in the Gawler area.

Since few stock are kept in the Barossa Valley and there are no point concentrations of animals, contamination from this source would be minimal. Stocking rates are higher in the upper catchment of the North Para and its tributaries and hence animal wastes may contribute contaminants to surface flows entering the Valley. No systematic sampling for indicator species has been undertaken for surface waters entering the Barossa Valley. However, Sanders (1975) states that total nitrogen concentrations are typical of streams subjected to agricultural and domestic pollution.

Whilst usage of fertiliser, insecticide, and herbicide is widespread, the depth of the water table and the low permeability of the soils suggests that accretion of these materials to the water table is limited. The half-life for the degradation of most herbicides, combined with the absorbing powers of the soils in the area, would effectively prevent deep percolation.

Before the establishment of common effluent or sewerage systems, houses were equipped with septic tanks. Septic-tank overflows were commonly disposed of down drainage wells, particularly in areas where soil permeability is low. Thus contaminants had direct access to the water table or deeper aquifers. The nitrate content of groundwaters is shown on Figure 28 with the depth of sample, and results from deep drilling in Table 6. Note that Figure 28 does not differentiate the aquifer from which the sample was collected.

It is obvious that contamination of groundwaters by nitrate has occurred, particularly in the water table aquifer in residential areas such as Bethany-Tanunda. Values range from less than 1 mg/L for the deeper aquifers, to a high of 479 mg/l just south of Tanunda. The latter is associated with a house well in a poultry yard, an obvious source of pollution. Nitrates are commonly over 50 mg/L in the Bethany-Tanunda area but reduction of nitrate concentration with depth reinforces the concept of nitrate contamination from the surface.

WATER BUDGET

Insufficient data are available to define approximate water budgets for individual aquifers. However, a budget can be estimated for the sedimentary sequence as a whole.

The water budget can be expressed as:

$$\pm DS = Rs + Rc + Ru - Uc - Uu - ETg - P \pm DSM$$

where DS = change in groundwater storage
Rs = recharge through the soil profile
Rc = recharge from creek flow
Ru = subsurface recharge from adjacent hard rock aquifers
Uc = groundwater outflow (seepage) into creeks
Uu = subsurface outflow of groundwater into adjacent hard rock aquifers
ETg = evapotranspiration of groundwater (where the water table is sufficiently shallow)
P = pumping withdrawals
DSM = change in soil moisture

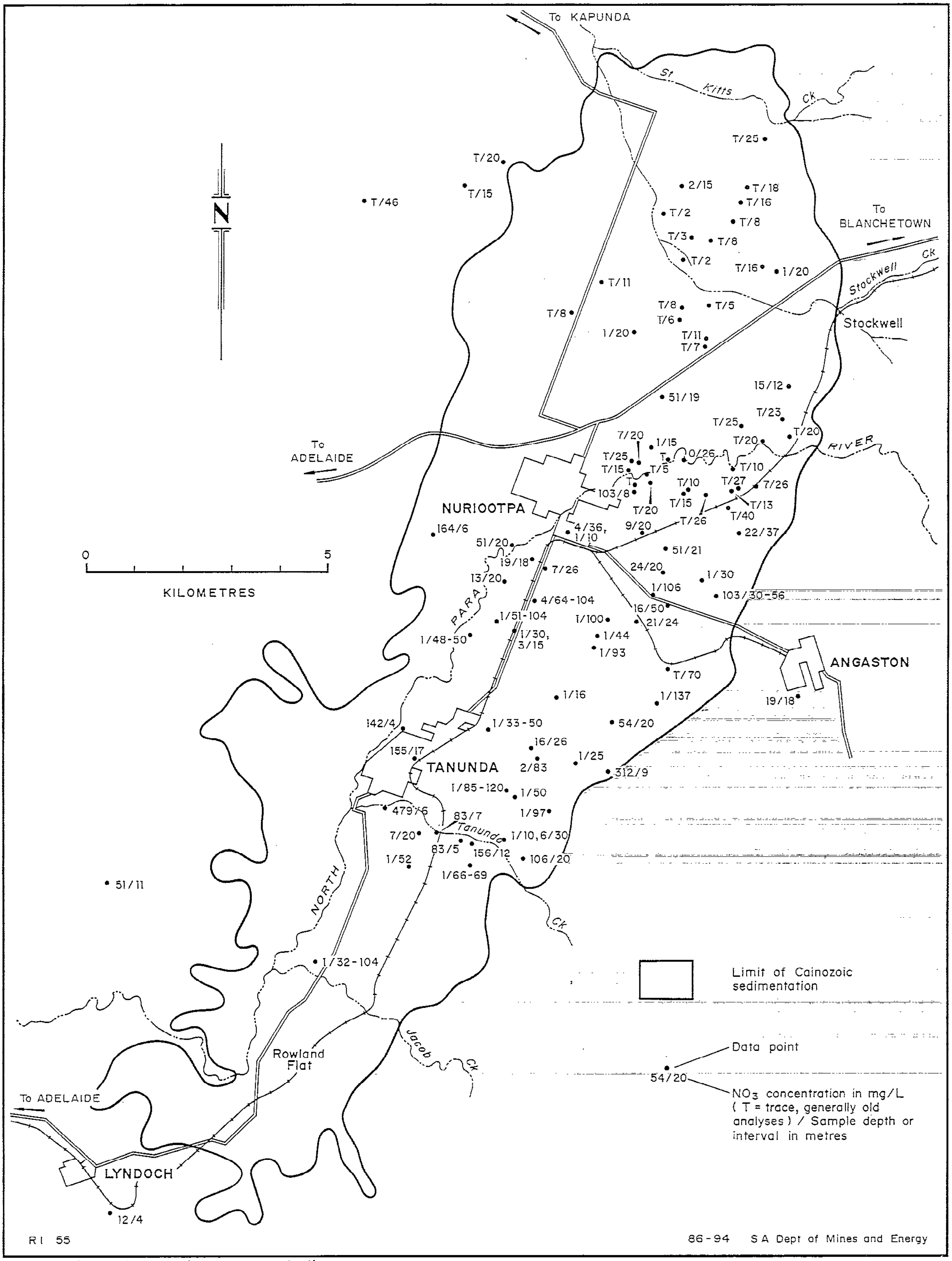

Fig. 28 Groundwater nitrate concentrations.

Table 6. Nitrate concentrations versus depth (deep drilling)

Observation Well No.	Depth (m)	Nitrate	Phosphate (mg/L)	Fluoride	Boron
MOR92	20	22	0.11	1.25	0.25
	28	22	0.06	0.55	0.20
	59	1	<0.01	1.20	0.15
	92	8	0.05	0.65	0.20
	93	9	0.01	0.85	0.30
	103	3	0.02	0.75	0.10
	115	3	0.02	0.80	0.20
MOR94	20	9	0.05	0.70	0.25
	24.5	1	0.06	0.70	0.10
	30	9	0.05	0.60	0.20
	35	5	0.05	0.70	0.25
	43	2	0.03	0.80	0.15
	49	3	0.05	1.05	0.15
	58	1	0.05	0.80	0.15
	67	3	0.04	0.80	0.20
	72	5	0.03	0.81	0.35
	81	<1	0.04	0.85	0.15
MOR99	26	7	0.13	0.50	0.35
	43	<1	0.06	0.45	0.10
	56	3	0.15	0.60	0.05
	60	4	0.63	0.70	0.10
	70	3	0.39	0.70	0.10
	75	2	0.41	0.70	0.10
	98	8	0.14	0.60	0.10
	109	16	0.37	0.75	0.05
	111	2	0.37	0.85	0.05
	117	8	0.07	1.15	0.15
MOR100	12	15	0.06	2.10	0.65
	24	9	0.05	2.25	0.55
	36	<1	0.03	0.90	0.15
	41	<1	0.04	1.20	0.10
	48	<1	0.04	1.20	0.15
	54	<1	0.05	1.25	0.10
MOR100	56	<1	0.36	1.20	0.10
	74	<1	0.14	1.10	0.20
	80	<1	0.14	1.45	0.20
	90	3	0.25	1.39	0.07
	107	<1	0.08	2.05	0.13
	112	<1	0.05	2.60	0.20
	120	<1	0.09	2.35	0.60
	128	<1	0.45	2.40	0.15
BLV2	20	1	0.07	0.55	2.20
	50	<1	0.09	1.95	0.55
	55	<1	0.08	1.75	0.50
	60	<1	0.05	2.25	0.55
	65	<1	0.05	2.45	0.30
	90	<1	0.05	2.90	0.10
	95	<1	0.03	2.50	0.15
	96	<1	0.07	2.50	0.25

The period from February 1979 to February 1980 was chosen for the budget calculation. It was assumed that soil moisture conditions would be sufficiently similar for both months and thus DSM = 0. Detailed calculations for each component are given in Appendices 4 and 5 and summarised here.

INFLOWS

Recharge through the soil profile (Rs)	= 3 630 000 m³
Recharge from creeks (Rc)	= 1 471 000 m³
Recharge from hard rock aquifers (Ru)	1 675 600 m³
	= 6 776 600 m³

OUTFLOWS

Seepage into creeks (Uc)	= 2 510 000 m³
Outflow into hard-rock aquifers (Uu)	= 45 000 m³
Evapotranspiration (ETg)	= 2 534 000 m³
Pumping withdrawals (P)	= 1 591 000 m³
	6 680 000 m³

The difference between the inflow and outflow for the budget period is + 96 600 m³ which means an *increase* in groundwater storage for the period.

An assessment of the net change in water table and confined aquifer's storages for the budget period, however, indicates a decrease from storage of 205 000 m^3. The estimated water budget may therefore be in error by 301 600 m^3 or 4.5 percent of the total outflow. Many assumptions have had to be made in calculating the individual components of the budget and it is felt that with the available data little refinement in the above figures can be obtained.

Hence, it is concluded that a near balance was being achieved in the water budget for that period, except in the Dorrien-Tanunda area where increased pumping in previous years has reduced groundwater storage. General increases in groundwater withdrawals for irrigation since the water budget date now means that an imbalance exists and this is being reflected in declining water levels.

ACKNOWLEDGEMENTS

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Drillers John and Peter Nitschke and Horwood Bagshaw Pty Ltd kindly allowed access to their records for wells drilled prior to the Water Resources Act, 1976.

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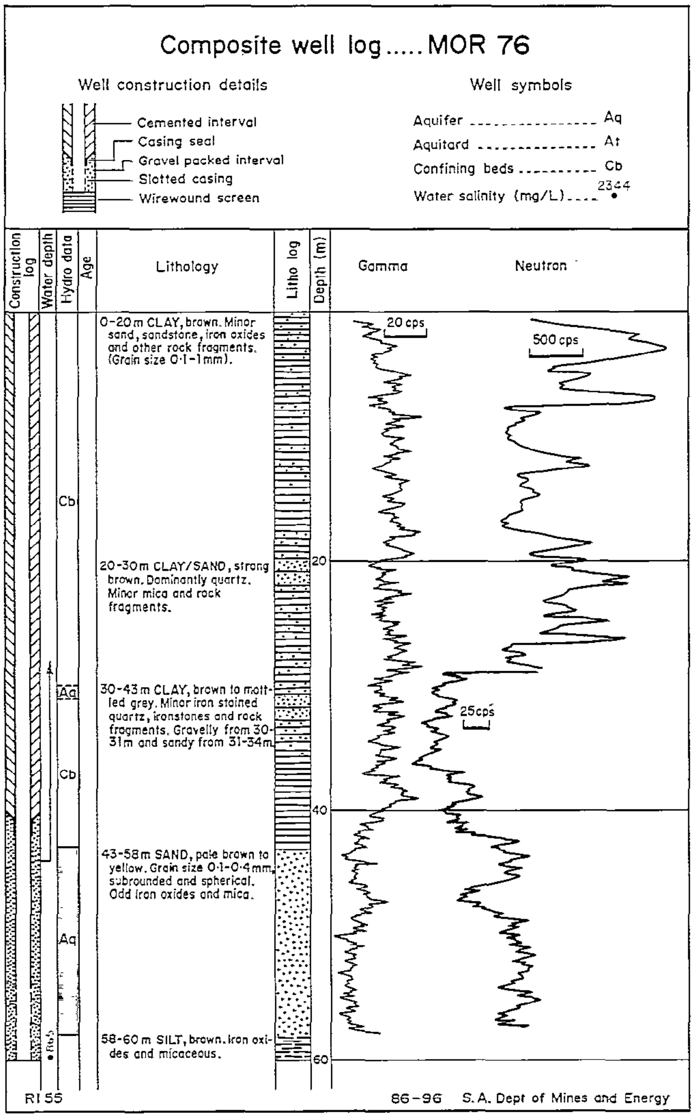
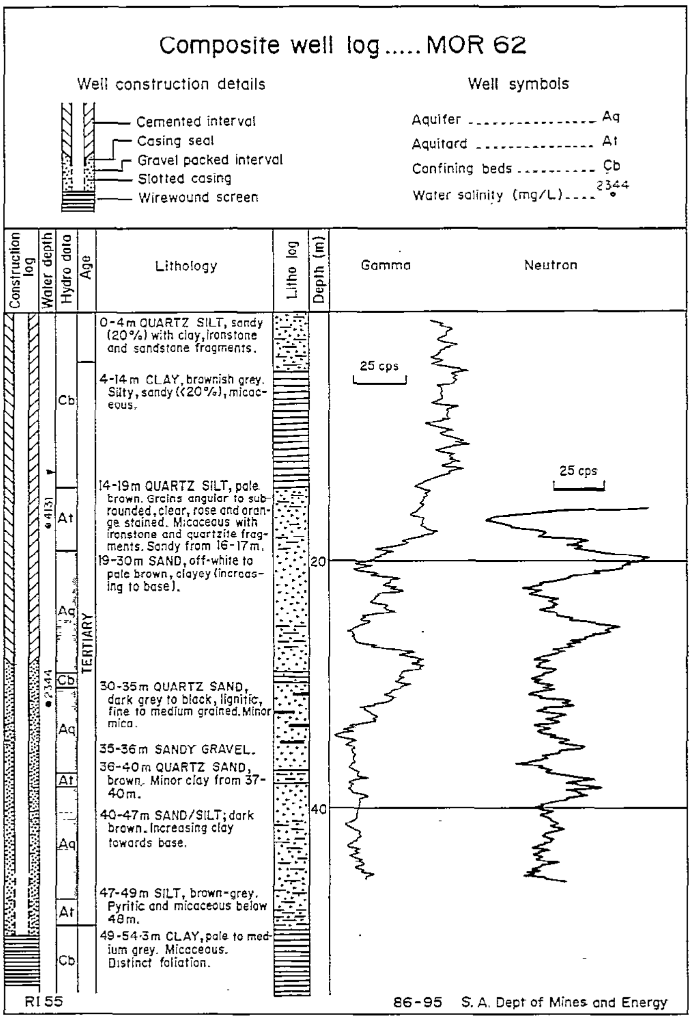
APPENDIX 1

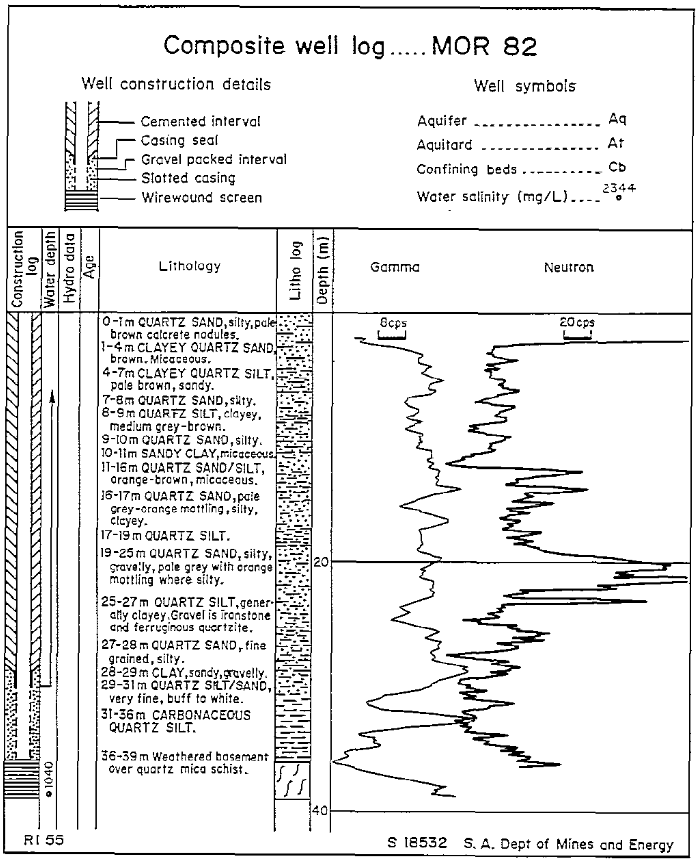
Composite well logs

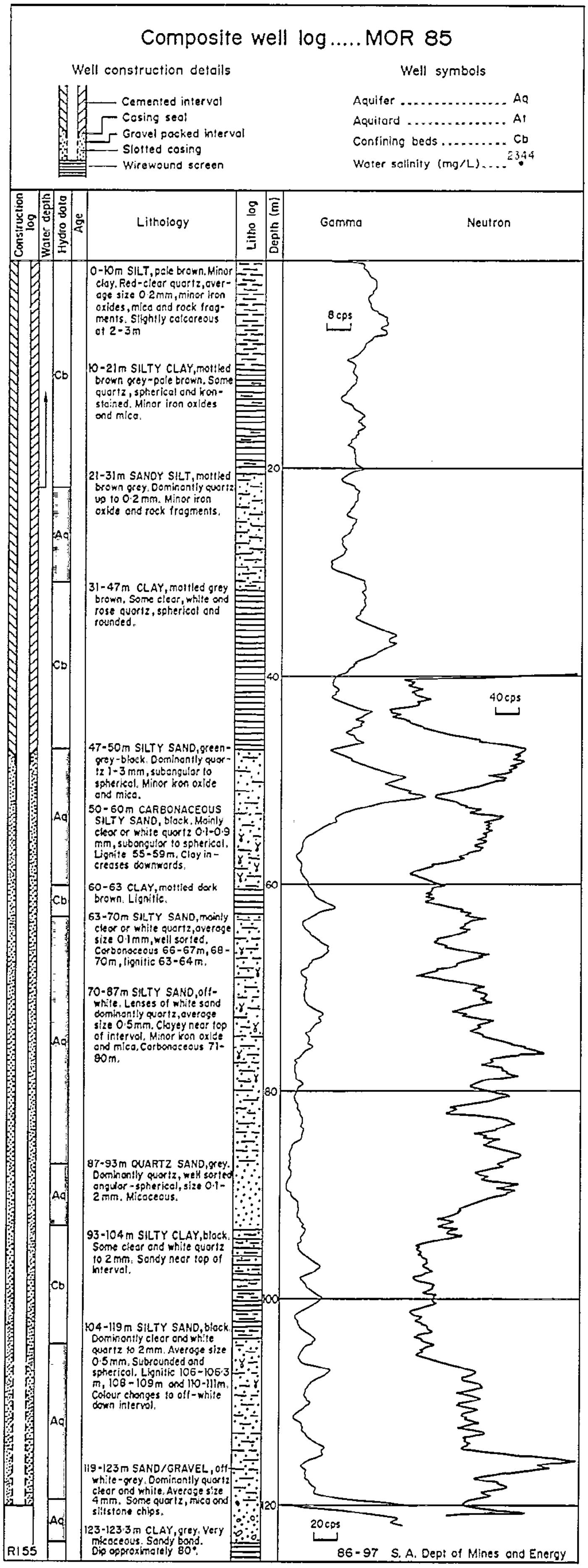
Well locations are shown in Fig. 69.

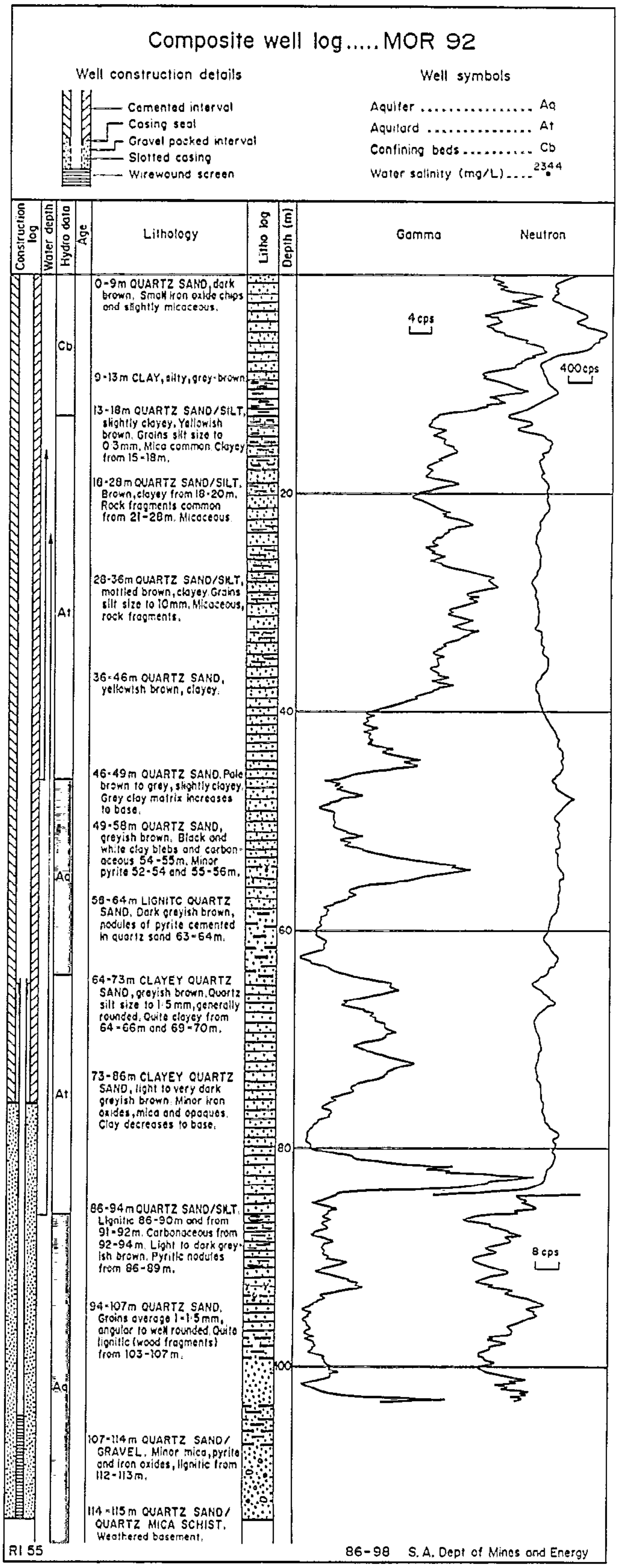
Figs 29 to 34

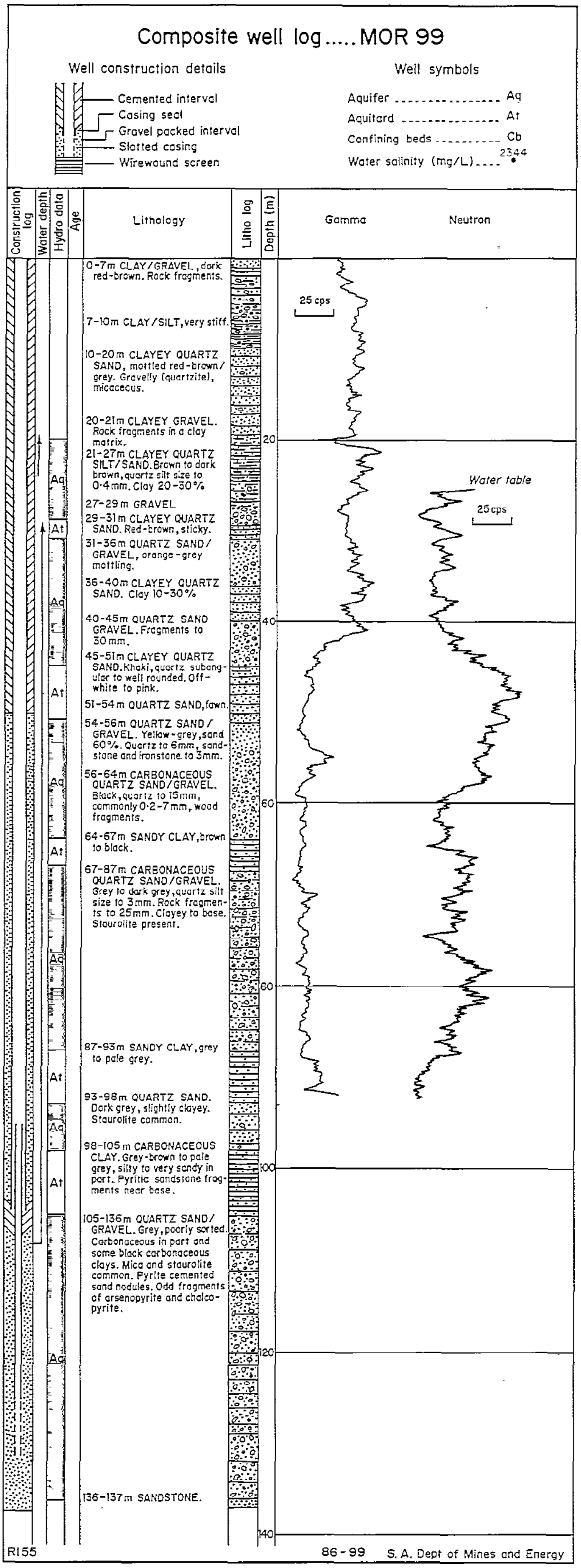







Composite well log.....MOR 85
Well construction details
Cemented interval
Casing seal
Gravel packed interval
Slotted casing
Wirewound screen
Well symbols
Aquifer .... Aq
Aquitard .... At
Confining beds .... Cb
Water salinity (mg/L).... 2344
Construction log
Water depth
Hydro data
Age
Lithology
Litho log
Depth (m)
Gamma
Neutron
0-10m SILT, pale brown. Minor clay. Red-clear quartz, average size 0·2mm, minor iron oxides, mica and rock fragments. Slightly calcareous at 2-3m
10-21m SILTY CLAY, mottled brown grey-pale brown. Some quartz, spherical and iron-stained. Minor iron oxides and mica.
21-31m SANDY SILT, mottled brown grey. Dominantly quartz up to 0·2 mm. Minor iron oxide and rock fragments.
31-47m CLAY, mottled grey brown. Some clear, white and rose quartz, spherical and rounded.
47-50m SILTY SAND, green-grey-black. Dominantly quartz 1-3 mm, subangular to spherical. Minor iron oxide and mica.
50-60m CARBONACEOUS SILTY SAND, black. Mainly clear or white quartz 0·1-0·9 mm, subangular to spherical. Lignite 55-59m. Clay increases downwards.
60-63 CLAY, mottled dark brown. Lignitic.
63-70m SILTY SAND, mainly clear or white quartz, average size 0·1mm, well sorted. Carbonaceous 66-67m, 68-70m, lignitic 63-64m.
70-87m SILTY SAND, off-white. Lenses of white sand dominantly quartz, average size 0·5mm. Clayey near top of interval. Minor iron oxide and mica. Carbonaceous 71-80m.
87-93m QUARTZ SAND, grey. Dominantly quartz, well sorted angular-spherical, size 0·1-2 mm. Micaceous.
93-104m SILTY CLAY, black. Some clear and white quartz to 2mm. Sandy near top of interval.
104-119m SILTY SAND, black. Dominantly clear and white quartz to 2mm. Average size 0·5mm. Subrounded and spherical. Lignitic 106-106·3 m, 108-109m and 110-111m. Colour changes to off-white down interval.
119-123m SAND/GRAVEL, off-white-grey. Dominantly quartz clear and white. Average size 4mm. Some quartz, mica and siltstone chips.
123-123·3m CLAY, grey. Very micaceous. Sandy band. Dip approximately 80°.
Cb
Aq
Cb
Aq
Cb
Aq
Aq
Cb
Aq
Aq
20
40
60
80
100
120
8 cps
40 cps
20 cps
RI 55
86-97 S. A. Dept of Mines and Energy


Composite well log.....MOR 92
Well construction details
Cemented interval
Casing seal
Gravel packed interval
Slotted casing
Wirewound screen
Well symbols
Aquifer .... Aq
Aquitard .... At
Confining beds .... Cb
Water salinity (mg/L).... 2344
Construction log
Water depth
Hydro data
Age
Lithology
Litho log
Depth (m)
Gamma
Neutron
0-9m QUARTZ SAND, dark brown. Small iron oxide chips and slightly micaceous.
9-13m CLAY, silty, grey-brown.
13-18m QUARTZ SAND/SILT, slightly clayey. Yellowish brown. Grains silt size to 0·3mm. Mica common. Clayey from 15-18m.
18-28m QUARTZ SAND/SILT. Brown, clayey from 18-20m. Rock fragments common from 21-28m. Micaceous.
28-36m QUARTZ SAND/SILT, mottled brown, clayey. Grains silt size to 10mm. Micaceous, rock fragments.
36-46m QUARTZ SAND, yellowish brown, clayey.
46-49m QUARTZ SAND. Pale brown to grey, slightly clayey. Grey clay matrix increases to base.
49-58m QUARTZ SAND, greyish brown. Black and white clay blebs and carbonaceous 54-55m. Minor pyrite 52-54 and 55-56m.
58-64m LIGNITC QUARTZ SAND. Dark greyish brown, nodules of pyrite cemented in quartz sand 63-64m.
64-73m CLAYEY QUARTZ SAND, greyish brown. Quartz silt size to 1·5 mm, generally rounded. Quite clayey from 64-66m and 69-70m.
73-86m CLAYEY QUARTZ SAND, light to very dark greyish brown. Minor iron oxides, mica and opaques. Clay decreases to base.
86-94m QUARTZ SAND/SILT. Lignitic 86-90m and from 91-92m. Carbonaceous from 92-94m. Light to dark greyish brown. Pyritic nodules from 86-89m.
94-107m QUARTZ SAND. Grains average 1-1·5mm, angular to well rounded. Quite lignitic (wood fragments) from 103-107m.
107-114m QUARTZ SAND/GRAVEL. Minor mica, pyrite and iron oxides, lignitic from 112-113m.
114-115m QUARTZ SAND/QUARTZ MICA SCHIST. Weathered basement.
Cb
At
Aq
At
Aq
20
40
60
80
100
4 cps
400 cps
8 cps
RI 55
86-98 S. A. Dept of Mines and Energy


Composite well log.....MOR 99
Well construction details
Cemented interval
Casing seal
Gravel packed interval
Slotted casing
Wirewound screen
Well symbols
Aquifer .... Aq
Aquitard .... At
Confining beds .... Cb
Water salinity (mg/L).... 2344
Construction log
Water depth
Hydro data
Age
Lithology
Litho log
Depth (m)
Gamma
Neutron
0-7m CLAY/GRAVEL, dark red-brown. Rock fragments.
7-10m CLAY/SILT, very stiff.
10-20m CLAYEY QUARTZ SAND, mottled red-brown/grey. Gravelly (quartzite), micaceous.
20-21m CLAYEY GRAVEL. Rock fragments in a clay matrix.
21-27m CLAYEY QUARTZ SILT/SAND. Brown to dark brown, quartz silt size to 0·4mm. Clay 20-30%
27-29m GRAVEL
29-31m CLAYEY QUARTZ SAND. Red-brown, sticky.
31-36m QUARTZ SAND/GRAVEL, orange-grey mottling.
36-40m CLAYEY QUARTZ SAND. Clay 10-30%
40-45m QUARTZ SAND GRAVEL. Fragments to 30mm.
45-51m CLAYEY QUARTZ SAND. Khaki, quartz subangular to well rounded. Off-white to pink.
51-54m QUARTZ SAND, fawn.
54-56m QUARTZ SAND/GRAVEL. Yellow-grey, sand 60%. Quartz to 6mm, sandstone and ironstone to 3mm.
56-64m CARBONACEOUS QUARTZ SAND/GRAVEL. Black, quartz to 15mm, commonly 0·2-7mm, wood fragments.
64-67m SANDY CLAY, brown to black.
67-87m CARBONACEOUS QUARTZ SAND/GRAVEL. Grey to dark grey, quartz silt size to 3mm. Rock fragments to 25mm. Clayey to base. Staurolite present.
87-93m SANDY CLAY, grey to pale grey.
93-98m QUARTZ SAND. Dark grey, slightly clayey. Staurolite common.
98-105m CARBONACEOUS CLAY. Grey-brown to pale grey, silty to very sandy in part. Pyritic sandstone fragments near base.
105-136m QUARTZ SAND/GRAVEL. Grey, poorly sorted. Carbonaceous in part and some black carbonaceous clays. Mica and staurolite common. Pyrite cemented sand nodules. Odd fragments of arsenopyrite and chalcopyrite.
136-137m SANDSTONE.
Aq
At
Aq
At
Aq
At
Aq
At
Aq
At
Aq
20
40
60
80
100
120
140
25 cps
Water table
25cps
RI55
86-99
S. A. Dept of Mines and Energy

APPENDIX 2

Surface Water Resources

The Barossa Valley surface drainage system is dominated by the North Para River and its major tributaries: Duck Ponds, Bethany (Tanunda), Angaston, and Jacob Creeks. Other minor tributaries rise in the eastern ranges and a few small creeks from the west. The northern portion of the Valley is drained by St Kitts and Stockwell Creeks, tributaries of the Light River.

Flow is intermittent, and it does not always reach Nuriootpa in the main channel of the North Para River; annual discharge has been recorded at over 60 times the minimum.

Gauging sites

Six gauging sites were established, four on the main channel of the North Para River and one each on Jacob and Tanunda Creeks (Fig. 17). Staff gauges were installed in 1975 and low concrete weirs were constructed in 1977 to provide a better control on low-flow readings and to ensure the staff was always at the lowest point in the channel. Rating of each staff was by current meter but the data collected was limited because:

- the equipment prevented rating above a staff gauge reading of around 1 m; thus all stage readings above this have been converted to discharge using extrapolation of the low flow gaugings.
- operators were based in Adelaide for the first few years and useful flows were not always rated.
- there were significant periods when no suitable flow was encountered.
- early data was often of poor quality.

River stage was read daily although this was only rigorous from 1979. In periods of peak flow several readings a day were obtained whenever possible. No rating curve is available for the North Para River-Tanunda staff through lack of data.

Discharge

Daily river stages in metres have been plotted. This is the stage recorded at the time of the staff gauge reading and does not necessarily reflect the peak stage for that day. If several readings on any one day were noted then the highest is shown. River stages are shown here since the rating curves for each gauge are extrapolations above a metre. When the higher part of the rating curves are confirmed then river discharges can be obtained with confidence. Approximate discharges using the rating curves have been used to prepare flow duration curves for each site (see later).

The most obvious feature is the very wide range in recorded stages both between years and in any one year. Modified flow duration curves for the various sites (that is, the percentage of recorded discharges that exceed a particular value of discharge) show that high flows are rare events, making up only a very small percentage of noted flows. This has obvious implications for disposal of wastes into tributaries at times of high flows. Note that these graphs do not contain zero discharges; if these periods of no flow were included then the position becomes much worse with high flows becoming even rarer events.

Salinity

Simultaneously with staff gauge readings a water sample was obtained for laboratory testing of conductivity or conductivity was measured directly in the field. Data for the early years is incomplete but data for 1979 and 1980 are good. The poor quality of the water early in the year is caused by the dominance of groundwater base flow and the solution of soil salts. As surface runoff increases, quality improves until later in the season when the gradual rise in salinity reflects the increasing contribution of base flow.

Using the data available for each site conductivity/duration curves have been prepared (Fig. 50). These show the percentage of times that a particular conductivity (salinity) was exceeded and indicate that Jacob Creek is consistently of better quality than any other stream and the North Para River at Tanunda is the worst. It is obvious from the curve for Stockwell Bridge that the quality of the water lost by infiltration to the water table is not always good and any change in the hydrological regime that would worsen quality could have long term repercussions. The median conductivities are given on Figure 9 and show some interesting features:

- the poor quality of Duck Ponds Creek compared with the North Para coming down from Flaxmans Valley and the effect on their combined flows.
- the rapid deterioration of water quality between Nuriootpa and Tanunda gauging sites; this is further shown by a salinity traverse conducted during a period of low flow early in 1979 (Fig. 51). The contribution of groundwater to the poor quality of the low flows from Nuriootpa to Yaldara weir is obvious.
- improvements in water quality in the North Para by Tanunda and Jacob Creeks.

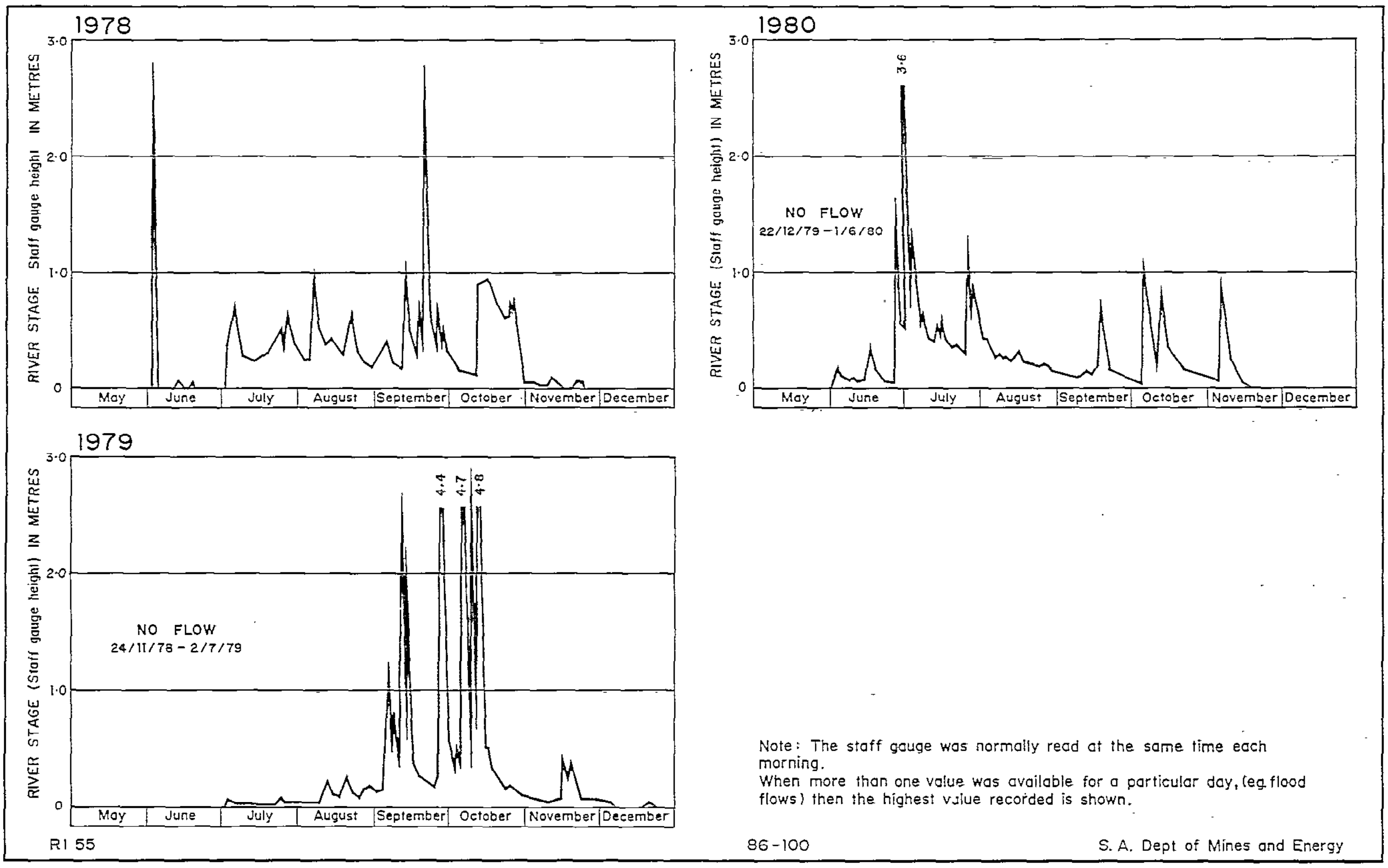


Fig. 35 Stockwell Road staff gauge: river stages 1978-80

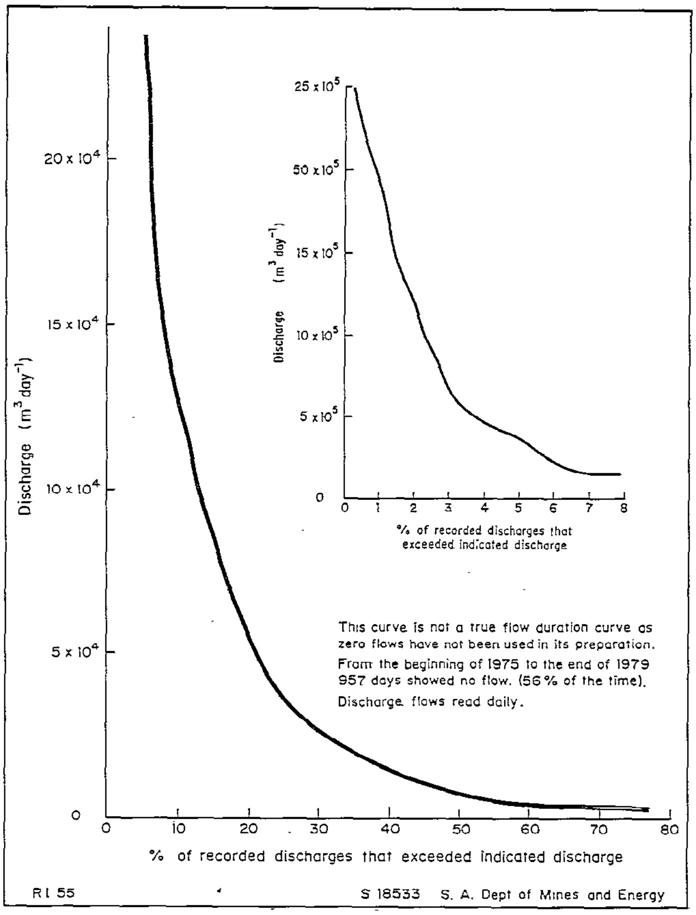


Fig. 36 Stockwell Road staff gauge: modified flow duration curve

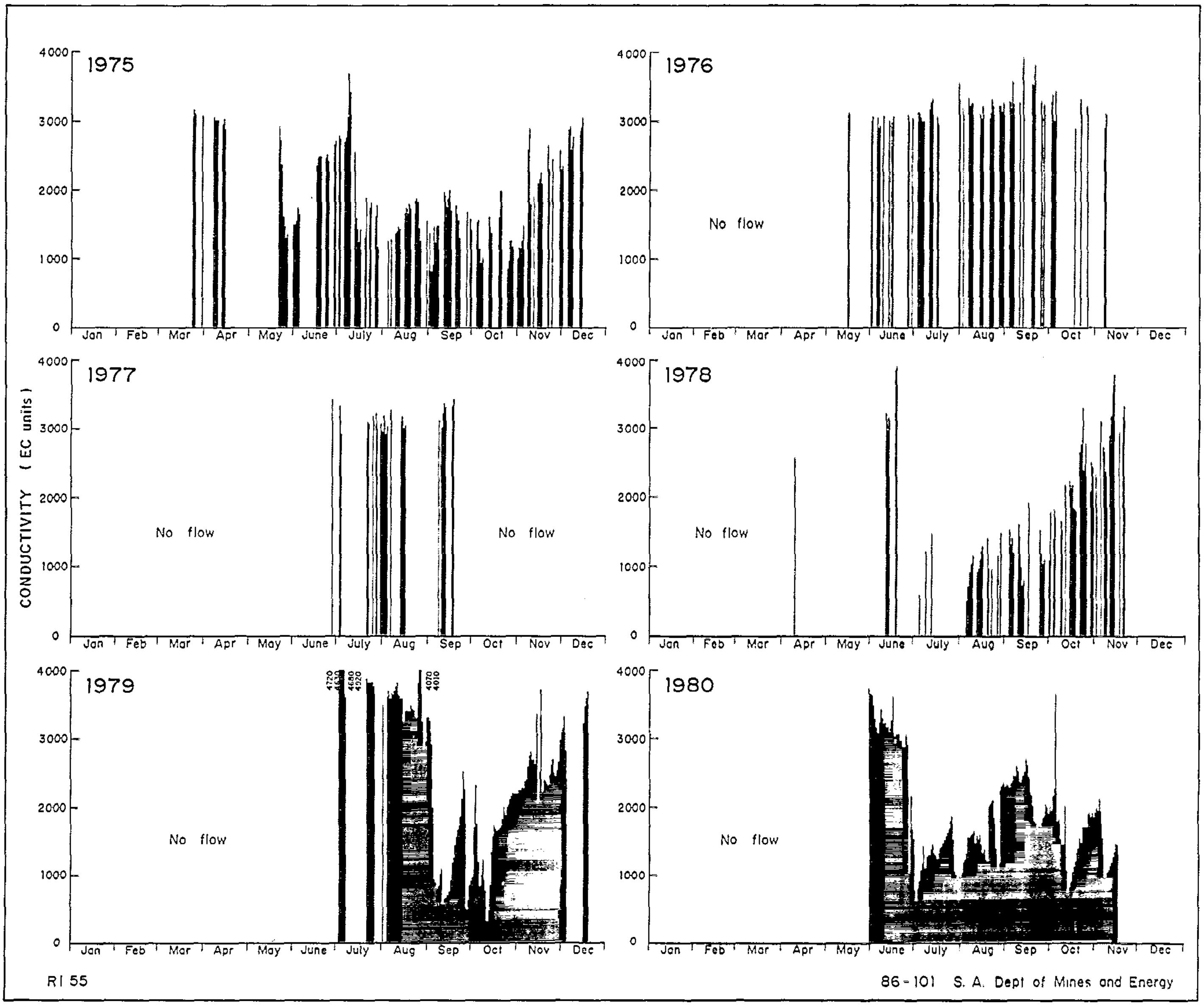


Fig. 37 Stockwell Road staff gauge: time/conductivity graphs 1975-80

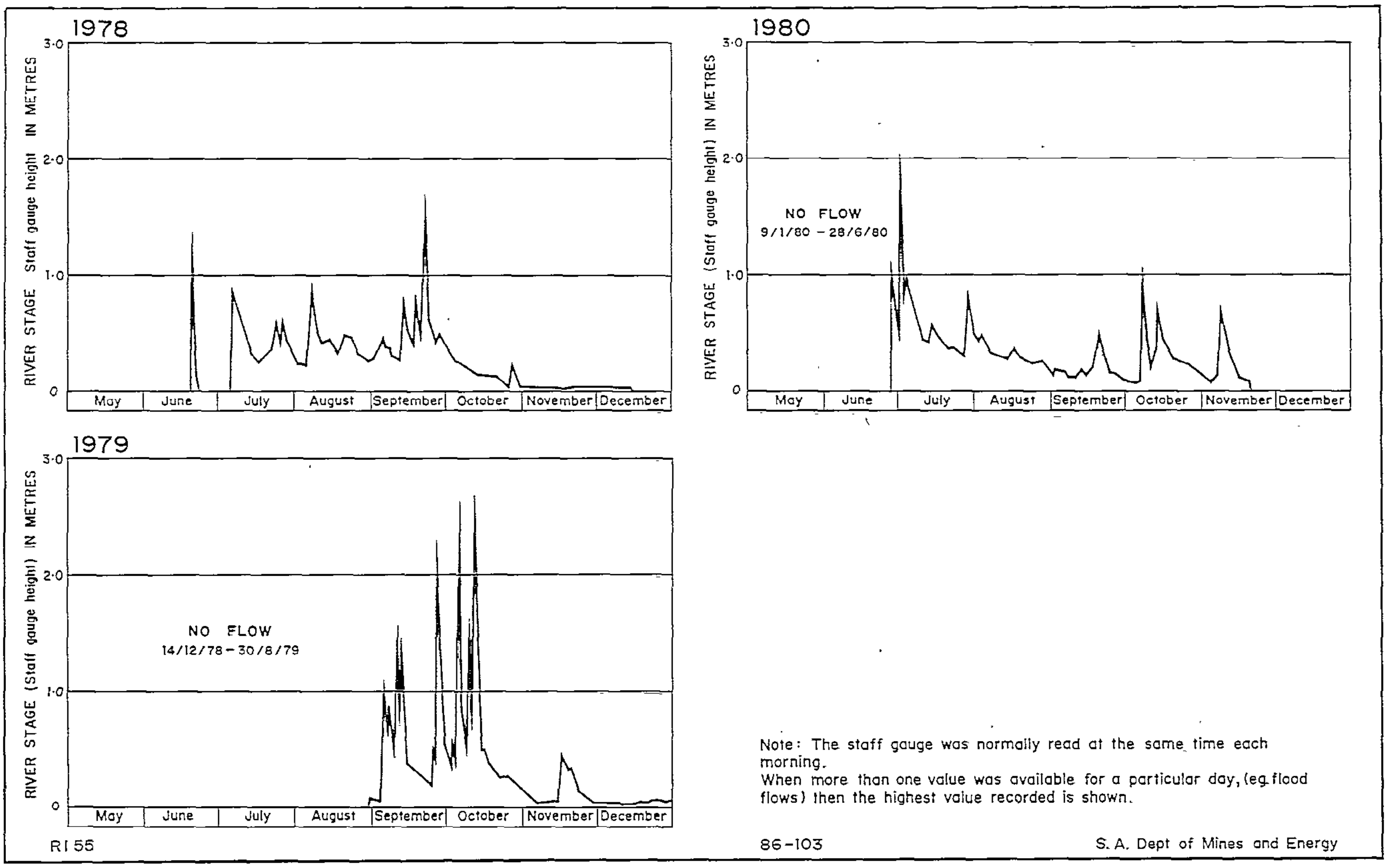


Fig. 38 Nuriootpa staff gauge: river stages 1978-80

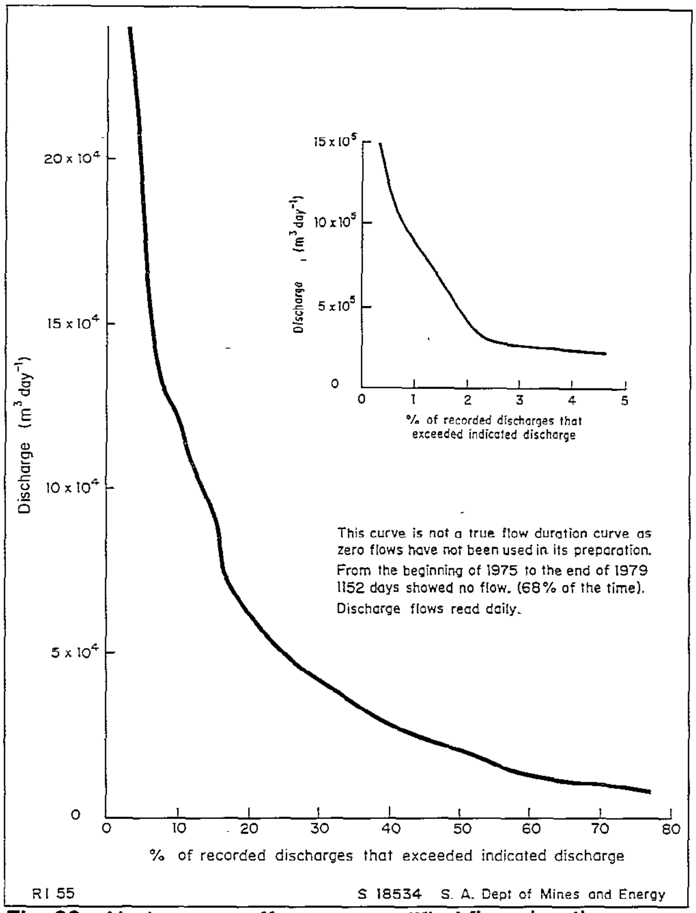


Fig. 39 Nuriootpa staff gauge: modified flow duration curve

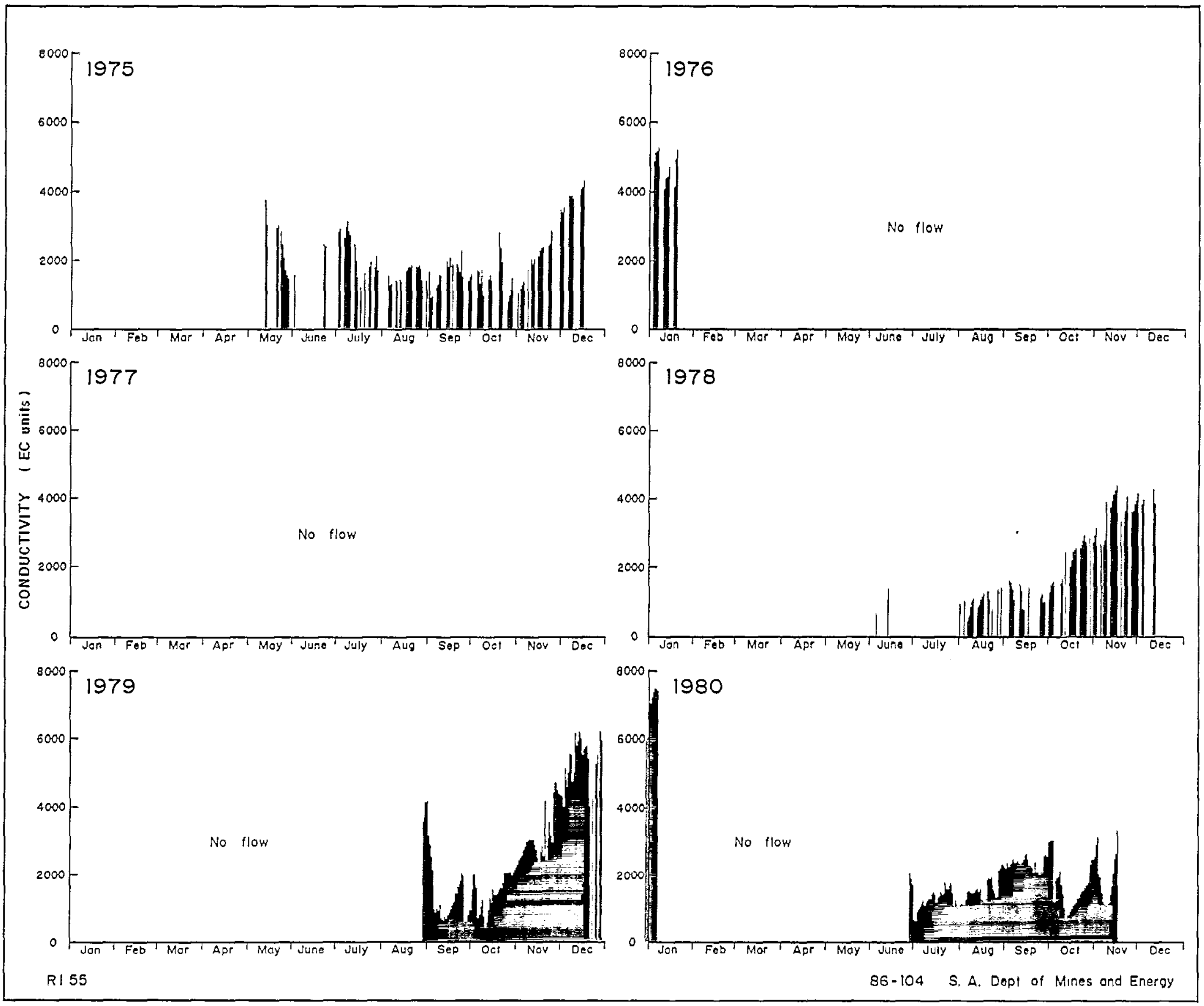


Fig. 40 Nuriootpa staff gauge: time/conductivity graphs 1975-80

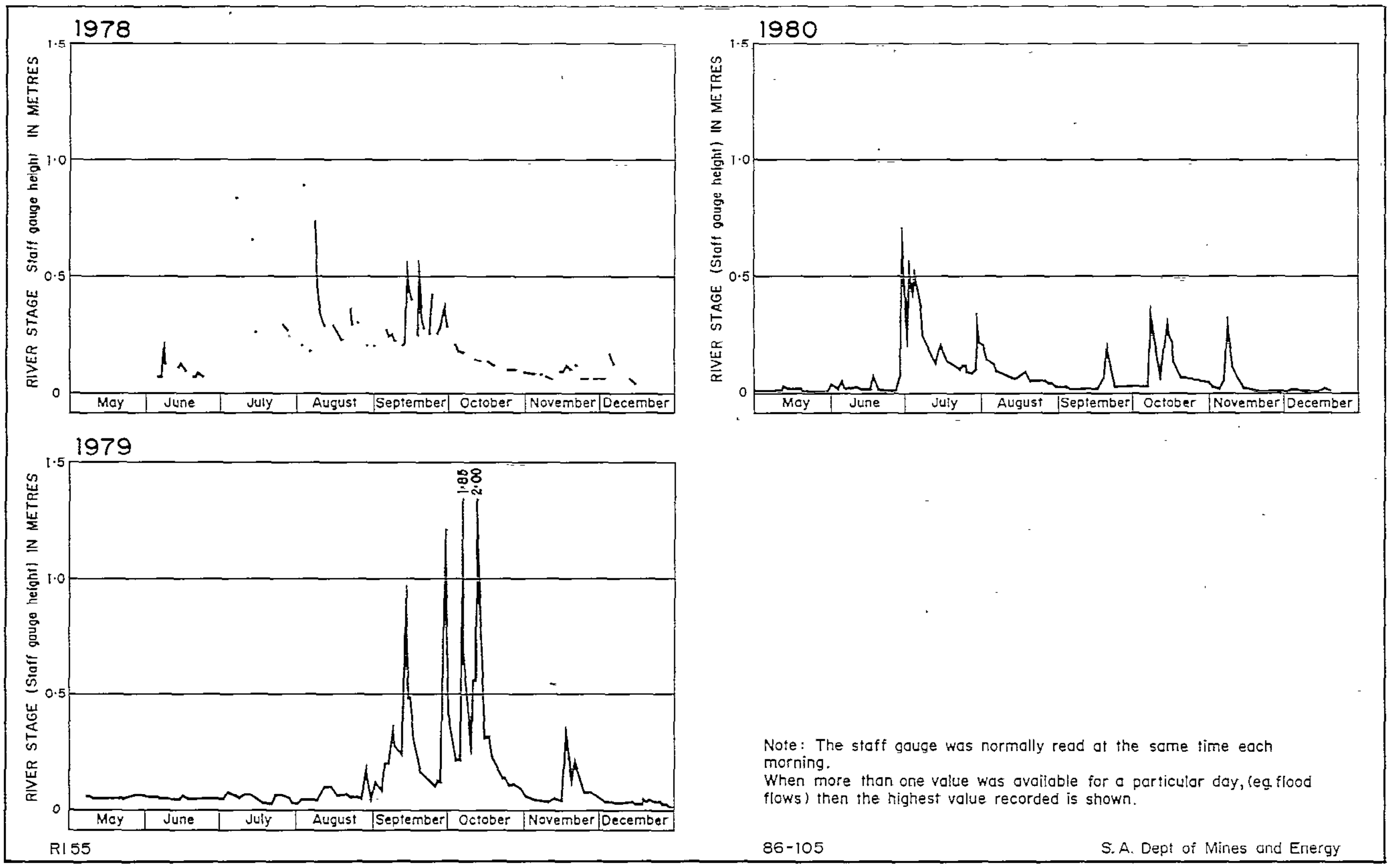


Fig. 41 Tanunda staff gauge: river stages 1978-80

Note: Insufficient data for a modified flow duration curve

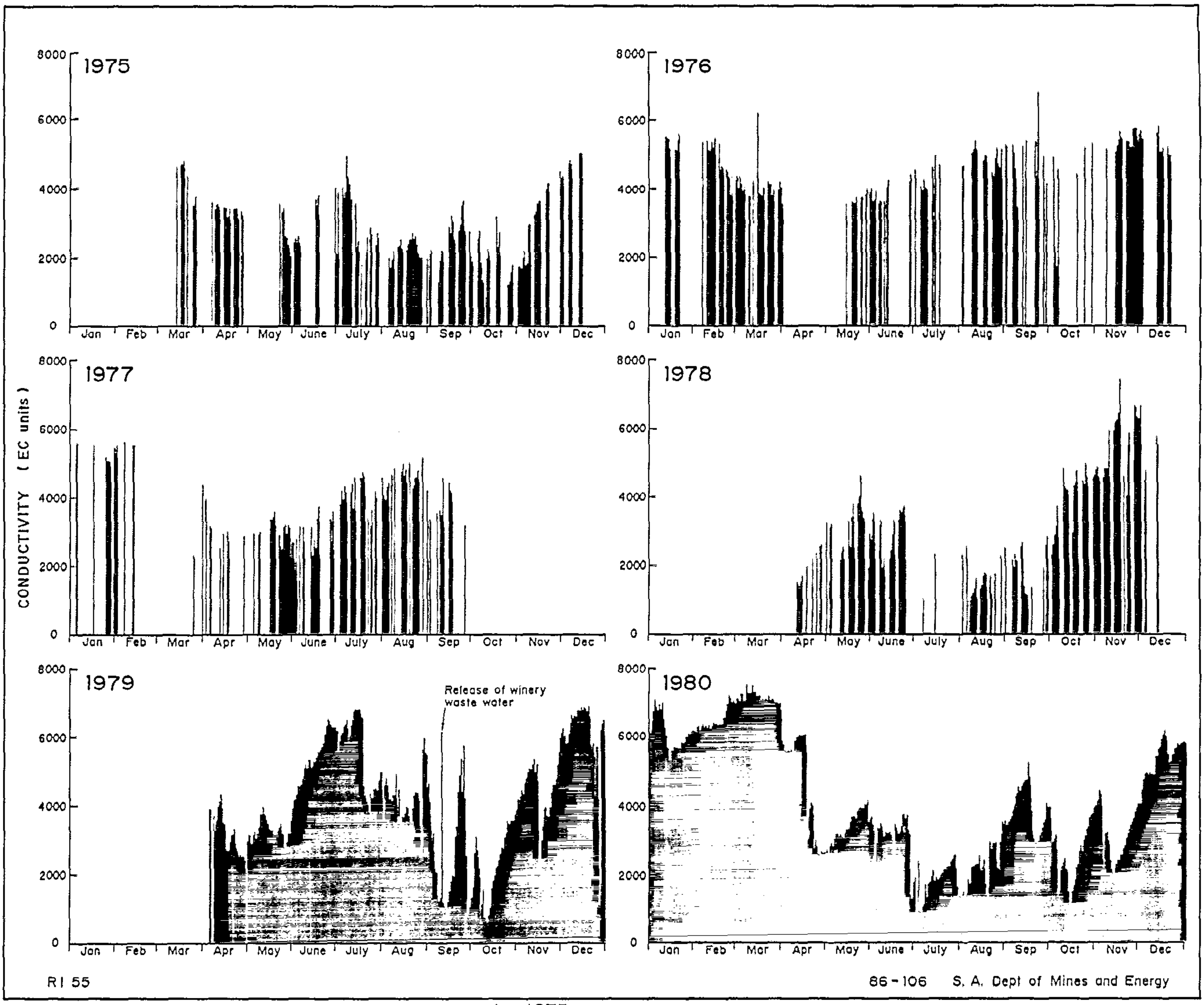


Fig. 42 Tanunda staff gauge: time/conductivity graphs 1975-80

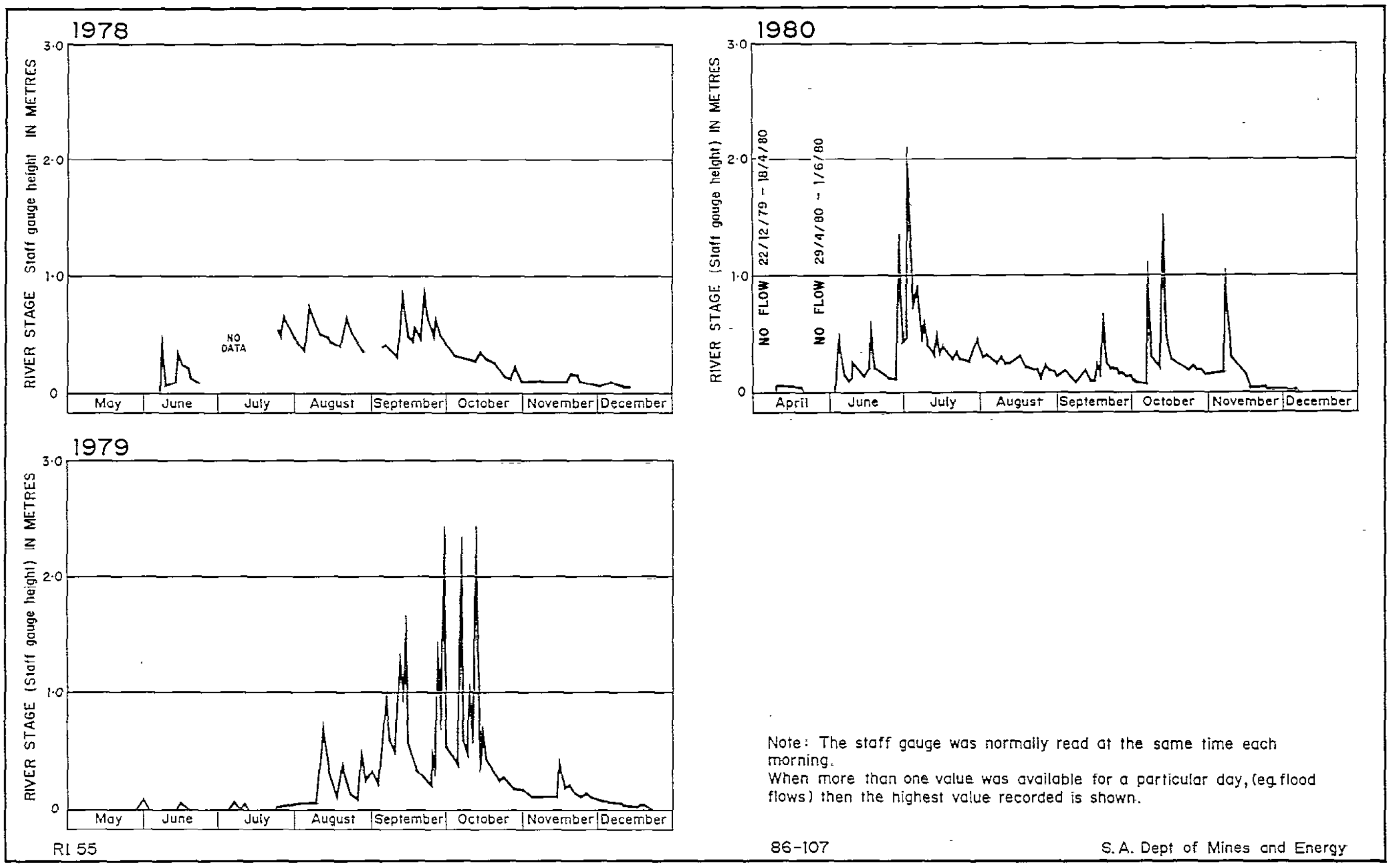


Fig. 43 Tanunda Creek staff gauge: river stages 1978-80

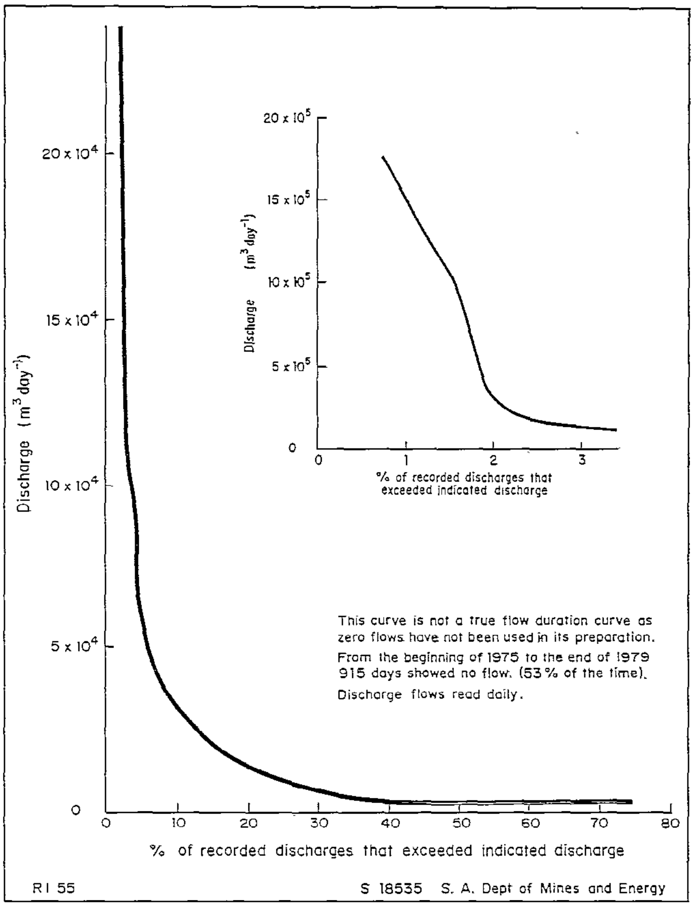


Fig. 44 Tanunda Creek staff gauge: modified flow duration curve

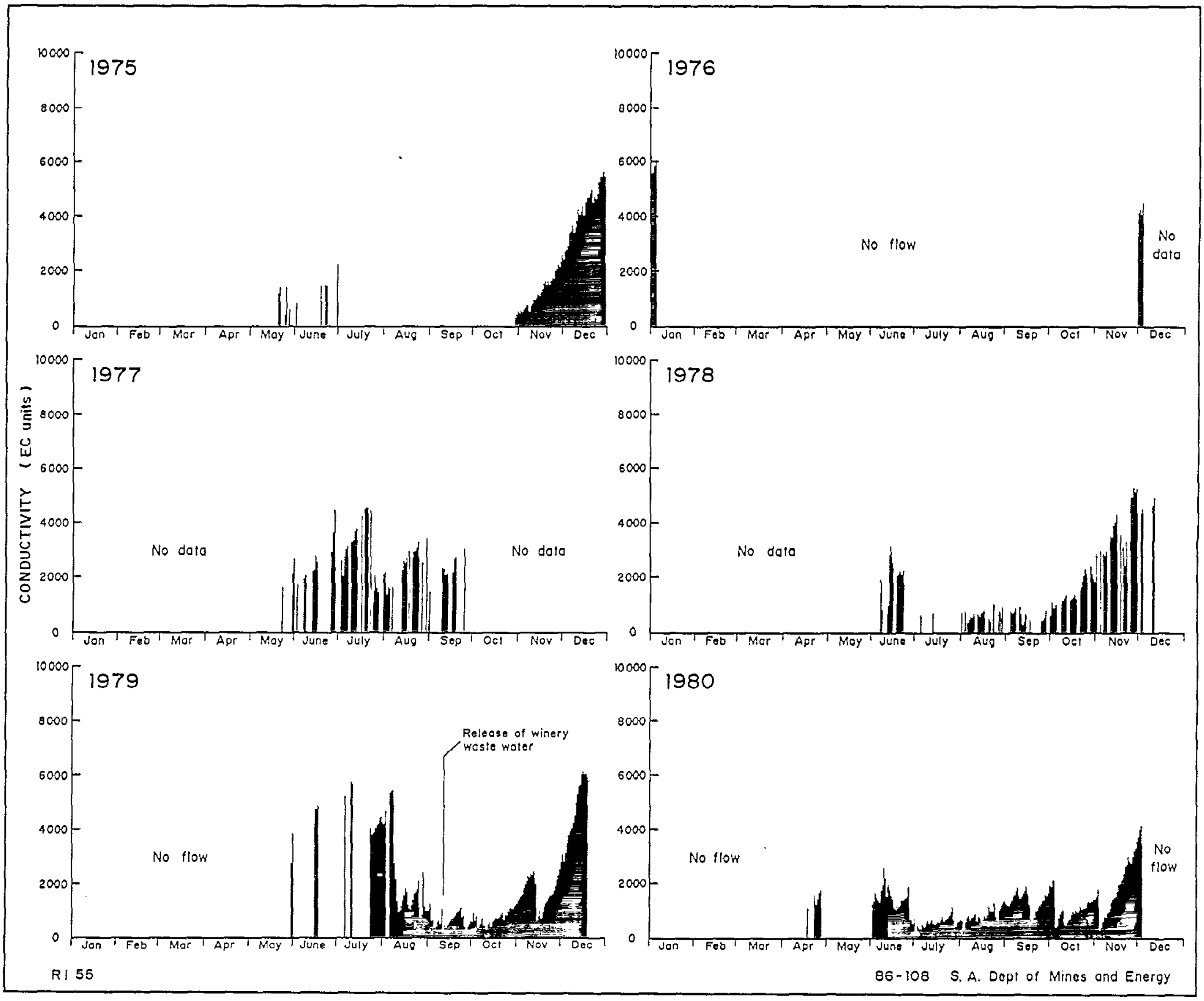


Fig. 45 Tanunda Creek staff gauge: time/conductivity graphs 1975-80

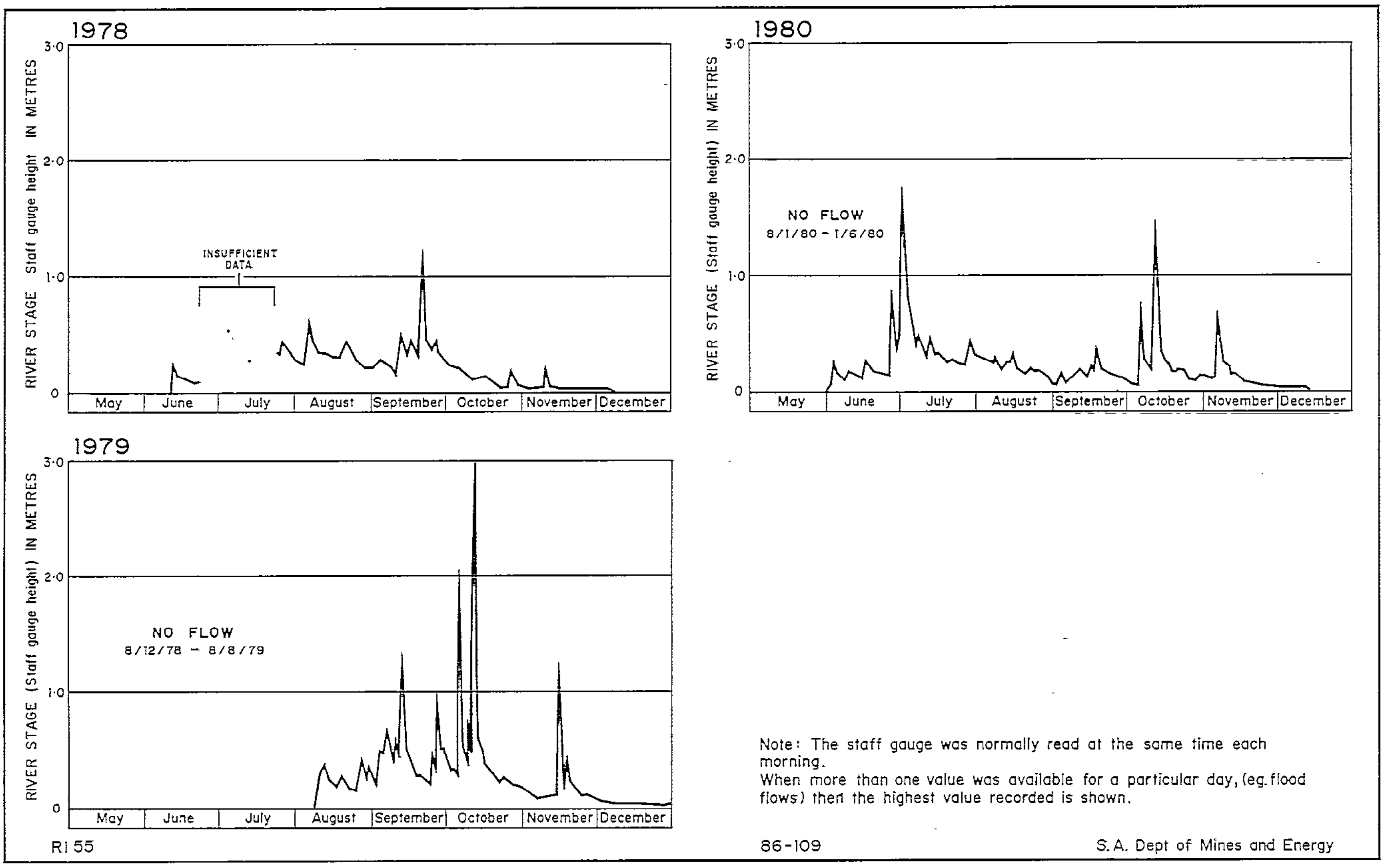


Fig. 46 Jacob Creek staff gauge: river stages 1978-80

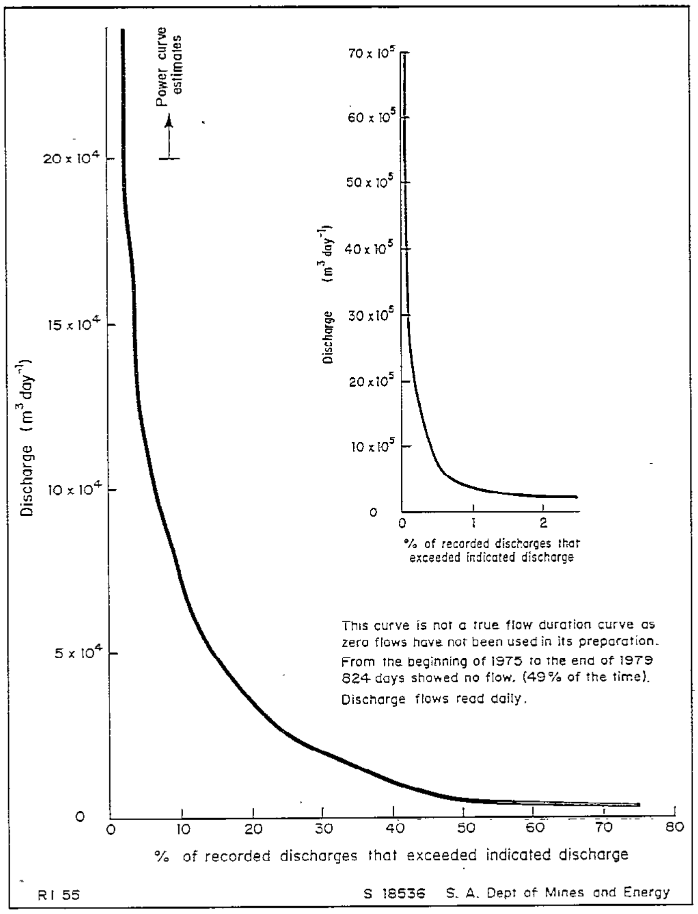


Fig. 47 Jacob Creek staff gauge: modified flow duration curve

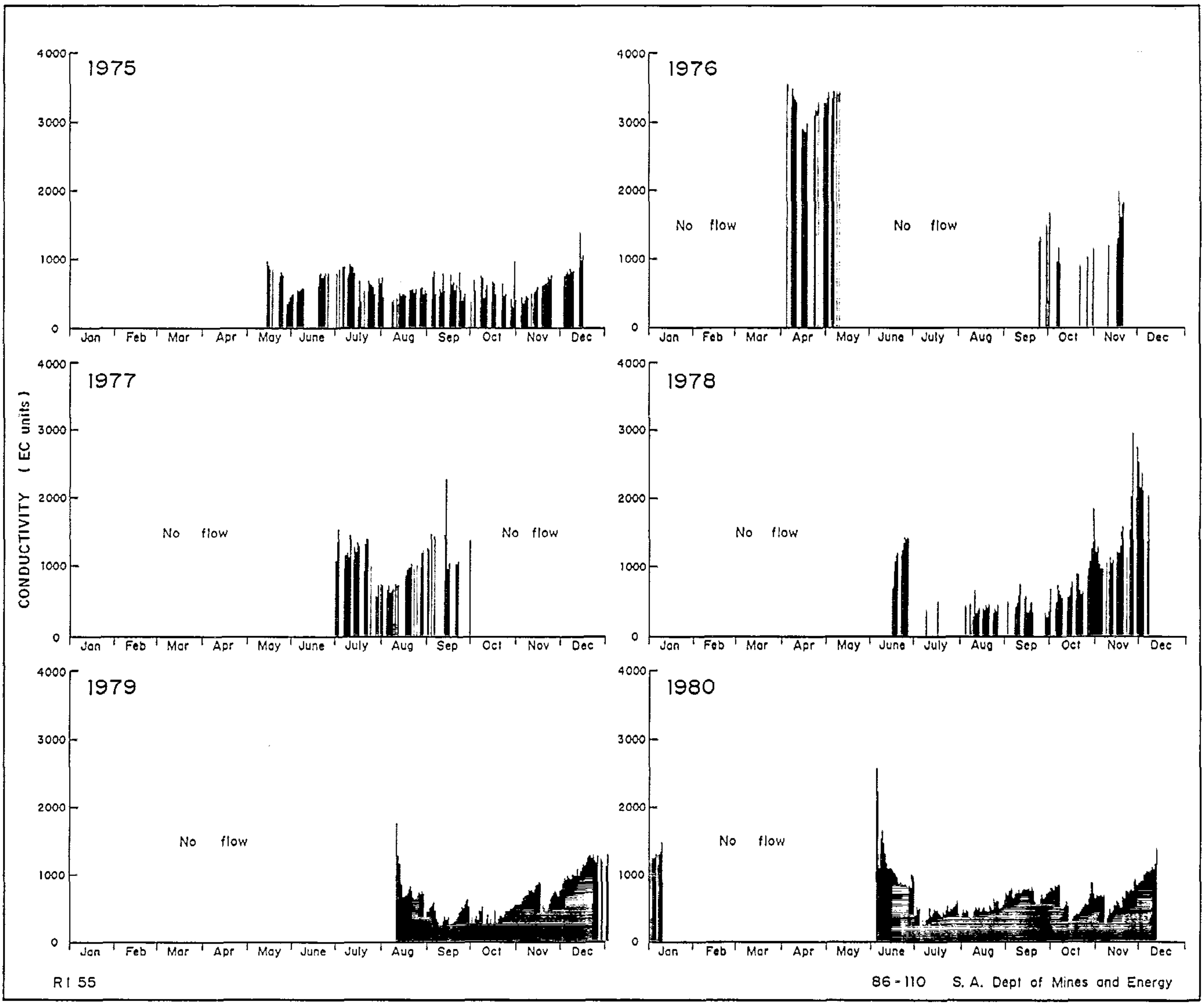


Fig. 48 Jacob Creek staff gauge: time/conductivity graphs 1975-80

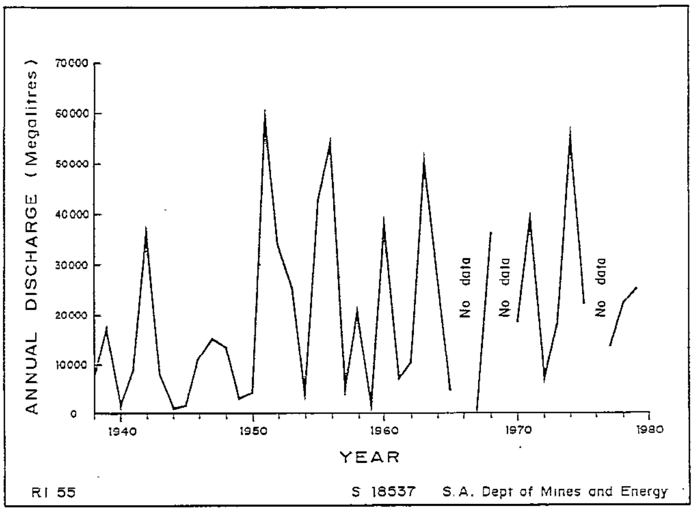


Fig. 49 Yaldara Weir: annual discharge 1938-79

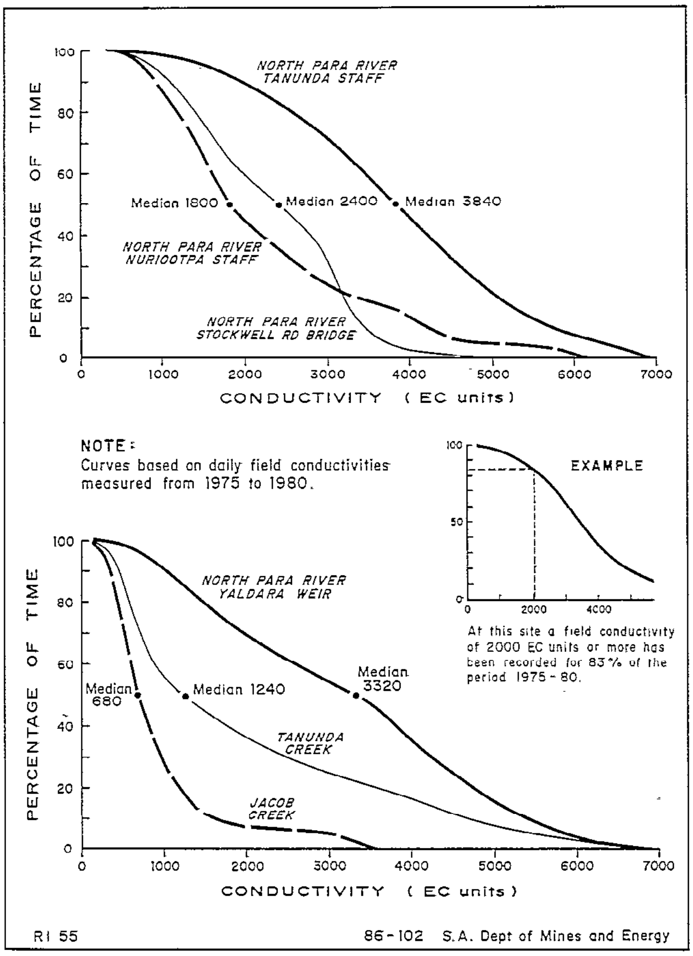


Fig. 50 North Para River, Tanunda Creek and Jacob Creek: conductivity/duration curves

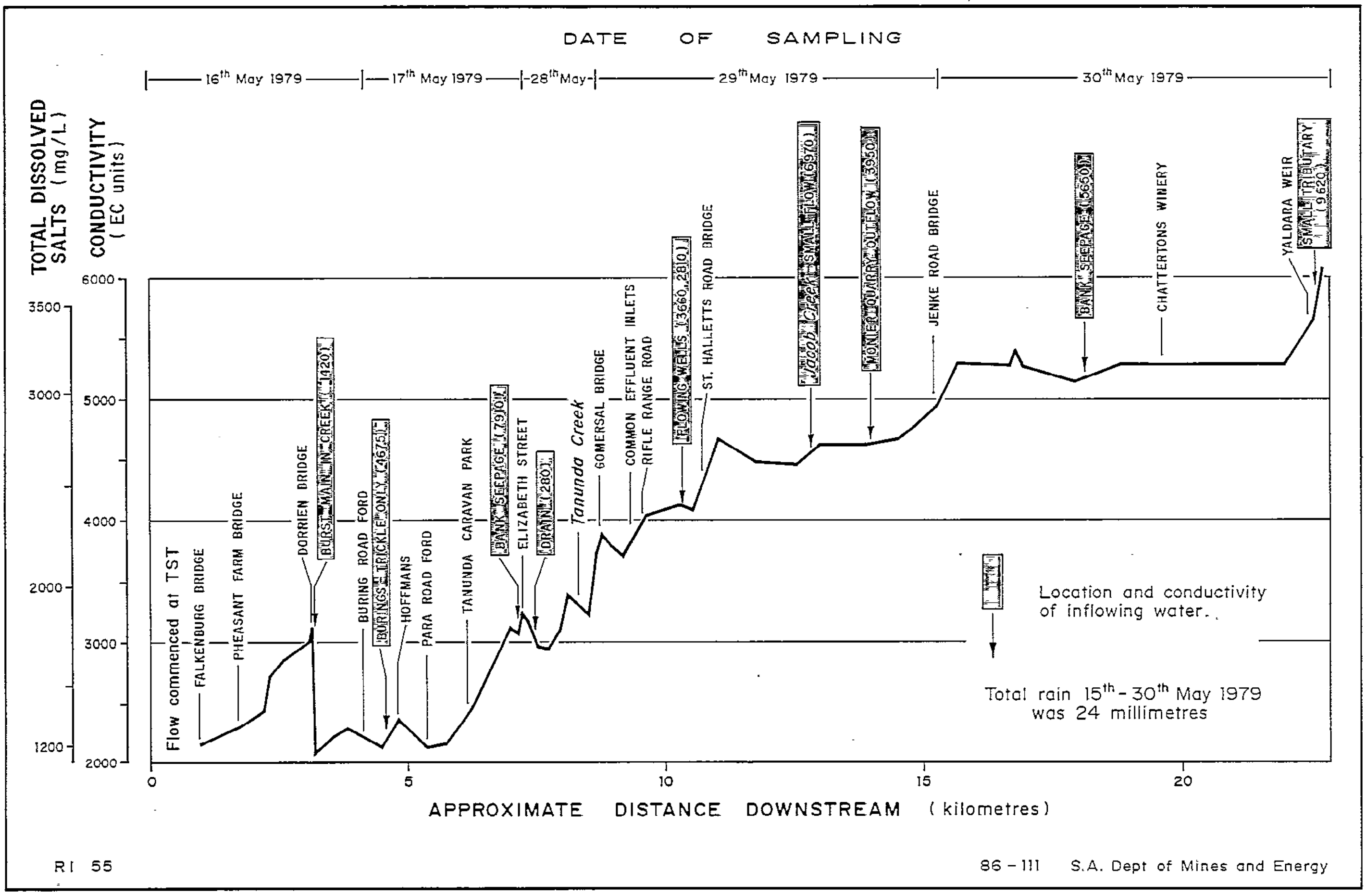


Fig. 51 North Para River: conductivity profile for May 1979

APPENDIX 3

Determination of Aquifer Parameters

To understand the groundwater flow regime of the Barossa Valley sediments it is necessary to have estimates of spatial variations in hydraulic parameters of each of the aquifers and their confining beds. The parameters required are the Transmissivity (T) and Storage Coefficient (S) of each aquifer (and their regional variations) and the leakage characteristics of any confining bed.

Such values can be determined in one of three ways:

1. Aquifer tests: Using a well and one or more observation wells allows the calculation of T, S and, under favourable conditions, the leakage characteristics of any confining bed.
2. Well tests: Similar to (1) but with no observation wells, these allow calculation of T but not S and are less reliable.
3. Drilling: Push tube cores collected during a drilling programme can be subjected to laboratory testing, particularly for vertical hydraulic conductivity (k) and porosity (n) but the small volume sampled is an inherent problem. Results from the drilling programme are given in Table 11.

AQUIFER TESTS

Two aquifer tests were conducted during the investigation, one in each of the two main aquifers. In an attempt to measure any leakage that could occur between the two aquifers under the stress of pumping, the tests were performed at one site immediately adjacent to Section 90, hundred of Moorooroo at the Lights Pass-Diagonal Road intersection (Fig. 1). Construction details of the pumping and observation wells and the types and durations of tests are given in Tables 7 and 8.

During testing of the middle aquifer using well MOR93, observation wells in the water-table aquifer, the middle aquifer and the lower aquifer were monitored. Similarly during the testing of the lower aquifer using well MOR92, all observation wells were again monitored.

Regional fluctuations in water level

To allow for the impact of any variation in regional water levels on the water levels measured during testing, all observation and pumped wells were monitored for periods before and after testing. Since regional water levels were declining during both aquifer tests, measured drawdowns had to be reduced by an amount obtained from the hydrographs. The values used are listed below (for well locations refer to Fig. 69).

Partial Penetration

Pumping test analysis assumes groundwater flow is horizontal. Where the screen length is less than the aquifer thickness then the well is considered to be partially penetrating and vertical flow components exist close to the well. These vertical flow components, which affect drawdowns measured in the observation wells, are considered to extend from the pumping well to a radius (r) equal to twice the aquifer thickness D.

In practice it is often found that the effects on measured drawdowns, especially with long pumping times, is small in the area of $D<r<2D$.

In this case the middle aquifer thickness can be taken as 24 m and the lower aquifer thickness 39 m. Inspection of Table 7 shows that, of the relevant observation wells, only MOR97 should show any effects ($r=40.2$ m, $D=39.0$ m). However, on a semi-log time-drawdown analysis, a correction only has to be made during the calculation of Storage Coefficient (S) not of Transmissivity (T).

Pumping Rate

During the tests discharge was measured by an in-line meter. The pumping rate was relatively constant during the MOR93 test but declined continuously during testing of MOR92 (lower aquifer) - see Figure 53. A method of analysis has been included to correct for this effect.

Results

After correction of the field data for exterior effects, the corrected data were interpreted by applicable methods. The results obtained and the methods used are presented in Table 9 and the corresponding data plots on Figures 54 to 62. Water quality changes during pumping are plotted on Figures 57 and 60.

WELL TESTS

Well tests consist of monitoring the drawdown in a pumped well and interpreting the results to obtain a value for the Transmissivity (T). Permission was obtained from eight landowners to monitor their wells when first switched on in the 1978-79 irrigation season. The tests generally ran for 60 minutes followed by recovery and the data were analysed by the method of Cooper and Jacob (1946). The largest error in the calculation involves the use of a landowners estimate of the pumping rate since discharge meters are seldom installed on irrigation wells.

The results obtained from the tests are given in Table 10.

LABORATORY TESTS

During the Departmental drilling programme push tube cores were taken at selected intervals and delivered to the E&WS Department's soils laboratory at Netley. The results obtained for moisture content, dry density, hydraulic conductivity (vertical) and porosity are given in Table 11.

Observation Well		Drawdown reduced at rate of
	MIDDLE AQUIFER TEST (pump well MOR93)	
MOR93 and 96		2 mm per hour
MOR92 and 97		14 mm per hour
	LOWER AQUIFER TEST (pump well MOR92)	
MOR92 and 97		20 mm per hour
MOR93, 96, 75		3 mm per hour

Table 7. Pumped and observation well details

Observation Well No.	Total depth (m)	Screened/ slotted (m)	Aquifer monitored	Function	Distance from MOR 92 (m)	Distance from MOR 93 (m)	Comments
MOR 74	24.0	20-24	Water-Table	Observation	38.4	42.3	Unaffected by testing.
MOR 75	56.0	50-56	Middle	Observation	36.6	40.5	Unaffected by testing; responded to regional decline after testing.
MOR 92	120.0	104.45-114	Lower	Pumping/ Observation		3.9	Lower aquifer pumping well; not affected by middle aquifer pumping.
MOR 93	66.0	54-64	Middle	Pumping/ Observation	3.9		Middle aquifer pumping well; not affected by lower aquifer pumping.
MOR 95	25.0	20-23	Water-Table	Observation	35.1	31.2	Unaffected by testing.
MOR 96	68.0	55-67	Middle	Observation	64.3	60.4	Good response to middle aquifer testing; unaffected by lower aquifer pumping.
MOR 97	115.5	103-115	Lower	Observation	40.2	44.1	Good response to lower aquifer testing; unaffected by middle aquifer testing.
MOR 98	115.5	109.5-115.5	Lower	Observation	72.0	68.1	Unaffected by testing; no useful results.

Table 8. Aquifer Test Details

Test type	Middle aquifer Pumped well MOR 93				Lower aquifer Pumped well MOR 92			
	Discharge (m^3day^{-1})	Time started	Date started	Useful obs. wells	Discharge (m^3day^{-1})	Time started	Date started	Useful obs. wells
Three-stage step drawdown with recovery between stages	$Q_1 = 131$ $Q_2 = 189$ $Q_3 = 112$	1330 0915 1400	30.8.77 31.8.77 31.8.77		518 850 1207	1415 0900 1550	20.9.77 21.9.77 21.9.77	
Main test with constant pumping rate; duration 7 days	79.2	1130	1.9.77	MOR 93,96	1067 Decreased during test	1110	22.9.77	MOR 92,97
Recovery test; duration 7 days		1130	8.9.77	MOR 93,96		1110	29.9.77	MOR 92,97

Table 9. Aquifer test results

Method of analysis	Aquifer thickness (m)	Transmissivity ($m^3day^{-1}m^{-1}$)	Storage Coefficient	Av. hydraulic conductivity ($m^3day^{-1}m^{-2}$)	Well analysed
MIDDLE AQUIFER (MOR 93 pumped)					
Cooper and Jacob (1946)	24	7.60	—	0.32	MOR93 drawdown
		7.80	—	0.33	MOR93 recovery
		11.07	3.80×10^{-4}	0.46	MOR96 drawdown
		9.70	—	0.40	MOR96 recovery
Theis match-point (1935)		15.80	3.10×10^{-4}	0.66	MOR96 drawdown, early time
		11.10	3.90×10^{-4}	0.46	MOR96 drawdown, late time
LOWER AQUIFER (MOR 92 pumped)					
Cooper and Jacob (1946)	39	63.00	—	1.62	MOR92 drawdown
		58.00	1.50×10^{-3}	1.49	MOR97 drawdown
Aron and Scott (1965)		51.00	2.50×10^{-3}	1.31	MOR97 specific drawdown
Theis match-point (1935)		70.00	6.94×10^{-4}	1.79	MOR97 drawdown

Table 10. Well test results, (irrigation wells)

Well unit number	Screened interval (m)	Aquifer monitored	Aquifer thickness (m)	Specific capacity ($m^3day^{-1}m^{-1}$)	Transmissivity ($m^3day^{-1}m^{-1}$)	Average hydraulic conductivity ($m^3day^{-1}m^{-2}$)	Comments and (location)
6629-460-00053	18-22	Upper gravels	4	102.00	670.0 380.0	168 95	Drawdown. Recovery; large well loss component (Nuriootpa).
6729-500-00675	46-49	Upper non-carbonaceous sand	>3	38.00	18.0	<6	Salinity of well rose during pumping. (Stockwell Rd)
6629-460-00008	Open hole 48-80	Hard rock	Assume 32	23.00	33.0	1	(Dorrien)
6729-500-00988	52.5-56	Lower	12	6.00	7.3	0.61	Water level stabilized after approx. 500 mins. (Nuriootpa)
6728-100-01670		Hard rock	Assume 100	1.25	0.3	3×10^{-3}	(Mount McKenzie)
6628-050-11156	58.5-61.5	Lower	4	0.02	26.0	6.5	(Tanunda area)
6729-500-00680	107.6-113.7	Lower	7.5		10.3	1.37	(Stockwell/Penrice Rd)
6629-460-00018	62+	Hard rock	62+	4.40	2.6		(Tanunda-Nuriootpa Rd., Dorrien)

Table 11. Laboratory results on push tube samples

Observation well No.	Tube interval below ground (m)	Moisture content (%)	Dry density lb/cu.ft.	Specific Gravity	Porosity	Vertical Hydraulic conductivity ($m^3day^{-1}m^{-2}$) at 20°C
MOR 58	10.45-10.60	11.9	105.0	2.67	0.370	1.43×10^{-3}
MOR 59	15.10-15.25	31.8	86.3	2.34	0.409	1.95×10^{-5}
	35.00-35.15	35.0	83.3	2.51	0.468	1.05×10^{-5}
	57.00-57.15	27.8	93.6	2.63	0.429	5.66×10^{-5}
MOR 62	5.30- 5.45	20.2	109.8	2.67	0.341	1.51×10^{-4}
MOR 65	19.30-19.45	13.3	119.2	2.69	0.290	3.46×10^{-5}
MOR 66	18.10-18.20	15.9	119.2	2.68	0.277	1.19×10^{-5}
MOR 68	10.45-10.60	20.4	108.8	2.73	0.311	1.14×10^{-4}
	21.70-21.80	20.6	106.8	2.71	0.296	5.20×10^{-5}
MOR 69	12.45-12.60	24.4	101.8	2.70	0.318	3.65×10^{-5}
	27.45-27.60	17.1	114.6	2.68	0.245	9.07×10^{-5}
MOR 70	15.95-16.10	22.5	104.0	2.69	0.380	1.18×10^{-4}
MOR 71	10.45-10.60	17.8	111.0	2.69	0.339	3.83×10^{-5}
	47.45-47.60	34.6	84.5	2.50	0.458	2.40×10^{-5}
	71.45-71.60	38.6	77.8	2.25	0.446	1.98×10^{-4}
MOR 72	15.15-15.30	17.8	108.7	2.69	0.353	2.37×10^{-4}
	30.45-30.60	19.3	110.6	2.69	0.340	7.48×10^{-4}
MOR 73	10.45-10.60	24.1	101.7	2.73	0.396	1.21×10^{-5}

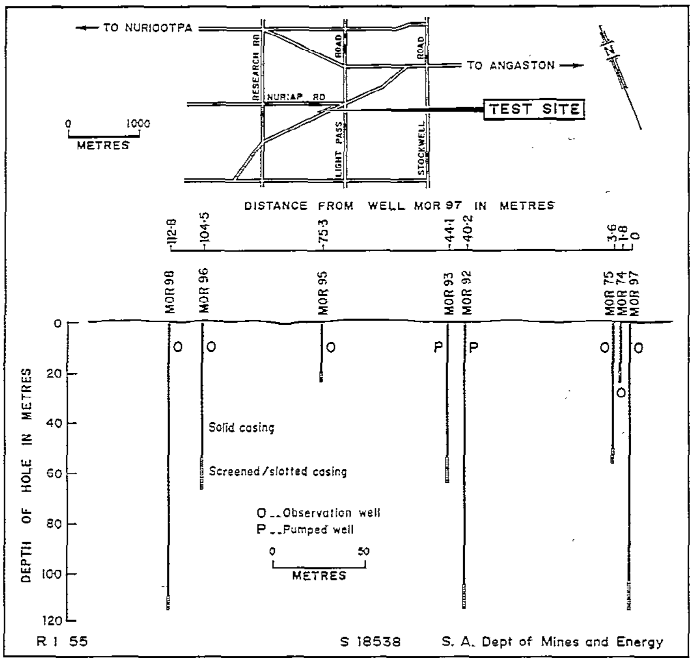


Fig. 52 Aquifer test layout

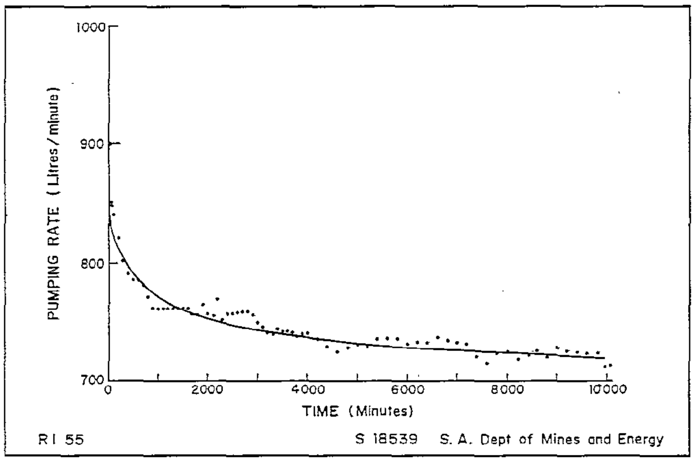


Fig. 53 MOR 92—pumping rate decline

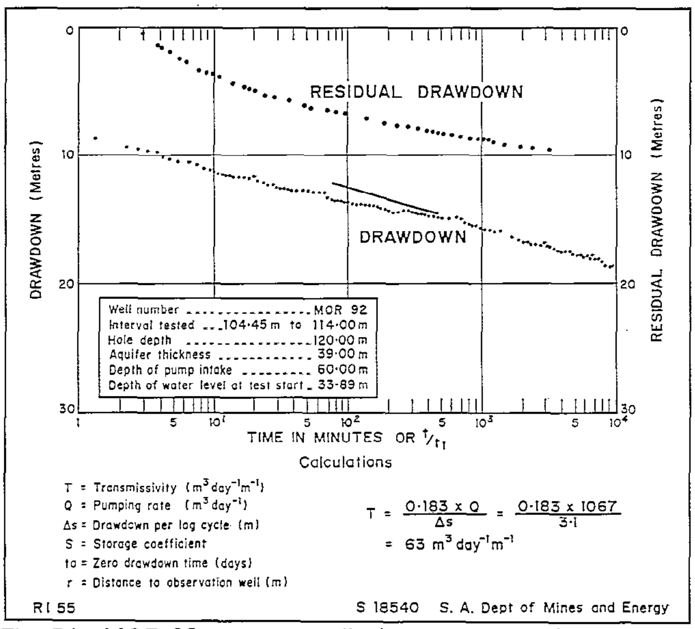


Fig. 54 MOR 92—constant discharge test graphs

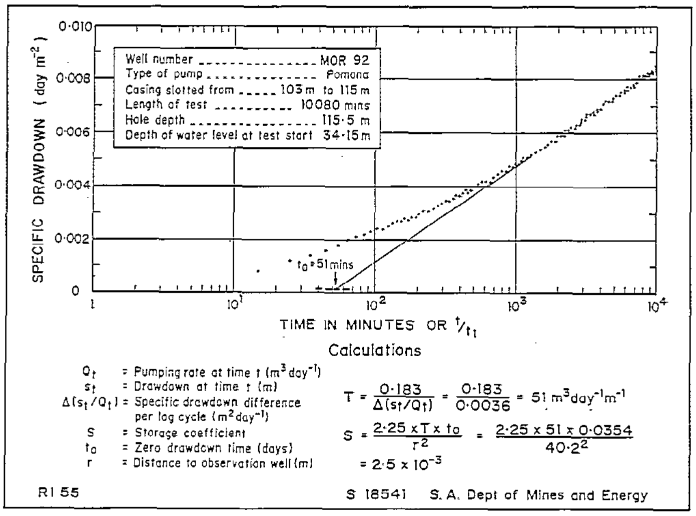


Fig. 55 MOR 92—time/specific drawdown graph

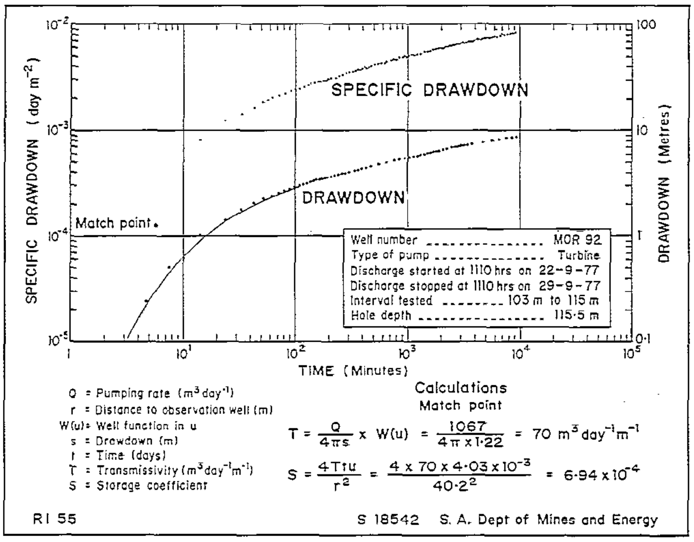


Fig. 56 MOR 92—log/log drawdown graph

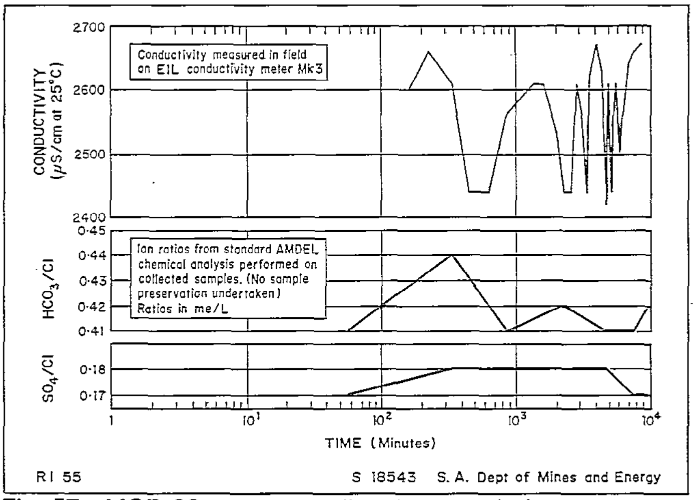


Fig. 57 MOR 92—water quality changes during test

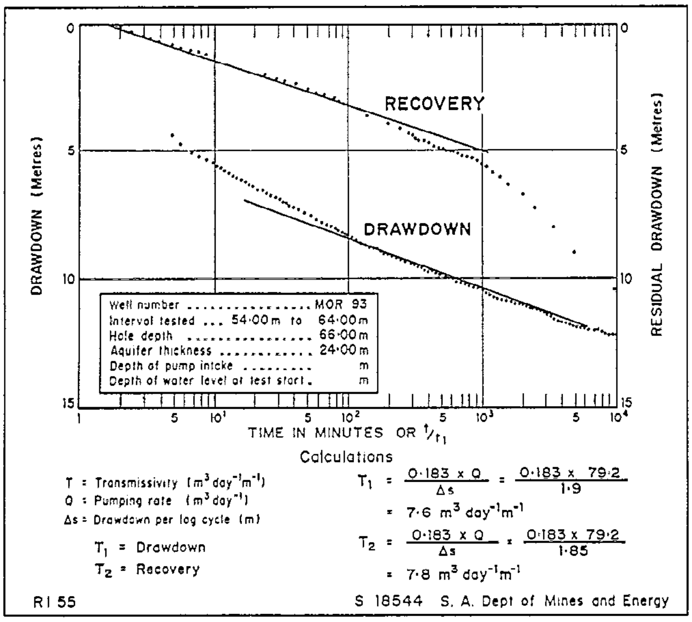


Fig. 58 MOR 93—constant discharge test graphs

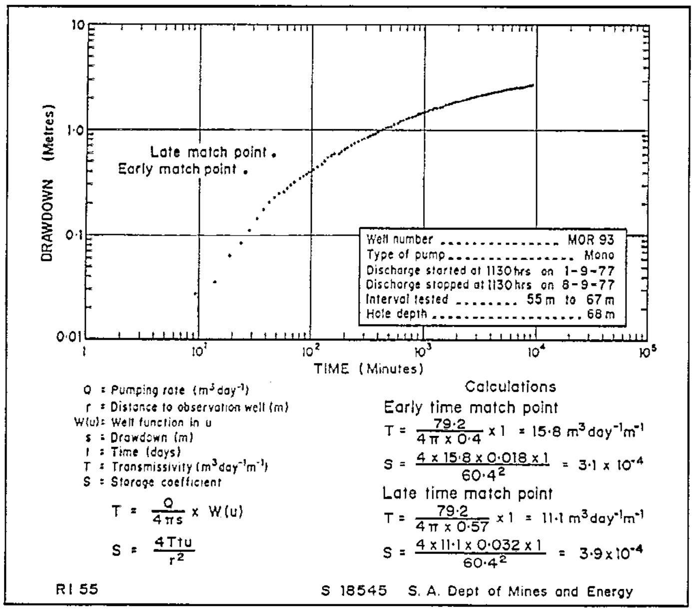


Fig. 59 MOR 93—log/log drawdown graph

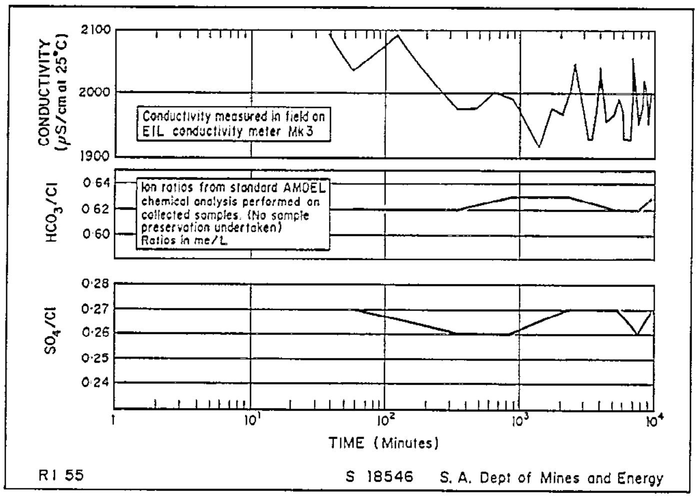


Fig. 60 MOR 93—water quality changes during test

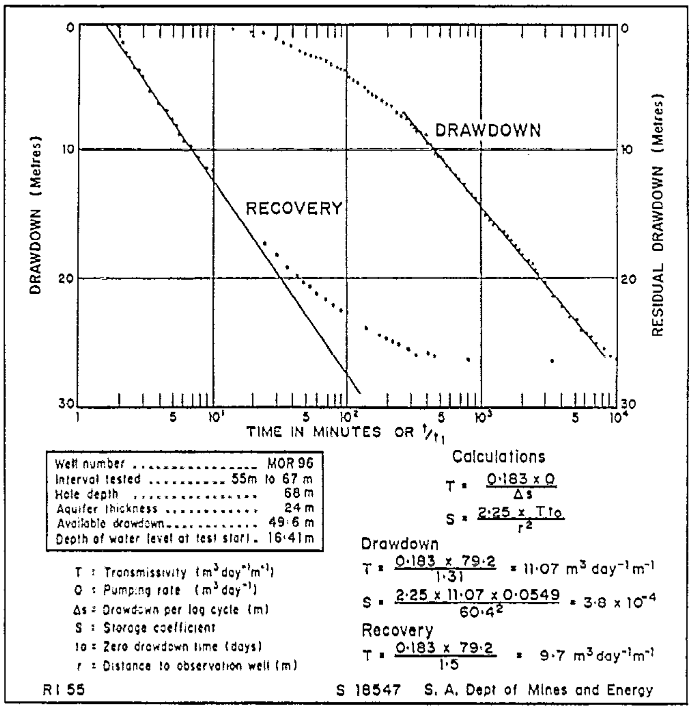


Fig. 61 MOR 96—constant discharge test graphs

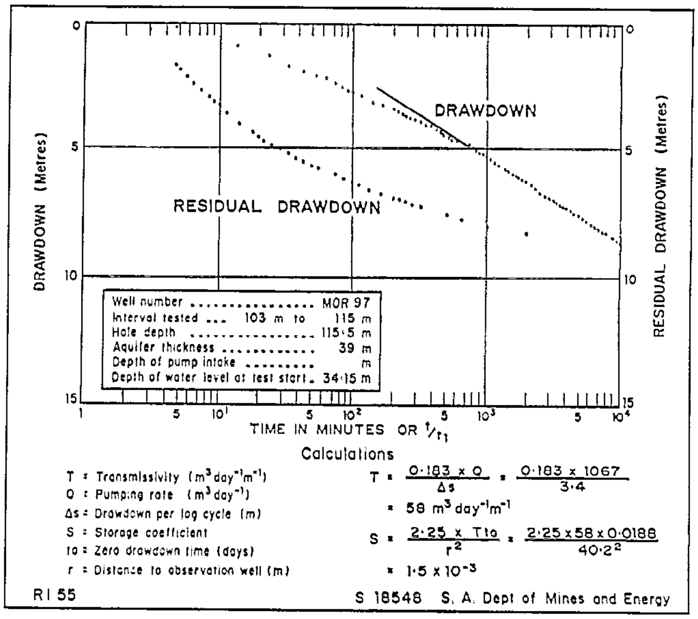


Fig. 62 MOR 97—constant discharge test graphs

APPENDIX 4

Estimation of Groundwater Recharge

From Climatological Data

Rain falling on the land surface has to satisfy several moisture deficits before any accession to the water table can take place. Initially evapotranspiration has to be accommodated and, depending on the rainfall intensity, some will run off into surface drainage lines. That which passes the root zone, after evapotranspiration has been satisfied, has to replace the soil moisture deficit existing at the end of the summer period. Long term considerations demand the use of average annual data.

Average annual rainfall isohyets for the Barossa Valley are given on Figure 2 and mean monthly rainfalls for Nuriootpa on Figure 3. Land surface slopes in the valley are low and direct surface runoff, except at times of high intensity rainfall, is negligible (except in urban areas). Average annual rainfall integrated over the valley can be assumed to satisfy the average evapotranspiration demand and infiltrate past the root zone. Work at the Department of Agriculture's Viticulture Research Station at Nuriootpa indicates an average end-of-summer soil moisture deficit of 210 mm* for the upper 2.4 m of soil profile (G. Schultz, Dept. Agriculture, pers. comm. 1984). These data were for a period of 4 to 5 years in a fine sand loam, though no attempt has been made to estimate values for different soil types.

It is a simplification that soil moisture deficits must be made up before drainage to the water table can take place. Soils and sediments still have a finite hydraulic conductivity (k) even at low moisture contents. The hydraulic conductivity/moisture content relationship is partly grain size dependent, thus finer grained soils show a rapid decrease in (k) with decreasing moisture content. Considering the soil types of the valley and the depth to the water table, the assumption that a significant part of the soil moisture deficit will be satisfied before active drainage to the water table takes place, is considered reasonable.

Potential evapotranspiration has been calculated by the method of Thornethwaite (1948) which requires values for mean monthly air temperature and the latitude of the area in question. The results are listed below and plotted on Figure 3.

Figure 3 shows that on average there are 5 months (May to September) where rainfall exceeds potential evapotranspiration with a total excess of 165 mm. This amount is potentially available for groundwater recharge. However, with an average soil moisture deficit of around 210 mm (soil depth 2.4 m) then most or all of the rainfall excess would be taken up satisfying this demand. The implication is that only in years of extreme rainfall or in soils with a much lower deficit would significant recharge through the soil profile occur. The depths of penetration (from 0.2 to over 2.0 m) of the April-October rainfall on a sandy red-brown earth at Nuriootpa Research Station for the years 1953 to 1961 are given on Figure 63. The depth to water table in this area ranges from 6 to 10 m.

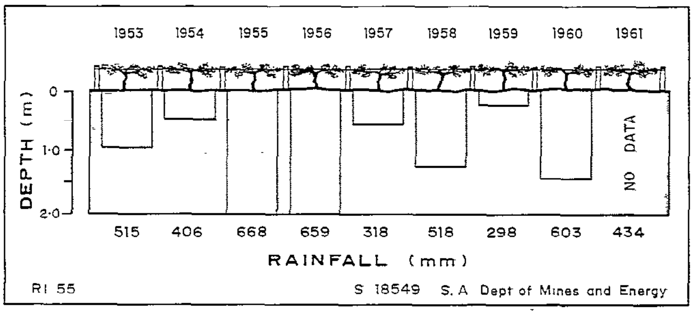


Fig. 63 Rainfall penetration under vines at Nuriootpa Viticultural Station

For the budget period the rainfall excess over potential evapotranspiration was 209 mm and therefore active recharge would be expected.

From Chloride content of the water table

The chloride (Cl) ion is a conservative tracer being neither precipitated nor absorbed on soil particles during a recharge event. Thus knowledge of the chloride content of both precipitation and the unconfined aquifer, combined with the average annual rainfall (R), provides an estimate of average annual recharge.

Average annual recharge (AAR) is given by:

$$AAR = \frac{\text{Chloride concentration in rainfall (mg/L)x Average annual rainfall (mm)}}{\text{Chloride concentration in water table groundwater (mg/L)}}$$

or $$\frac{Cl_R xR}{Clgw}$$

Potential Evapotranspiration in mm (Thornethwaite, 1948)

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Standardised Potential Evapotranspiration (mm)	96.08	92.00	80.00	56.00	39.00	30.00	24.50	28.50	37.50	50.00	67.00	80.00
Correction factor for latitude	1.23	1.04	1.06	0.94	0.89	0.82	0.87	0.94	1.00	1.13	1.17	1.25
Assessed potential evapotranspiration (mm); annual total= 731.1 mm	118.20	95.70	84.80	52.60	34.70	24.60	21.30	26.80	37.50	56.50	78.40	100.00

* Based on a wettest recorded profile of 680 mm (field capacity) and a typical water content of 470 mm at the end of summer.

and the relation between average rainfall chloride concentration and distance from the sea as:

$$\text{Chloride (meq/L)} = \frac{0.99}{d^{0.25}} - 0.23 \text{ (Hutton, 1976)}$$

where d = distance in km from the ocean in the direction most likely to contribute maximum oceanic salt.

Since rainfall that would contribute maximum salt is associated with southwesterly winds, the distance from the ocean (St Vincent Gulf) was measured in that direction. Combining the calculated Cl content of rainfall with the rainfall (R) contours allowed plotting of equal $Cl_R xR$ contours. These were then used to estimate average annual recharge based on available chemical analyses for shallow groundwaters. Caution should be used with data from wells close to surface drainage lines since groundwater quality would be affected by seepage of stream flow water of varying chemical composition. The values for average annual recharge in mm so calculated are given on Figure 64.

The data indicate that, despite an average annual rainfall ranging from 500 to 650 mm, the corresponding long term recharge through the soil profile is less than 6 mm and commonly 1-3 mm. In addition recharge appears to be higher adjacent to the eastern margin of the valley, which may reflect subsurface inflow from the higher rainfall hard rock areas. Higher rainfall is probably also responsible for apparent marginally higher recharge in the Rowland Flat-Lyndoch area.

From Fluctuations in the water table

The water table is generally at its deepest in February of each year and then rises over the winter period to peak in September. This rise is a reflection of recharge to the water table and its magnitude could be correlated with the actual amount of rainfall.

Plotting annual rises in the water table from all available wells, against effective winter rainfall (May-October) yielded no useful relationships even considering the actual depth to the water table. This relationship assumes that the Specific Yield (Sy) of the material through which the water table fluctuates is areally consistent. This is probably not the case considering the wide range of sediments forming the unconfined aquifer.

The recharge takes place is demonstrated by the observed rises in observation wells (Fig. 70). Plotting the annual net change in the water table against annual rainfall ideally yields a straight line with a slope being the inverse of Sy. For the Barossa Valley a scatter of data occurs (Fig. 65) but an average Sy is 0.05. On an areal basis this figure is probably fairly representative.

If the water table rises are averaged for 1979 for all observation wells than a rise of 1 m is obtained. This is probably biased on the high side since most of the observation points are in areas of the shallowest water table. However, assuming an average Sy of 0.05 (gravity drainage of silts), then 50 mm of rainfall recharged accessible parts of the water table in 1979.

Considering the depth to, and fluctuations in, the water table it is assumed that recharge actually took place where the water table is less than 10 m below ground level. The area of sedimentation where this condition is met is $7.25 \times 10^7 m^2$ giving a recharge volume of $2.63 \times 10^6 m^3$. This figure is probably an overestimate considering the value of Sy used and comments in the previous two sections.

Figure 65 shows that in the long term, for no overall loss in storage from the water table, the annual rainfall must equal 450 mm. This of course does not take into account the actual rainfall distribution in time or its intensity.

From Stream Flow Losses

All creeks emanating from the ranges (particularly from the east) are losing streams for a variable part of their journey across the Valley floor. That is, water seeps through their beds and banks to recharge the local water table.

To assess the volume of stream-flow loss recharging the water table, staff gauges were installed at selected sites, calibrated, and river stage (height) recorded generally on a daily basis. Details are given in Appendix 2.

After conversion of river stage to instantaneous discharge it was assumed that this represented the flow for the particular 24 hours during which the staff was read. When a flood peak passed the gauge site and several values of stage were recorded, these were plotted against time and the area under the curve integrated. This provided a more accurate estimate of discharge than using just the peak stage. These values were then summed for each month that flow

Estimation of stream flow losses, North Para River, Stockwell-Road Bridge-Nuriootpa Caravan Park, 1979-80

Month	Flow past Stockwell Bridge (I) (m^3)	Flow past Nuriootpa (O) (m^3)	Potential Evapotranspiration (ET) (m^3)	Rainfall on river (R) (m^3)	I—ET+R
July	11 016	—	7 029	4 158	8 145
August	129 387	—	8 844	6 658	127 201
September	5 121 892	3 610 684	12 375	10 511	5 120 028
October	7 184 008	4 701 207	18 645	7 499	7 172 862
November	179 356	192 122	25 872	5 231	158 715
December	3 499	6 819	33 000	2 195	—27 306
January (7 days)	—	2 672	8 808	—	—8 808
TOTAL	12 629 158	8 513 504	114 573	36 252	12 550 837

occurred. For the staff gauges on the North Para River at Stockwell Bridge and Nuriootpa these monthly flows were subtracted to obtain water losses through this reach of the river. The monthly losses were adjusted to allow for potential evapotranspiration losses and rainfall gains considering a strip 20 m wide each side of the river channel. The resulting preliminary recharge volumes were summed for the period of flow recorded and the total reduced by the pumped withdrawals through this section obtained from owner's estimates of volumes withdrawn. An estimate of flow loss per unit length of channel could then be obtained.
The main sources of error are caused by:

- Extension of the rating curve past the highest stage height calibrated.
- Flooding in the Lights Pass-Nuriootpa area which effectively spreads water over a significant area, to be lost by evapotranspiration.
- Assuming that instantaneous discharges could be used to calculate daily discharges, especially at times of rapid stage changes.
- Extrapolating through periods when river stage was not measured.
- Variations in actual volumes withdrawn by pumping.
- Missing peak flow heights, when the peak passed at other than reading time. Note that the peak could often be recorded by fine debris on staff or creek banks.

For the 1979-80 river flow period the volumes passing the Stockwell Bridge and Nuriootpa Caravan Park sites along with evapotranspiration and rainfall data are given below (left).

Stream losses = (I—ET+R)—O—P

where the symbols are as given at the top of the table and P = volume removed by pumping, estimated as 133 182 m³.

Stream loss = 12 550 837 — 8 513 504 — 133 182 m³
= 3 904 151 m³

For flow past Stockwell Bridge over about 160 days this equals approximately 24 400 m³day⁻¹.

For a river length of 8250 m to Nuriootpa Caravan Park gauge, this equals approximately 473 m³m⁻¹.

Combining this equals approximately 3m³day⁻¹m⁻¹ length of river for infiltration.

These figures are considered to be much too large and result from the effects of flooding. During late September to middle October the North Para flooded the relatively flat ground in the Lights Pass area several times. This area is between the Stockwell Bridge and Nuriootpa staff gauges and hence any losses through flood water infiltration and evaporation would be recorded at the Nuriootpa gauge. Thus the total difference in discharge between the two gauges given above would include this loss and this has falsely been ascribed to infiltration through the creek bed and banks.

For the 1980 river flow period calculated data are given below.

Assume volume removed by pumping (P) was 133 182 m³

Stream losses = (I—ET+R)—O—P
= 7 146 020 - 6 798 708 - 133 182 m³
= 214 130 m³ representing 3 per cent of flow past Stockwell Bridge

For flow past Stockwell Bridge over the 173 days period this represents an approximate seepage rate of 1 240 m³day⁻¹. For a river length of 8250 m this equals about 26 m³/m of creek. Combining this equals approximately 0.15 m³day⁻¹m⁻¹ length of river over the flow period and for a river length of 8250 m.

Three shallow hand-augered piezometers were constructed in the river bank at Stockwell Bridge at a right angle to the river direction, and water levels were monitored daily and are given on Fig. 66. To estimate horizontal hydraulic conductivities (k) in the vicinity of each of the piezometers a volume of water was rapidly removed from each in turn and the rate of rise in water level noted. Analysis yielded an average value for (k) of 2.2 x 10⁻³cm³sec⁻¹cm⁻² or 1.9 m³day⁻¹m⁻² which is consistent with the sandy silts and silty fine to medium sands encountered. A poor geological log, slightly downstream from the site, indicates a clay layer at depth giving an average aquifer thickness of 9 m. Using daily hydraulic gradients between MOR118 and 119 and the changing aquifer thickness between them with water level fluctuations, then the rate of groundwater flow away from the river on one side of its centerline could be calculated. This was performed for the total period of flow plus the few extra days for the mound under the river to dissipate. The daily flows, which represent infiltration through the creek

Estimation of stream flow losses, North Para River, Stockwell Road Bridge-Nuriootpa Caravan Park, 1980.

Month	Flow past Stockwell Bridge (I) (m³)	Flow past Nuriootpa (O) (m³)	Potential Evapotranspiration (ET) (m³)	Rainfall on river (R) (m³)	I—ET+R
June	689 931	345 996 (3 days)	8 118	8 778	690 591
July	4 594 634	3 967 632	7 029	7 285	4 594 890
August	463 623	659 405	8 844	2 129	456 908
September	304 563	255 737	12 375	2 434	294 622
October	749 368	859 837	18 645	8 036	738 759
November	385 173 (20 days)	700 101 (20 days)	17 076	2 153	370 250
TOTAL	7 134 570	6 798 708			7 146 020m³

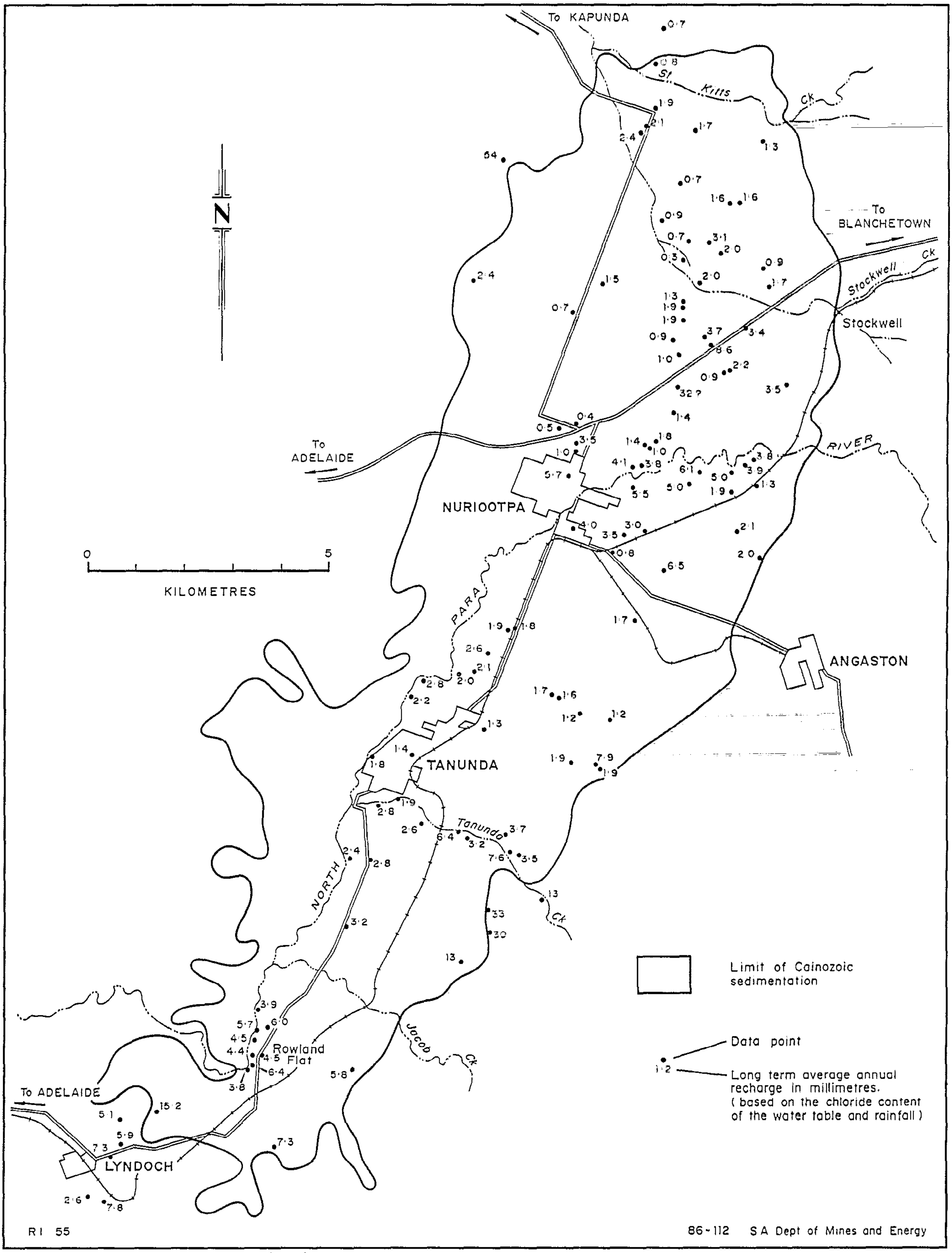


Fig. 64 Long term average annual recharge

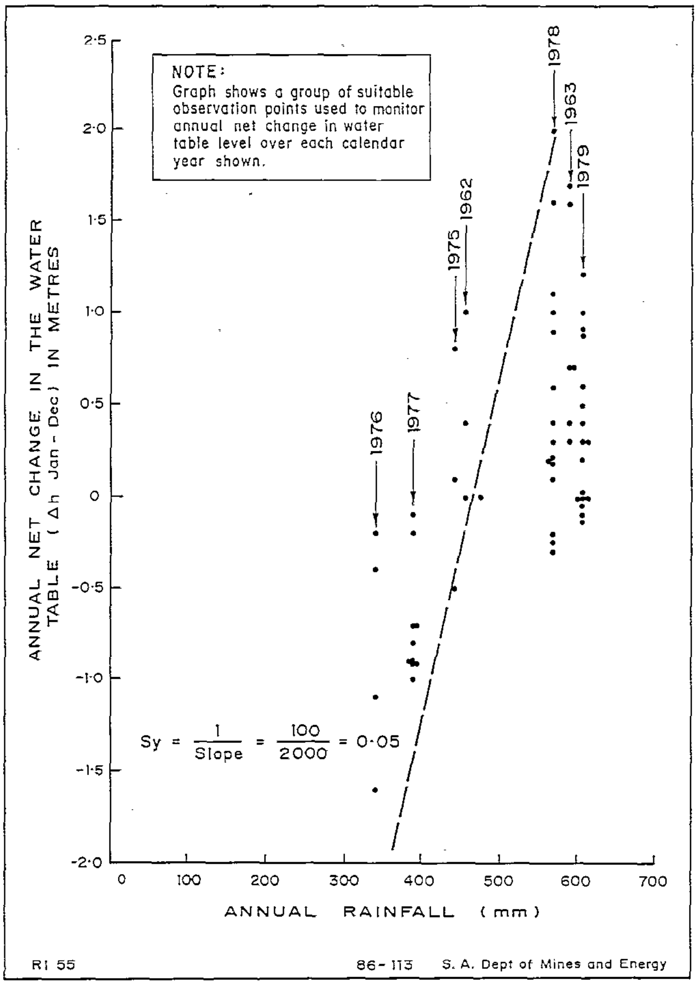


Fig. 65 Annual net change in water table as a function of annual rainfall

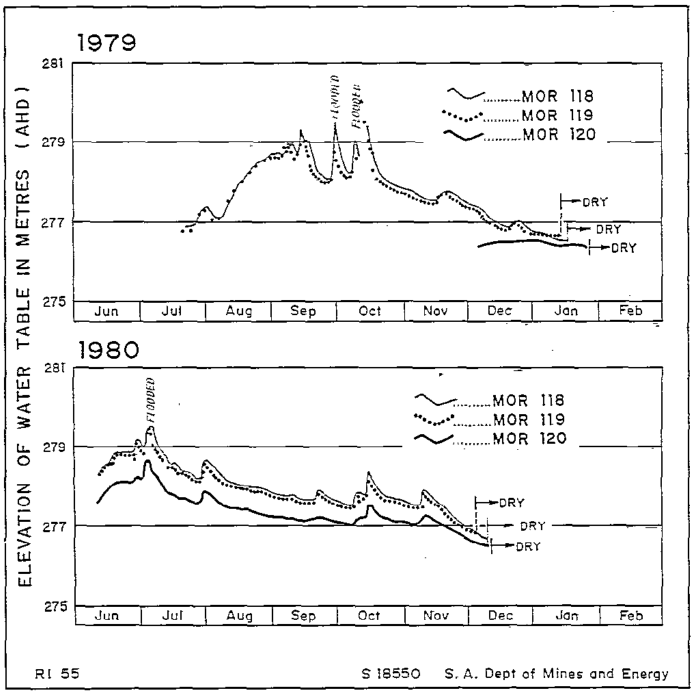


Fig. 66 Hydrographs for observation wells MOR 118, 119 and 120

bed and banks, were summed and doubled (to allow for both sides of the river) and yielded a figure of 140 m^3m^{-1} of river for the total 1979 river flow period. Over a river distance of 9150 m (from basement outcrop east of Stockwell Bridge downstream to the Nuriootpa gauge) this would represent a total infiltration of recharge volume of about 1 280 000 m^3, less than a third of the computed differences in flow past the two staff gauges. Plotting the daily infiltration rate against the river stage recorded on that day, yields no useful relationship (Fig. 67). The rather rapid rise and fall of many of the significant flow events is generally too quick for the groundwater body to respond to any marked degree. Some of the larger peaks on Figure 67 relate to periods of inundation of the piezometers.

On the Bethany (Tanunda) and Jacob Creeks, staff gauges were installed only on their lower reaches just before they join the North Para River. Thus no direct measure of flow losses along their lengths is possible. However, assuming that infiltration rates are similar to the North Para, that is 0.87 m^3day^{-1} per metre length of creek where infiltration is taking place, then an estimate of losses can be made. Account has been taken of the total flow period for the year in question when calculating recharge.

Tanunda Creek is a losing stream for only a relatively short distance upon entering the Valley (refer water table contours on Fig. 20). Assuming this distance equals 500 m then recharge equals 68 000 m^3. Similar comments can be made about Jacob Creek but inspection of water table depths and field observations suggest a losing section about 1000 m long. This yields a recharge value of 123 000 m^3.

Thus for the budget period, creek recharge is estimated at 1 471 000 m^3.

Other creeks entering the Valley would also contribute a small but unknown recharge volume to the water table.

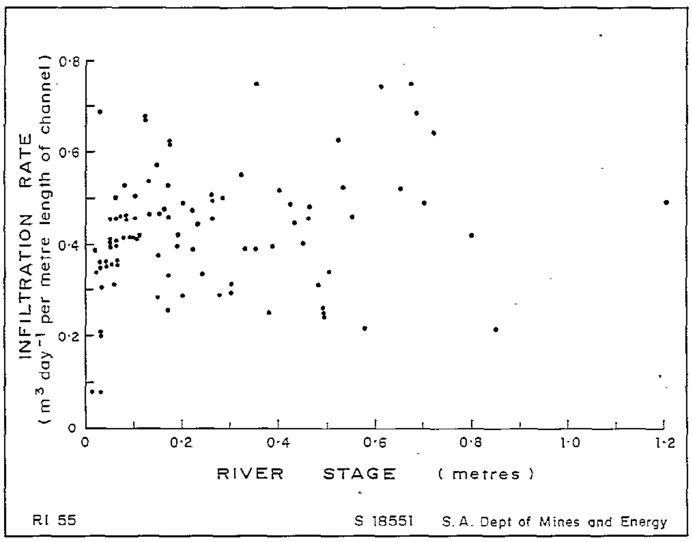


Fig. 67 Infiltration rates and river stages for the North Para River at Stockwell Road Bridge

APPENDIX 5

Estimation of water budget components.

The water budget for the bulk sediments has been defined as:

$\pm DS = Rs + Rc + Ru - Uc - Uu - ETg - P \pm DSM$

where
- DS = change in groundwater storage
- Rs = recharge through the soil profile (by infiltration of rainfall)
- Rc = recharge from creek flow
- Ru = subsurface recharge from adjacent hard-rock aquifers
- Uc = groundwater outflow (seepage) into creeks
- Uu = subsurface outflow of groundwater (into adjacent hard-rock aquifers)
- ETg = evapotranspiration of groundwater (where the water table is sufficiently shallow)
- P = pumping withdrawals
- DSM = change in soil moisture

The period February 1979 to February 1980 was chosen to attempt a budget. It is probable that no net soil moisture change took place over this period thus DSM = 0 is a reasonable assumption.

Change in groundwater storage (DS)

Any imbalance between recharge and discharge from an aquifer is reflected in change of storage. If recharge exceeds discharge, storage is increased and water levels will rise.

All available hydrographs were inspected for water levels in February 1979 and February 1980 and their difference noted. A lower level in February 1980 reflects a decrease in storage and is thus recorded as a discharge.

An adequate number and spacing of data points for each aquifer is rarely available, hence contours of head rise or decline for each aquifer are generalised.

For the water table and upper aquifers, which were combined for purposes of the calculation, the changes in storage were computed from these contours. To convert to an actual net volume of water gained or lost a Specific Yield (Sy) of 0.05 was assumed:

Volume of aquifer drained	7 400 000 m³
Volume of aquifer with increases in storage	2 775 000 m³
Net volume drained	−4 625 000
x SY	0.05
Net loss in storage	−231 000 m³

For a confined aquifer the material is not physically drained as for the water table but there is a rise or fall in the pressure surface. Similar procedures as above were followed, but to calculate change in volume the Storage Coefficient (S) was used (refer Appendix 3).

For the middle aquifer the volume gained was 8 325 000 m³, the volume lost 11 562 500 m³, leaving a net loss of 3 237 500 m³. Using a Storage Coefficient of 3.6×10^{-4} the volume lost from storage was 1165 m³.

For the lower carbonaceous sands and gravels there was an overall rise in the potentiometric surface equivalent to an increase in the volume of 17 325 000 m³. Using a Storage Coefficient of 1.56×10^{-3} then a net gain in storage of 27 110 m³ occurred.

Thus for the total sediments:

$$DS = -231\,000 - 1\,165 + 27\,110 \text{ m}^3 = -205\,000 \text{ m}^3$$

Recharge through the soil profile (Rs)

In Appendix 4 estimates of recharge through the soil profile were attempted using different methods. For the budget period a value of 3.63×10^6m³ was obtained, but this may be an over estimate.

Recharge from creek flow (Rc)

Appendix 4 contains estimates of flow losses in the North Para River and its tributaries related to recharge to the local water table. For 1979, flooding between the gauges prevented determination of these losses by simple difference between the corrected flows past the two gauges in question. However, use was made of water level observations in shallow piezometers augered adjacent to the upper (Stockwell Road bridge) staff gauge to estimate recharge, yielding a figure of 1 280 000 m³. Note that this figure represents 10 per cent of the total estimated flow of 12 630 000 m³ past the Stockwell Bridge gauge. For Tanunda Creek a recharge volume of 68 000 m³ was obtained, and for Jacob Creek 123 000 m³, giving a total estimated recharge of 1 471 000 m³.

Other creeks entering the Valley would also contribute a small but unknown recharge volume to the water table.

Subsurface recharge from adjacent hardrock aquifers (Ru)

The sediments of the Barossa Valley and the surrounding and underlying hard-rocks are hydraulically connected and thus interchange of groundwaters occurs, the direction depending on the relative heads of the two systems. For all lateral interflow calculations it has been assumed that the water table represents the head distribution in the hard rocks and that it remains relatively constant throughout the year.

The hydraulic conductivity (k) of the hard rocks will vary over several magnitudes depending on the degree of fracturing, size of openings and their interconnection. Three well tests were performed and the values obtained for (k) are given in Appendix 3. Considering the major rock types making up the eastern ranges a value for (k) of 10^{-2} m³day⁻¹m⁻² is assumed.

Figure 20 shows that groundwater enters the Barossa Valley sediments from the eastern ranges across the Stockwell Fault. Assuming that the limiting factor to flow is the hydraulic conductivity of the hard rocks, and that seepage occurs along a length (1) of 29 000 m (Fig. 20) and a depth (b) of 100 m (average saturated thickness of sediments from Figures 10 and 20) then an approximate subsurface recharge volume can be computed. An average hydraulic gradient (i) of 0.07 exists in the ranges adjacent the valley margin.

Thus:

$$Ru = kbli$$
$$= 10^{-2} \times 100 \times 29\,000 \times 0.07$$
$$= 2030\ m^3day^{-1}$$
$$= 741\,000\ m^3year^{-1}$$

Figure 20 also indicates that groundwater recharges the sediments in the northwestern area over a distance of 11 500 m. The interface between hard rocks and sediments is sloping and characterised by a thin but variable section of weathering products. To simplify, a (k) of 10^{-2} $m^3day^{-1}m^{-2}$ and a flow path thickness of 30 m is assumed. Hydraulic gradients are variable but average 0.01.

Thus for this area:

$$Ru = kbli$$
$$= 10^{-2} \times 30 \times 11\,500 \times 0.01$$
$$= 34.5\ m^3day^{-1}$$
$$= 12\,600\ m^3year^{-1}$$

Pumping of the basal aquifer during summer produces head reductions such that an upward gradient exists between the underlying hard rocks and this aquifer. The gradient exists across a clayey weathered section commonly up to 20 m thick (see log of MOR94). On a regional scale the sediment/hard rock interface can be considered horizontal thus the weathered hard rock layer can be thought of as a confining layer between two flat-lying aquifers. A hydraulic conductivity of 10^{-4} $m^3day^{-1}m^{-2}$ is assumed for the weathered zone. Hydraulic gradients vary both in space and time during irrigation and recovery. By comparing Figures 14 and 15 with Figure 13, approximate areas of equal head difference were computed, vertical gradients calculated and an estimated upward leakage determined. For February (maximum head differences) leakage was estimated at 100 000 m^3 and for August (minimum differences) leakage was estimated at 37 000 m^3. Linear proportioning for other months yielded an annual leakage of approximately 922 000 m^3.

The calculation of this volume is very sensitive to the value assumed for (k) which has not been directly measured. The relatively low value is based on the weathering products being a clayey silt which has been confirmed from drilling data. However this, combined with a wide variation in the thickness of the weathered section, leads to the probability of errors in the calculation.

Groundwater outflow (seepage) into creeks (Uc)

When the water table rises above the topographic level of a creek, groundwater can seep into the creek forming its base flow over which peak flows are overprinted. When daily flow figures are available for the total flow period there are arbitrary methods to separate base flow from instantaneous discharges.

The E&WS Department gauging weir at Chateau Yaldara on the North Para River is the nearest site downstream and daily discharges are available for the year 1979. These were supplemented with Dept Mines and Energy data for January 1980.

For the water budget period, flow separation techniques indicate a base flow of 6 568 500 m^3 out of a total flow of 24 806 000 m^3. Assuming that all areas of the catchment contribute equally to this base flow irrespective of the hydrogeology, then the ratio of the area of sedimentation in the Barossa Valley to the total catchment area, allows an estimate of the base flow generated from the sediments. This would be a maximum value since stream density on the valley floor is significantly lower than in the hills portion of the catchment and thus water table access to a stream is much reduced.

Total area of sedimentation = 145 km^2
Area of sedimentation in catchment = 108 km^2
Total area of catchment = 383 km^2
Ratio of area of sedimentation in catchment to total catchment = 0.28.
Base flow from sediments
= 0.28 $\times$ 6 568 500 m^3
= 1 870 000 m^3

The northern portion of the Barossa Valley drains towards St Kitts Creek and thence into the River Light. No comparable flow data is available for this system, thus losses from the sediment groundwater can only be estimated with reference to the North Para System.

Thus, in the North Para System, if a base flow of 1 870 000 m^3 is generated from a sediment area of about 108 km^2 then a base flow of 640 000 m^3 is generated by the 37 km^2 draining northwards.

Total sediment groundwater loss as base flow then becomes $2.51 \times 10^6 m^3$.

It is interesting to note the water salinities for the first four months of the 1979 flow year. The high salinities reflect almost total dominance of base flow until surface runoff becomes active and starts to reduce recorded salinities.

Subsurface outflow of groundwater (Uu)

In the southern, southwestern, and northern portions of the Barossa Valley groundwater leaves the sediments as underflow (Fig. 20). The sediment/hard rock interface is sloping and the lower sand and gravel aquifer exhibits lower heads than the hard rocks and thus accepts groundwater from then. Consequently the vertical distance between the water table and the base of the middle aquifer has been taken as the depth of the flow path (b) and averages 30 m. Assuming that the limiting hydraulic conductivity (k) is 10^{-2} $m^3day^{-1}m^{-2}$, an average hydraulic gradient (i) is 0.018 and the distance over which flow occurs (1) is 20 000 m.

Then:

$$Q = kbli$$
$$= 30 \times 10^{-2} \times 0.018 \times 20\,000$$
$$= 108\ m^3day^{-1}$$
$$\text{or}\quad 39\,400\ m^3year^{-1}$$

In the northern portion of the valley similar outflow occurs and the following parameters are estimated: $k = 10^{-2} m^3day^{-1}m^{-2}$, 1 = 5000 m, b = 30 m and i = 0.009.

Then:

$$Q = 13.5\ m^3day^{-1}$$
$$\text{or}\quad 5000\ m^3year^{-1}$$

Thus approximate groundwater outflow into the hard rocks is 45 000 m^3.

Evapotranspiration of groundwater (ETg)

If a water table is at a depth below ground such that its capillary fringe approaches the land surface, then direct evaporation can take place (White, 1932). Figure 68 shows that for water tables deeper than 1 m evaporation is minimal. However, evapotranspiration from deeper water tables can take place through the action

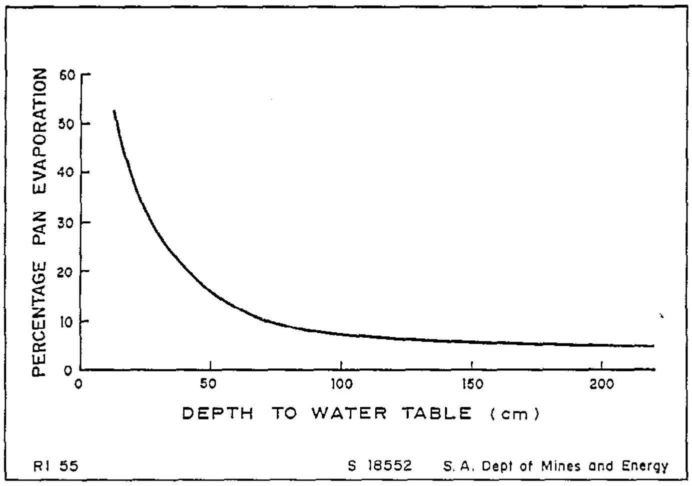


Fig. 68 Relationship between water table evaporation and depth

of deep rooted plants. The soils containing the water table are generally of a fine grained nature and thus a significant capillary fringe will exist. The following table indicates the range in distances from the water table to the highest elevation to which capillary water would rise for a variety of cohesionless soils (Lane and Washburn. 1946):

Soil Type	Particle Size D10 (mm)	Capillary Rise (cm)
Silt	0.006	359
Fine Sand	0.03	166
Medium Sand	0.02	240
Coarse Sand	0.11	82
Silty Gravel	0.06	106
Fine Gravel	0.30	20
Sandy Gravel	0.20	28
Coarse Gravel	0.82	5

It is thus probable that because of the fine grained nature of the soils that evapotranspiration may affect the water table even to a depth of 5 m or more, for at this depth in a silt the capillary fringe may rise up to 140 cm below ground level. Assuming that areas with a water table less than 5 m deep are affected by evapotranspiration then the difference between the potential evapotranspiration and the rainfall actually occurring can be assumed to be made up by removal from the water table.

That is:

Annual Potential evapotranspiration - Actual rainfall = ETg

$$731.1 - 589.8 = 141.3 \text{ mm}$$

Over an area of $1.9 \times 10_7$ m_2 this represents a loss from the water table of 2 722 000 m_3. Since a proportion of this area is irrigated from sources other than groundwater this has the effect of increasing the 'rainfall' reaching the area and hence reducing ETg.

If we assume that irrigation is evenly spread over the Valley then the volume applied where the water table is shallower than 5 m can be estimated from the ratio of this area to the valley area, that is 17 per cent. However, a greater than average proportion of this area is under non-irrigated pasture grasses and residential and industrial development, thus a more realistic figure of 10 per cent is assumed. With a total of 1 881 000 m^3 being applied as irrigation water about 188 000 m^3 is assumed to be applied in areas with a water table shallower than 5 m. Thus ETg = 2 722 000 − 188 000 = 2 534 000 m^3.

Pumping withdrawals (P)

Water well field surveys by Herraman (1976a, 1976b, 1977) and data from wells drilled under permit since proclamation of the Water Resources Act in 1976 indicate that approximately 200 irrigation or industrial wells are capable of withdrawing water from sediments of the Barossa Valley. A very small number of wells withdraw water for stock or domestic purposes (Fig. 8). Summing the nominal yields of these wells indicates that potentially about 100 000 m^3day^{-1} could be extracted from these sediments.

Data from the Bureau of Census and Statistics for the District Council areas of Angaston, Barossa and Tanunda give areas of various crops irrigated (Figs. 6 and 7) and the source of the irrigation water (Fig 5). These are listed below in total for 1979 for the areas occurring in the Valley proper, excluding the hills. This is combined with estimated application rates (C. Rudd, Dept of Agriculture, pers. comm. 1984), and the proportion of irrigation volume attributable to the various water sources, to obtain approximate total volumes of irrigation water from each source.

If it is assumed that the percentage area of each crop watered from a particular source is constant irrespective of the actual crop or whether it is within the hills or on the valley floor, then an estimate can be made of the total groundwater pumped from the sediments.

Crop	Total Area irrigated (ha)	Estimated area in Barossa Valley (ha)	Application per season (mm)	Estimated Volume applied	
				Total Area (m^3)	On Valley Floor (m^3)
Vineyards	1760	1500	100	1 760 000	1 500 000
Vegetables	67	67	300	201 000	201 000
Orchards	69	40	100	69 000	40 000
Pasture, Lucerne, etc.	206	70	200	412 000	140 000
			Total	2 442 000	1 881 000

Source	Total area irrigated in District Councils of Angaston, Tanunda, Barossa in 1979 (ha)	Percent of total area
Groundwater	1 634	78
River & creeks	143	7
Farm dams	279	13
Reticulated	46	2
Total	2 102	100

Thus if the total volume of irrigation water applied to crops in the Barossa Valley proper is 1 881 000 m^3 and 78 per cent of the water is obtained from groundwater resources then approximately 1 467 000 m^3 was withdrawn in that year. Considering soil types, plant requirements, the relatively low irrigation application rates, the method of application, and the depth to the water table, it has been assumed that this volume is a net loss with no irrigation water recycling to the water table.

Two obvious sources of error inherent in this calculation are: firstly, the percentage irrigated by farm dams is too high for the Valley proper, being biased by such development in the hills; and secondly, some of the groundwater for irrigation in the Valley is obtained from the underlying bedrock or hard rock aquifers. These two errors are to some extent self-cancelling.

It is assumed that the local dam and creek supplies, and the water imported into the area through the reticulation system, is totally evapotranspired with no drainage to the water table and hence does not contribute to the groundwater budget.

Groundwater is also withdrawn by the winery complexes at Nuriootpa for cooling purposes. Well records indicate that this groundwater is pumped entirely from the upper aquifer. Data obtained from the wineries indicate that approximately 124 000 m^3 is withdrawn during vintage although no records are kept by the companies. This withdrawal is a net loss, with the water not being lost within the complex draining to the North Para River.

Change in Soil Moisture (DSM)

During the budget period, February 1979 to February 1980, it is assumed that no net soil moisture change took place and that DSM = 0.

Water Budget

The volumes calculated for individual components of the water budget are:

Inflows (m^3)	Outflows (m^3)
Rs = 3 630 000	P = 1 591 000
Rc = 1 471 000	ETg = 2 534 000
Ru = 1 675 600	Uc = 2 510 000
	Uu = 45 000
6 776 600	6 680 000

The difference between the inflow and outflow equals + 96 600 m^3, whereas from storage changes a net loss in storage of —205 000 m^3 was calculated. It is felt that with the available data little refinement in the above figures can be obtained.

APPENDIX 6. Observation well hydrographs and conductivity changes

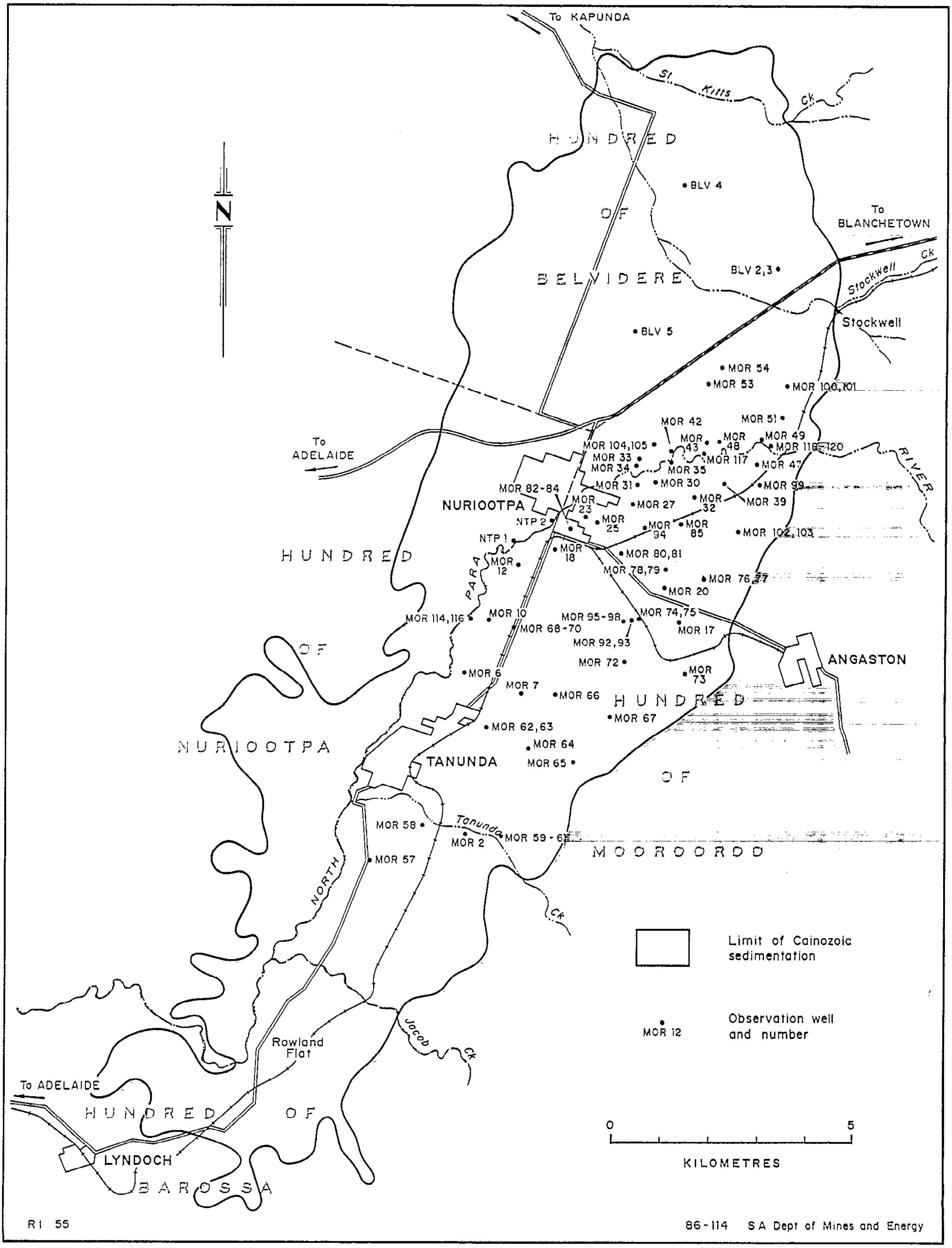


Fig. 69 Location of observation wells

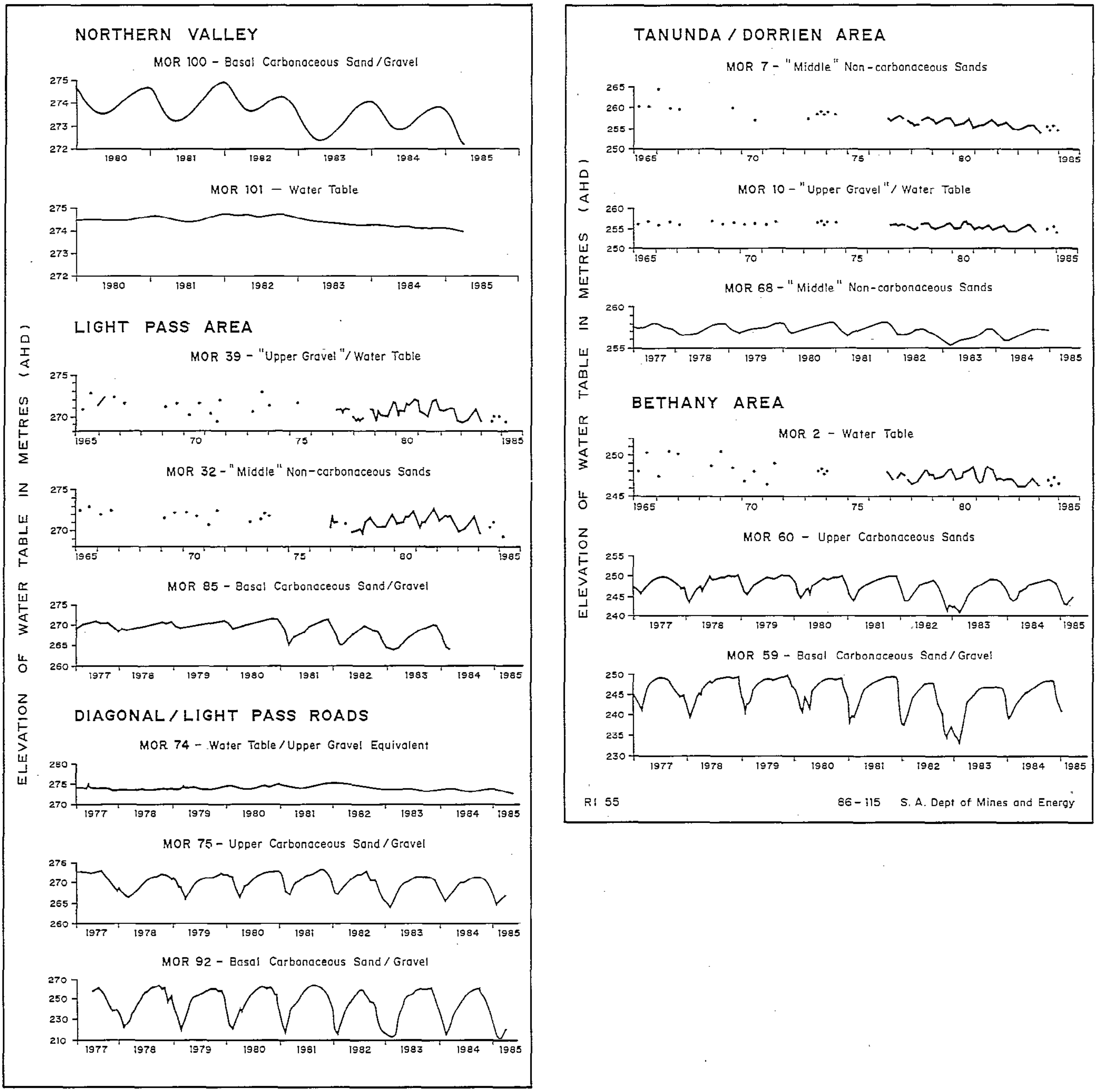


Fig. 70 Observation Well Hydrographs

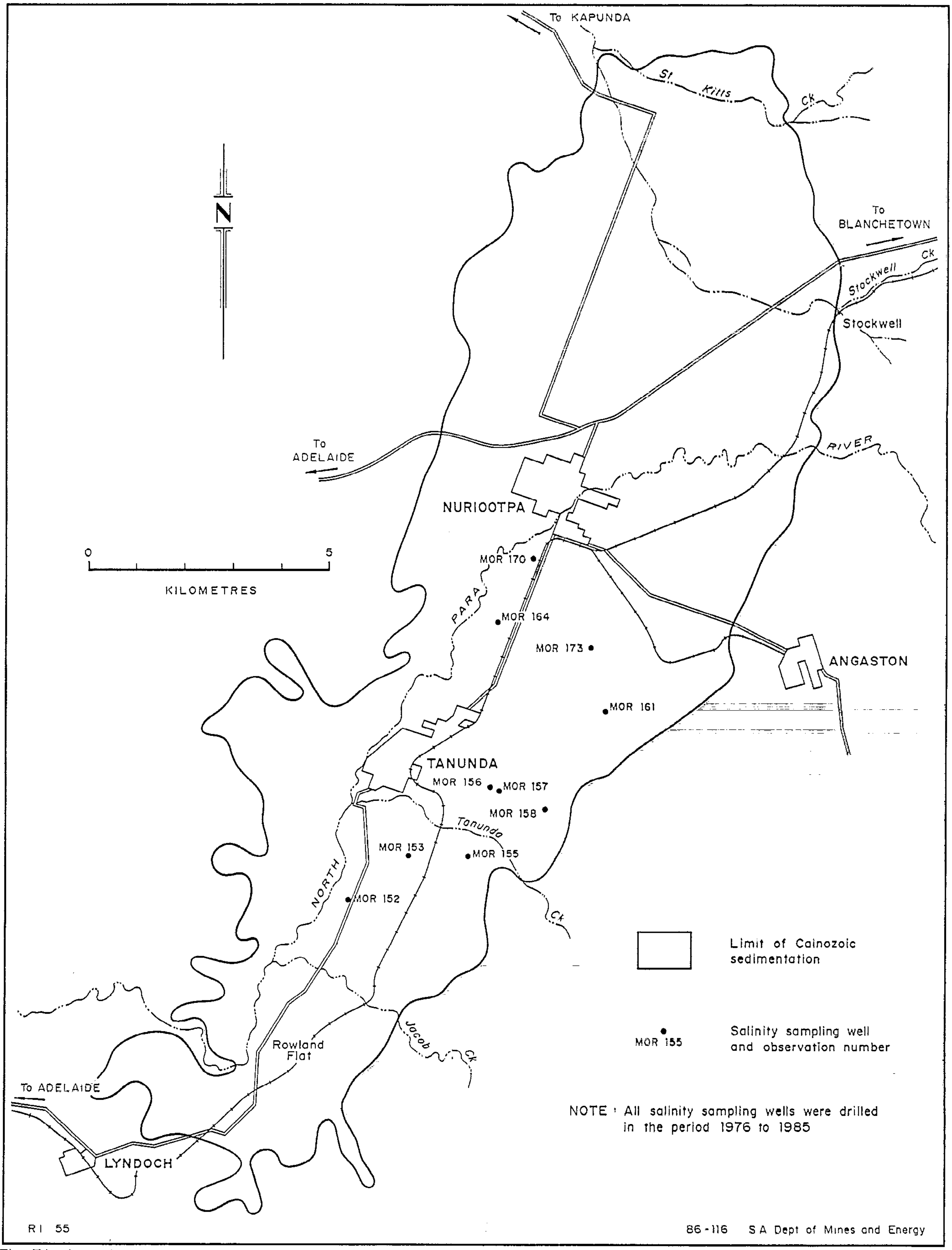


Fig. 71 Location of conductivity sampling wells

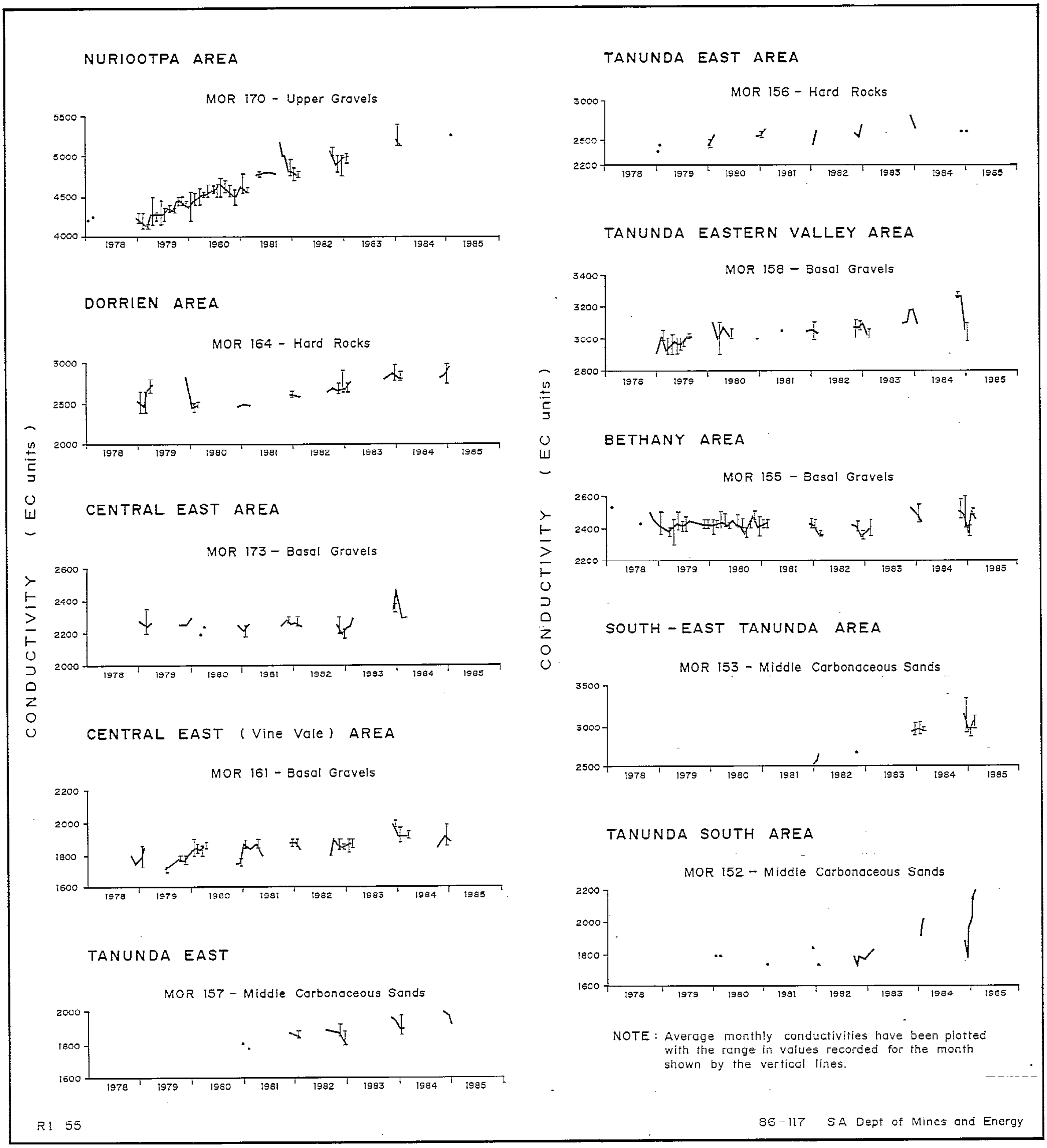


Fig. 72 Conductivity changes in aquifers from 1979-81