DWLBC REPORT

Overview of the hydrogeology of the Adelaide metropolitan area.

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Government of South Australia
Department of Water, Land and Biodiversity Conservation

Overview of the hydrogeology of the Adelaide metropolitan area

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
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EXECUTIVE SUMMARY

The study area occupies about 560 km^2 of the Adelaide Coastal Plain and is divided geologically into the Golden Grove-Adelaide Embayment and the Adelaide Plains Sub-basin. The plains are formed by Tertiary and Quaternary sediments up to 600 m thick, which contain up to ten aquifer systems, overlying a Precambrian fractured rock aquifer.

On several occasions since 1915 the uppermost Tertiary aquifer has been used to supplement the metropolitan water supply.

At present, extraction of 6000–8000 ML per year occurs from approximately 200 wells completed in the first Tertiary aquifer. Most of the water is used for industry, schools and recreation grounds.

During the course of this study, the observation networks of Quaternary, Tertiary and fractured rock aquifers were upgraded to cover the whole area, with the number of wells increased from 53–425. Wirelines downhole geophysical logging was carried out in all Mines and Energy Resources SA wells. Aquifer parameters were calculated accurately from several prolonged aquifer tests.

Salinity distribution within the lower Quaternary aquifer suggests that natural recharge is a mechanism which is more complex than previously thought. It suggests that lateral flow of better quality water from another aquifer, together with upward recharge, is more important than direct downward recharge.

Historic water level data suggests that the deeper Quaternary aquifers had a higher head than overlying aquifers. This upward hydraulic gradient is characteristic of the discharge side of the groundwater cycle. Upward flow (leakage) within the Quaternary aquifers would result in increasing salinity near the surface and discharge from the system, either by evaporation from overlying confining beds, or by flow in the shallower aquifer to surface streams flowing into the Gulf. This explains the gradual decrease in the size of the less than 1500 mg/L salinity zone from the deepest Quaternary aquifer (Q6) towards the most shallow one (Q1).

Past studies have left a number of important questions unsolved, including recharge mechanisms, aquifer extent and interconnection, and salinity stratification in some aquifers. Extensive groundwater development in recent years has necessitated a comprehensive study to examine the potential of the Tertiary aquifer.

The bulk of extracted groundwater is obtained from the T1 Aquifer; consequently it is recognised as the superior aquifer in terms of depth and salinity.

Salinity distribution in the T1 Aquifer suggests two flow mechanisms. The first is a flow to the west in the Little Para River area, while the second is a flow originating in the area southeast of Adelaide adjacent to the Eden-Burnside Fault. This recharge water flows towards the northwest through the area southwest and west of Adelaide. These two major salinity corridors are separated by a zone of relatively higher salinity, which is undoubtedly located at the extreme edge of recharge and flushing fronts.

The reconstructed pre-development potentiometric surface indicates that regional flow in the aquifer is similar to the general flow direction deduced from salinity distribution within the aquifer. It is similar to the regional flow of the overlying Quaternary aquifer.

EXECUTIVE SUMMARY

The present study indicates that the potentiometric surface of the uppermost Tertiary aquifer has reached, and is maintaining a new equilibrium, which does not recover to the level which existed prior to European settlement. This new equilibrium is probably not due solely to over-exploitation but is the result of several factors, including: continuous pumping for industry; the relatively low permeability of the top of the Tertiary sediments; upward leakage into Quaternary aquifers acting as ‘thief zones’ viz corroded casing; and possibly the most important, the effect of accumulated residual drawdown, resulting from 30 to 40 years of continuous, heavy pumping during summer.

It is estimated that between 500–600 wells were drilled in zones 2 and 3 into the Tertiary aquifer. Although only seven wells were completed in the second Tertiary aquifer, the information obtained was of great value for reconstructing the pre-pumping potentiometric surface.

Salinity distribution within Tertiary aquifers supports a revised recharge mechanism. The evidence suggests that major recharge to the Tertiary system occurs from basement rocks of the Mt Lofty Ranges into a deep, Tertiary aquifer along the Eden-Burnside Fault zone.

Evidence for salinity stratification within the second Tertiary aquifer suggests that this essentially unexploited water resource should be treated with caution and requires further investigation.

The ‘boundary’ separating the Adelaide Metropolitan Area and the Northern Adelaide Plains (NAP) is based on a high salinity zone, the result of differences in flushing and recharge mechanisms between the two areas. Recently constructed potentiometric surfaces confirm the hydraulic connection between the Adelaide Metropolitan Area and the Northern Adelaide Plains.

The inferred positions of the Para Fault and its splinters need to be revised. Several additional faults have been inferred parallel to the Eden-Burnside Fault zone and also west of the Para Fault.

1. INTRODUCTION

The Adelaide metropolitan study area occupies about 560 km^2 of the Adelaide Coastal Plain. It is bounded to the east and southeast by the Adelaide Hills, which consist of Proterozoic basement (meta-sediments), and to the west by Gulf St. Vincent. The plains are formed by Tertiary and Quaternary sediments up to 600 m thick, which contain several aquifer systems overlying basement rocks.

The area under consideration is divided geologically into two sub areas (Fig.1): the Golden Grove-Adelaide Embayment; and the Adelaide Plains Sub-basin (Daily et al, 1976).

The superficial sediments are primarily of deltaic origin, formed by the accumulation of sediments from the Adelaide Hills. Several ephemeral watercourses, including the River Torrens and the Sturt River, drain westerly and northwesterly towards the Gulf. Several small creeks enter the plain from the hills, with five reaching the River Torrens on its southern side and the sixth, Brown Hill Creek, discharging into the Sturt River.

During the early days of Adelaide settlement, water supplies were obtained from surface drainage. As the demand for water increased shallow wells were dug adjacent to rivers. However, these were unreliable and gradually settlers constructed deep wells into the Tertiary aquifers, where large quantities of good quality water (less than 1000 mg/L) were intersected at depths between 50–120 m. The bulk of abstracted groundwater was obtained from the top of Tertiary sediments comprising four main confined aquifers, designated first, second, third and fourth in order of increasing depth.

On six occasions since 1915, it has been necessary to augment the metropolitan water supply with groundwater. The latest occasion was in the 1967-1968 summer, when between 9500–10 700 ML was pumped from Tertiary aquifers into the distribution system during a seven month period.

At present, large quantities of groundwater are being pumped from the Tertiary aquifers for use in industry, schools and recreation grounds. Extraction from approximately 200 wells exploiting the first Tertiary aquifer has been estimated at between 6000–8000 ML in 1984.

The problem of contamination of good quality water by saline water from overlying aquifers has been recognised. Causes include indiscriminate drilling; incorrect drilling technique; failure to seal old wells; and overpumping of the Tertiary aquifer, which could induce downward leakage.

The study documented by this report concentrated on recognising the hydrogeological units, their distribution and relation to the general stratigraphic framework. Salinity distribution within each aquifer, and interaction and interconnection between aquifers, were also examined. As the study progressed, it became essential to re-examine recharge mechanisms and to calculate a reliable water balance. Information from 800 wells drilled into Quaternary and Tertiary sediments and basements were examined. Where information was deficient MESA (Mines and Energy Resources South Australia) drilled investigation wells.

Wireline geophysical logging was carried out in all MESA wells and private wells when available. This enabled correlations of stratigraphic and hydrogeological units where strata samples were not available or inaccurate.

The stratigraphy and hydrogeology of the area was studied in detail, including structure contour, isopach, aquifer thickness, depth to aquifer and other maps produced.

The Tertiary and fractured rock aquifers observation network was upgraded to cover the whole area, with the number of wells increased from 53–364. The Quaternary aquifer observation well network of 91 wells was established from private wells and the drilling of 43 MESA wells.

Several aquifer tests were carried out (each up to 120 hours duration), which enabled some hydraulic parameters to be calculated with reasonable accuracy.

Information on the second Tertiary aquifer (approximately 230 m deep) in the area west of the Para Fault was obtained by drilling seven additional wells, and by deepening and pressure-cementing two existing wells.

2. AIM AND OBJECTIVES

Figure 1 shows the coastal plain underlain by near-horizontal clay, sand, gravel and limestone of Tertiary and Recent age. The plain is bounded to the east by the Mount Lofty Ranges, formed mainly by gently folded, slightly metamorphosed Proterozoic sediments, including slates, phyllite, quartzite, limestone and dolomite.

The stratigraphy is summarised in Table 1. Table 2 summarises the geological history of the area. Deposition began in the Adelaide Geosyncline approximately 1000 million years ago. During the Tertiary, older structures were reactivated and led to the formation of half grabens (St Vincent Basin) and high relief topography (Mount Lofty Ranges) (Fig. 1). Sedimentation was initiated by further subsidence and was followed by marine transgression. Renewed tectonism during the late Tertiary/early Quaternary period resulted in basement uplift, gentle folding of Tertiary sediments and later marine regression. This was followed by the deposition of Quaternary and Recent fluviolacustrine and alluvial sediments, with interruptions by minor marine events.

Two major fault zones, along the Eden-Burnside Fault and the Para Fault, control the topography of the area. They are responsible for most of the major dislocation and tilting of the Precambrian rocks and for formation of the two embayments, the Golden Grove-Adelaide Embayment and the Adelaide Plains Sub-basin (Fig. 1). Several other faults were inferred during this study, parallel to the existing major structures.

3. METHODOLOGY

The Adelaide area has a typical Mediterranean-type climate, hot, dry summers and cool, wet winters. The average annual precipitation at Adelaide City is 531 mm (Fig. 2) with 60–65% of annual rainfall occurring during the period from May to September. The lowest rainfall occurs in January and February and accounts for only 3–4% of the yearly average, while June and July have the highest average, each 14% of total average annual rainfall.

In the Mount Lofty Ranges there is a surplus of precipitation over evapotranspiration of approximately 500 mm per annum. The hills catchments in this area are formed by basement rocks. If favourable lithological and structural conditions are present, a large proportion of the winter surplus is available for recharge.

4. RESULTS

Several ephemeral watercourses, including the River Torrens and the Sturt River, drain westerly and northwesterly towards Gulf St Vincent (Fig. 3). Six smaller creeks enter the plains from the hills and discharge into the River Torrens on its southern side, while Brown Hill Creek discharges into the Sturt River. Sixth Creek (Deep Creek) flows northesterly before discharging into the Torrens Gorge.

During the early days of settlement, water supplies were obtained from these watercourses and as the demand increased, shallow wells were dug adjacent to them.

Rainfall in the surface water catchments ranges from 800–1200 mm per annum.

The streams flow during all winter months but in summer the flows decrease dramatically in major streams and cease completely in smaller streams.

5. DISCUSSION

The Adelaide area is part of the St Vincent Basin and is divided geologically into two subareas, the Golden Grove-Adelaide Embayment and the Adelaide Plains Sub-basin (Fig. 1).

For this present study, approximately 800 wells (Fig. 4) were examined to delineate the stratigraphy and hydrogeology (Table 1). Stratigraphic boundaries were based on lithology and were correlated with logs previously described by Lindsay (1969) and Cooper (1979).

The oldest rocks are the Precambrian crystalline ‘Barossa Complex’, consisting of schist and micaceous gneiss. These rocks are unconformably overlain by younger Precambrian cover (Adelaidean), which extends northward to include the Mount Lofty and Flinders Ranges and forms part of the Adelaide Geosyncline. The Adelaidean is preserved as rocks of various lithologies including tillite, quartzite, felspathic quartzite, dolomite, phyllite, slate and siltstone. The Adelaidean is unconformably overlain by Tertiary and Quaternary sediments up to 600 m in thickness. Tables 2 and 3 summarise the stratigraphy of the area. The Adelaide area is part of the Tertiary St Vincent Basin as shown in Figure 1.

6. SUMMARY

Quaternary sediments contain up to six thin aquifers, while the Tertiary contains up to four aquifers. Groundwater of varying quality occurs in the Quaternary and Tertiary aquifers. Precambrian rocks (where they subcrop) can form useful fractured rock aquifers with generally good quality water at shallow depth.

Both the Quaternary and Tertiary aquifers were designated numbers in order of increasing depth (table 4), and the aquifer numbers were prefixed with Q, T and P respectively, viz:

- Quaternary aquifers — Q1 to Q6
- Tertiary aquifers — T1 to T4
- Precambrian fractured rock aquifer — P.

Despite the fact that the aquifers are identified with letters indicating their age, they remain realtively independent of stratigraphic units.

6.1 HYDROGEOLOGICAL ZONES

Hydrogeological zones are defined (Fig. 5) on the basis of hydrogeological characteristics assessed in this study. Table 5 summarises the aquifer distribution in each zone.

Zone 1

This zone covers the basement rocks of the Adelaide Hills and contains fractured rock aquifers.

Zone 2

This zone covers the area between Brown Hill Creek and Gult St Vincent. It contains from two to four Quaternary aquifers and from two to four Tertiary aquifers (Figs 5a–b). Only the T1 Aquifer is used significantly as it consists mainly of highly permeable formations (sandy limestone) and contains water of low salinity. Major pumping occurs from this aquifer.

Zone 2a

This hydrogeologically important, highly faulted, zone connects zone 2 with zone 3. Limited information is available for deep aquifers hence interpretation of major structures is speculative. Major features include up to four Quaternary aquifers and possibly three or four Tertiary aquifers.

Zone 3

This zone contains five to six Quaternary aquifers and also three to four, almost flat lying, Tertiary aquifers (Fig. 5a). The first and second Tertiary aquifers are the thickest and the most productive, with relatively low salinity. The greatest proportion of abstracted groundwater for industrial and recreational use comes from the first Tertiary aquifer.

This aquifer (at present) exhibits several cones of drawdown coinciding with known pumping centres; accordingly this zone is subdivided into five subzones as follows:

- Subzone 3A, Little Para River (irrigation)
- Subzone 3B, Penrice (ICI) – SAMCOR (industrial)
- Subzone 3C, West Lakes (irrigation)
- Subzone 3D, Torrens Valley (irrigation)
- Subzone 3E, Thebarton (industrial).

Zone 4

This zone covers a large portion of the Golden Grove-Adelaide Embayment. It contains up to three Quaternary and two Tertiary aquifers, and a fractured rock aquifer (Fig. 5c). Each Tertiary aquifer consists mainly of thin layers of fine sand with low yield. Most of the Quaternary and Tertiary aquifers become thin, shallow and interconnected in the vicinity of the River Torrens. The shallow fractured rock aquifer near the River Torrens contains groundwater of low salinity and significant yield.

Zone 4a

This zone is located between the Eden-Burnside Fault and the extension of the proposed Hope Valley Fault. It contains up to five Quaternary aquifers, one thick Tertiary aquifer (up to 130 m thick) and also one fractured rock aquifer.

7. CONCLUSIONS AND RECOMMENDATIONS

The main lithology of the Quaternary sediments is mottled clay and silt with interbedded sand, gravel and thin sandstone. The sands, gravels and sandstones represent aquifers; some near rivers and creeks were used extensively to supply water for the first European settlers. The present withdrawal from these aquifers is negligible. Up to six thin aquifer zones can be recognised from cross section, drill log and geophysical log interpretation (Figs 5a and 5c).

These are designated Q1 to Q6 in order of increasing depth (Table 6).

The Quaternary aquifers vary greatly in thickness (from 1–18 m), lithology and hydraulic conductivity. Generally, grain size decreases towards the coast, and with increasing distance from surface drainage and major structures such as the Para Fault.

The confining beds between the Quaternary aquifers consist of clay and silt and range in thickness from 1–20 m. These confining beds are absent in some areas, allowing hydraulic connection between aquifers. This can be observed, for example, between the fifth and sixth aquifers in certain subzones such as 3A and 3B.

Hydrogeological sections (Figs 5a–e) and salinity plans (Figs 6, 10, 12, 14–16) indicate the distribution of Quaternary aquifers.

7.1 FIRST QUATERNARY AQUIFER (Q1)

This aquifer, which is well distributed over the area (Table 6), is located at depths between 3 and 10 m below ground with an average thickness of 2 m. In the proximity of major structures and surface drainage, aquifer materials tend to be coarser and thicker and therefore more transmissive.

This aquifer was previously regarded as unconfined, but careful examination of water cut data has revealed that, in the majority of wells, confined conditions exist. This observation is important as it implies that, as long as the aquifer is fully saturated, changes in head are elastic responses. Average supplies from this aquifer rarely exceed 2 L/sec, from wells mostly located along major drainage lines and major structures where coarser fractions and thicker aquifers occur.

7.1.1 SALINITY

Figure 6 shows salinity distribution within the Q1 Aquifer. Low salinity is believed to be due to active recharge from surface drainage and from lateral inflow from the fractured rock aquifer.

In the Le Fevre Peninsula area where the Q1 Aquifer is overlain by dune sands, good quality water occurs in the sand dunes due to local direct recharge from precipitation. This water is used extensively for garden watering (approximately 600 wells are recorded). An underlying layer, with poor water quality (salinities up to 21 000 mg/L) also occurs.

It appears that there is no reliable confining bed separating these layers. The fresh water distribution is governed by the topography of sand dunes. Fresh water lies on top of the underlying salty water due to the density contrast, with little mixing. It is expected that over-pumping of good quality water from this area could introduce sea water intrusion or upconing from the underlying salty aquifer.

7.1.2 POTENTIOMETRIC SURFACE AND GROUNDWATER FLOW

A network of Q1 Aquifer observation wells (Fig. 7) was established in 1980-81 to examine the potentiometric surface of the area. Figure 8 was constructed from water levels observed during winter to minimise seasonal effects. The contours show that groundwater flows uniformly towards the northwest across the area in the first Quaternary aquifer.

The potentiometric surface gradient is steep in the east adjacent to the Mount Lofty Ranges. Near the coast and west of the Para Fault the gradient is almost flat.

This flat gradient of 1 m/km may be a result of higher transmissivity and/or the effect of gentle topography. Heavy pumping from the underlying Tertiary aquifer has induced downward leakage, which has led to the development of a cone of depression in the Q1 Aquifer in the northern part of the area. This may induce sea-water intrusion into the Q1 Aquifer in this area.

In general, the outflow from the Q1 Aquifer to Gulf St Vincent is small, as the gradient at the coast is flat and the transmissivity is relatively low.

7.1.3 WATER LEVEL FLUCTUATIONS AND CHANGES

The 1981 observation well network has provided limited information for extensive interpretation during its short period of monitoring. However, selected hydrographs from each zone (Figs 9A–C located in Fig. 7) show the following:

- A rise in water level in 1981 and 1983 in response to above average winter rainfall;
- An overall steady decline in water level during the five years of measurements, in spite of 1981 and 1983 above average rainfall; and
- Seasonal water level fluctuations.

Miles (1952, p.55) reported a water level decline of 0.53 m/year during three and a half years of observation between 1927–30. Present average yearly decline in water level is 0.15 m.

The rate of yearly decline of water level and change in aquifer storage is controlled by several factors, including rate of recharge, extraction from aquifer, evapotranspiration, movement of water down gradient, downward leakage and natural discharge.

The mean annual rainfall over Adelaide for all years of record is 531 mm, which is less than the mean annual rainfall of 550 mm between 1981–86. This indicates that the continuous observed decline in water level is a result of contributing factors such as:

- Urbanisation;
- Lining of surface drainage with concrete, thus reducing recharge to the aquifer;
- Extensive local pumping from the first Quaternary aquifer (e.g. in Observation well. ADE 104);

- Continuous downward leakage resulting from development of the basin and elimination of historic recharge to this aquifer, as a result of reversing historic head gradient; this is caused mainly by extensive pumpage from the underlying Tertiary aquifer; and
- Continuous leakage from the aquifer into the old corroded sewage pipes.

If the rate of water level decline of 0.15 m/year is accurate and constant, then the total decline of head during the last 50 years is 7.5 m.

Information obtained from a study carried out in the vicinity of the old clay plughole in the Bowden-Brompton area suggested an average of 4 m decline of water level over the last 50 years.

Seasonal fluctuations of up to 0.5 m have been observed over most of the area in response to recharge, downward leakage, evapotranspiration, and changes in pressure transmitted across the formations.

7.2 SECOND QUATERNARY AQUIFER (Q2)

This aquifer is well distributed over most of the area except along the River Torrens upstream of Thebarton, where it merges with the first Quaternary aquifer (Fig. 10).

The aquifer top lies between 16 and 30 m below ground. Its thickness ranges from 0.5–10 m with an average thickness of 2 m. In general, the aquifer is thicker near major surface drainage lines, and available information suggests that 4 m of gravel can supply up to 550 m^3/day (6 L/sec) west of the Para Fault. The grainsize of aquifer material, and hence available yield, decreases towards the coast and with increasing distance from surface drainage.

7.2.1 SALINITY

This aquifer shows a very wide range in salinity, from less than 500 mg/L (obs well 712) to 29 300 mg/L. Figure 10 shows the generalised salinity distribution within the Q2 Aquifer.

The lowest salinities are found adjacent to streams and fractured rock aquifers of the Mount Lofty Ranges (First Creek to Fifth Creek). Low salinity is also recorded along the northern side of the River Torrens.

High salinities occur away from the above recharge influences. In particular, salinities greater than 5000 mg/L occur adjacent to the coast and adjacent to the fractured rock aquifers just west of Brown Hill Creek.

This salinity distribution suggests some direct recharge from the River Torrens and the Little Para River. The extent of less than 1500 mg/L water beneath the River Torrens in Q2 is, however, much greater than in Q1, suggesting that lateral flow of better quality water from another aquifer is more important than simple direct downward recharge.

7.2.2 POTENTIOMETRIC SURFACE AND GROUNDWATER FLOW

The limited information which is believed to be reliable (Fig. 11) suggests a potentiometric surface which is similar to the potentiometric surface of the first Quaternary aquifer. This indicates that flow would be towards the northwest, which is similar to the general flow direction deduced from salinity distribution within the aquifer. One observation well (ADE 116) shows an average decline in water level of 0.25 m/year.

7.2.3 HEAD DIFFERENCE BETWEEN Q1 AND Q2 AQUIFERS

Available information shows a very small head difference between Q1 (obs well ADE 115) and Q2 (obs well ADE 116), which indicates either inadequate isolation of aquifers during well construction or effective hydraulic continuity between the two aquifers. Limited information suggests that the water level in Q1 (obs well ADE 176) is 4–5 m higher than in Q2 (obs well ADE 177) in proximity to the Eden-Burnside Fault.

7.3 THIRD QUATERNARY AQUIFER (Q3)

This aquifer is widely distributed except along the River Torrens east of the City of Adelaide, where it merges with other aquifers (Fig. 12). Depth to Q3 is between 31–45 m below ground. The aquifer dips gently to the northwest, similar to the overlying Q2 Aquifer.

The Q3 Aquifer consists of gravel and sand with an average thickness of 2 m. Adjacent to major surface drainage features, yields of up to 300 m^3/day are common.

7.3.1 SALINITY

Figure 12 shows salinity distribution within the Q3 Aquifer. Salinity values adjacent to the Eden-Burnside Fault are represented by only four wells. They show low salinity in this area, which indicates that recharge is dominated by lateral flow from the fractured rock aquifer.

There is some evidence of high salinity zones between Brown Hill Creek (2400 mg/L) and the Sturt River (6300 mg/L). These higher salinities may be a result of contamination from the overlying Q2 Aquifer during sampling, or they may be related to an area of near stagnation caused by exceptionally low aquifer permeability.

In the area west of the Para Fault, salinity distribution shows several interesting features, which include:

- North of the River Torrens, the extent of less than 1500 mg/L water is similar to the Q2 Aquifer. However, in most wells the salinity of Q3 is significantly lower than that in Q2 (obs wells 526, 517, 530 and 504).
- South of the River Torrens, the salinity of less than 1500 mg/L is better than that of Q2, which lies within the 1500-2500 mg/L zone.
- In general the extent of the salinity zone of less than 2500 mg/L is much greater in Q3 than in Q2, while the extent of the zone of greater than 5000 mg/L is far less than in Q2.

An overall comparison between salinity distribution in the Q3 and Q2 Aquifers indicates that the extent of lower salinity zones in Q3 is much greater than in Q2, suggesting that recharge is more complex than downward leakage.

7.3.2 POTENTIOMETRIC SURFACE AND GROUNDWATER FLOW

Figure 13 shows the potentiometric surface of the Q3 Aquifer, constructed from limited cable tool drilling information collected prior to extensive groundwater development in the area.

This information shows that the regional flow is towards the northwest, similar to the general flow directions of the two overlying Quaternary aquifers.

7.4 FOURTH QUATERNARY AQUIFER (Q4)

This aquifer, which is located at depths between 46–60 m below ground, is well developed near major structures and in areas west of the Para Fault (Fig. 14). In the area between the Eden-Burnside Fault and the Para Fault, the aquifer merges with underlying and/or overlying aquifers. It consists mainly of gravel and sand and/or sandstone. Average yield is estimated at 100 m^3/day; however, exceptionally high yields of up to 760 m^3/day were recorded from two observation wells (project no's 570 and 575).

7.4.1 SALINITY

Figure 14 shows the salinity distribution within the Q4 Aquifer. It is based on very limited information.

Data from two observation wells (project no's 188 and 721) located near the Eden-Burnside Fault indicate low salinities of 685 and 705 mg/L, suggesting direct recharge from the fractured rock aquifer.

The area just west of the Para Fault in the vicinity of Brown Hill Creek, has recorded two low salinity values of 630 and 870 mg/L. This suggests that recharge occurs via lateral flow from another aquifer (possibly T1 Aquifer).

Low salinity of less than 1000 mg/L was recorded in three observation wells (project no's 523, 526 and 505) along the northern side of the River Torrens.

Further towards the west, salinity increases dramatically to more than 20 000 mg/L (project no's. 523, 670, 497, 540 and 717).

Several recorded values are significantly lower than the salinity of the overlying Quaternary aquifer. This indicates that downward leakage is not the prime mechanism responsible for flushing of this system.

Salinity distribution over the whole area suggests a flow direction towards the west and northwest. In addition, it is concluded that most of the recharge occurs as a result of lateral flow from adjacent aquifer(s).

7.4.2 POTENTIOMETRIC SURFACE, GROUNDWATER FLOW AND SEASONAL FLUCTUATIONS

Using the available water level data it is not possible to construct an accurate potentiometric surface map.

Recent observation of three wells (obs well no's YAT 86, 111 and 124) shows an almost continuous decline in water level of 0.2 m/year and also a seasonal fluctuation between 0.2–0.8 m. As there is no pumping from this aquifer, the recently observed decline in water level is believed to be due to downward leakage in response to pumping from underlying aquifers. Seasonal fluctuations are apparently caused by pressure transmitted across the confining bed as a result of seasonal pumping from the Tertiary aquifer.

7.5 FIFTH QUATERNARY AQUIFER (Q5)

The distribution of this aquifer is restricted to west of the Para Fault, apart from a small area in proximity to the Eden-Burnside Fault (Fig. 15).

In the Little Para River area, the Q5 Aquifer is difficult to identify and appears to merge with other aquifers. Where merging is suspected, some information from the Q4 and Q6 Aquifers has been used in constructing the salinity distribution.

The depth to the Q5 Aquifer is between 65 and 80 m below ground. Aquifer thickness averages 2 m and yield rarely exceeds 60 m^3/day. Two observation wells (project no's. 535 and 575) show that the aquifer can attain a thickness of 12 m and can supply up to 1000 m^3/day.

7.5.1 SALINITY

Salinity distribution (Fig. 15) shows a level of up to 1900 mg/L along the River Torrens in proximity to the Para Fault. This indicates that recharge from surface water drainage does not reach the Q5 Aquifer in this area, contrary to the conclusions of previous studies (Miles, 1952).

The zone of less than 1500 mg/L salinity immediately west of the Para Fault indicates that lower salinity groundwater inflows across the Para Fault from aquifers to the southwest. Generally, flow is towards the north to northwest.

The areal extents and locations of the less that 1000 mg/L and the greater than 5000 mg/L salinity zones do not correlate with similar zones in the Q4 Aquifer. This suggests that historic recharge to the Q5 Aquifer did not occur from downward leakage; that is confining beds separating Q5 and Q4 are of low permeability.

7.5.2 POTENTIOMETRIC SURFACE AND GROUNDWATER FLOW

The few existing water levels obtained prior to extensive groundwater development which are believed to be reliable, show that pre-development water level elevation ranges between 9 m in the eastern area and 2 m near the coast, indicating groundwater flow directions towards the west-northwest. This flow direction is similar to the general flow direction deduced from present day water level elevations and salinity distributions within the aquifer, and from the overlying Quaternary aquifers.

The pre-development general hydraulic gradient can be estimated at 1×10^3, and the present day gradient at 0.85×10^3, indicating a slightly flatter gradient in response to downward leakage.

7.5.3 WATER LEVEL DECLINE AND SEASONAL FLUCTUATIONS

A comparison between historic and present day data indicates that water level shave declined at least 3 m over the last 40–50 years. However, information from wells in the eastern area shows that water was flowing at ground level (7.2 m Australian Height Datum (AHD)), which represents a water level elevation of 7.2 m+ prior to 1934. If this assumption is valid, then the aquifer has lost at least 8 m of head during the last 50–70 years. At present, there is no pumping from this aquifer and the observed seasonal fluctuations range between 0.4 m in the eastern area and 2 m in the western area of the zone. Summer and winter water level elevations (below zero) indicate that there is no outflow from this aquifer under the Gulf.

These observations (decline in water level, seasonal fluctuations and water land elevation) indicate that this aquifer provides downward leakage to an underlying aquifer. The leakage (possibly representing outflow) may be equal to total inflow to this aquifer (lateral flow plus leakage from the Q4 Aquifer).

7.6 SIXTH QUATERNARY AQUIFER (Q6)

The distribution of this aquifer is limited to the area west of the Para Fault (Fig. 16). The depth to aquifer top is 80–100 m below ground and average thickness is 2 m. Generally, the Q6 Aquifer consists of sand and gravel with low yield (range is from 86–216 m^3/day).

7.6.1 SALINITY

Figure 16 shows the generalised salinity pattern. It ranges from less than 700 mg/L in several areas to 45 500 mg/L near the Gulf.

Salinity of up to 1375 mg/L was recorded near the River Torrens (project no. 526) in proximity to the Para Fault, which indicates that surface water does not influence recharge to this deep Quaternary aquifer. There are obvious similarities in salinity distribution between the Q6 and Q5 Aquifers, in particular the extent of the less than 1000 mg/L zone, which dominates the area centred on the River Torrens.

In some wells salinity values in the Q6 Aquifer are lower than those in the Q5 Aquifer, suggesting a recharge from the better quality water of the underlying first Tertiary aquifer.

7.7 QUATERNARY AQUIFER CONFINING BEDS

A maximum of seven Quaternary confining beds were recognised during this study and designated Cb1 to Cb7 in order of increasing depth. Their positions in relation to aquifers and average thickness in zone 3 are summarised as follows:

- Cb1, overlies the Q1Aquifer
- Cb2, separates the Q1 and Q2 Aquifers
- Cb3, separates the Q2 and Q3 Aquifers
- Cb4, separates the Q3 and Q4 Aquifers
- Cb5, separates the Q4 and Q5 Aquifers
- Cb6, separates the Q5 and Q6 Aquifers
- Cb7, separates the Q6 Aquifer and the underlying first Tertiary aquifer.

These confining beds consist mainly of clay with minor silt and occasionally sand.

Two wells were drilled in zone 3 to examine the hydraulic conductivity of the confining beds. The first well (obs well no. ADE 190) is located near the Para Fault and the River Torrens in the Thebarton area; the second well (obs well no.YAT 123) is located in the Grange area adjacent to Gulf St Vincent (Tables 7–8).

To reduce total drilling costs, continuous coring was not undertaken. Instead, a series of spot (PQ) cores were collected at predetermined intervals, and laboratory tests were carried out to determine vertical and horizontal hydraulic conductivities.

It is of some significance that Cb5 and Cb6 have vertical conductivity (Kv) which are at least an order of magnitude lower at Grange (obs well no. YAT 123) compared with Thebarton (obs well no. ADE 190). The lithological descriptions (Tables 7–8) list the YAT 123 samples as grey and brown clays, whilst samples from observation well number ADE 190 are described as silty clays and clayey silts.

The position of the wells with respect to the likely sediment source (from the east) is consistent with the ADE 190 site receiving slightly coarser material (silt rather than clay) and therefore having a probability of slightly higher hydraulic conductivities.

It should be remembered, however, that these confining beds were samples and tested approximately 50 years after commencement of development of the groundwater resource. The Grange area has been subjected to heavy withdrawals which has resulted in considerable drawdown in the Tertiary aquifer. Some consolidation of overlying confining beds, with resultant reduction in porosity and permeability, seems likely. Part of the difference between Cb5 and Cb6 at these sites may be due to different levels of drawdown, as well as to lithological differences.

7.8 QUATERNARY AQUIFER HEAD RELATIONSHIPS

7.8.1 HISTORIC HEAD RELATIONSHIPS

Information such as water cuts and water levels from early cable tool drilling was used to assess pre-development aquifer relationships. In spite of few data points and some dubious data, evidence suggests that deeper aquifers did have a higher head than overlying aquifers.

This upward hydraulic gradient is characteristic of the discharge side of the groundwater cycle. Upward flow (leakage) within the Quaternary would result in increasing salinity near the surface, and discharge from the system, either by evaporation from Cb1 or flow in the shallower aquifers to streams and to the Gulf.

This explains the gradually decreasing area of the 1500 mg/L salinity zone from Q6 towards the Q1 Aquifer. As the better quality water leaks upward, evaporation concentrates the salt in the first Quaternary aquifer and/or the soil profile. This phenomenon can be seen in the salinity plans and section.

In areas near surface drainage, west of the Para Fault, some wells show the Q2 Aquifer head higher than Q1.

7.8.2 PRESENT DAY HEAD RELATIONSHIPS

Information from the scattered observation wells indicates downward leakage between all aquifers.

In the area west of the Para Fault, there is some evidence indicating that the Q1 and Q2 Aquifers are hydraulically connected and respond as one aquifer.

In summary, evidence from the area west of the Para Fault and southwest of Adelaide City, and between the Para Fault and the Eden-Burnside Fault, indicates that the present day downward vertical gradient is not consistent with the observed water quality distribution. Historically, recharge to deep Quaternary aquifers occurred as a result of upward leakage from underlying aquifers, with some redistribution from lateral flow.

In the area bounded by the Para and Eden-Burnside Faults, the limited historic and recent information suggests that the head in shallow aquifers is generally higher than in underlying aquifer(s), indicating downward flow in the same direction as the salinity increase. However, at one location close to the Eden-Burnside Fault, evidence suggests that downward leakage is negligible.

7.9 OUTFLOW FROM QUATERNARY AQUIFERS

7.9.1 HISTORIC OUTFLOW

Quaternary aquifer water levels indicate a general flow towards the northwest with ultimate discharge under Gulf St Vincent. The deepest point in the Gulf is 25 m, indicating that only the Q1 and Q2 Aquifers may naturally outflow into the Gulf. Deeper Quaternary aquifers are overlain by thick, low permeability sediments with their discharge opportunities limited to structures (faults) under the Gulf and/or through upward leakage. Provided that these structures possess sufficient permeability, they may form discharge boundaries. Their permeabilities control the amount of outflow from aquifers, head relations between aquifers, and hence leakage direction.

A highly permeable discharge boundary does not restrict outflow from an aquifer, but allows groundwater mixing at the boundary. This facilitates equilibration of heads in the various aquifers, which results in horizontal flow towards the boundary being the dominant flow mechanism.

Information from the previously discussed aquifer head relations (deep/shallow) indicates that these deep aquifers produced flowing wells in proximity to the Para Fault. It is possible that the discharge boundary is of low permeability, restricting lateral groundwater outflows and enhancing upward leakage, which may even form the total outflow from the majority of deep Quaternary aquifers (Q5 and Q6).

The suggested Quaternary aquifer outflow mechanisms are summarised as follows:

- Q1 Aquifer; lateral outflow into the Gulf, surface drainage, and evapotranspiration where the water table is within a few metres of the land surface.
- Q2 Aquifer; lateral outflow into the Gulf and upward leakage to the Q1 Aquifer.
- Q3 and Q4 Aquifers; possibly minor outflow into the Gulf but primarily upward leakage.
- Q5 and Q6 Aquifers; mostly upward leakage.

7.9.2 PRESENT DAY OUTFLOW

Available information suggests that major components of the Q1 Aquifer outflow are:

- Extraction from shallow backyard wells
- Downward leakage
- Lateral flow into the Gulf
- Base flow into the River Torrens in most of zone 4.

Most of the outflow is from the remaining Quaternary aquifers (Q2-Q6); limited recent information from these aquifers suggests two mechanisms of outflow:

- Downward leakage
- Lateral flow into the Gulf.

8. TERTIARY AQUIFERS

Tertiary sediments contain several aquifer systems, each of which may comprise various subaquifers.

Groundwater occurs mainly in four, mostly confined aquifers, designated T1, T2, T3 and T4 in order of increasing depth.

These aquifers are relatively independent of the stratigraphic units. Their distribution (Table 9; Figs 5a–e) depends largely on the depositional environment, major structure, movements along major faults, and the general geological history of the area.

These aquifers exhibit large various in thickness, lithology, salinity distribution and yield. The first Tertiary aquifer (T1) is recognised as the superior aquifer in terms of salinity and yield. It is also the shallowest and therefore the most easily developed of the four Tertiary aquifers. As the bulk of abstracted groundwater is obtained from T1 Aquifer, this study has focused on this aquifer and its relationship with other aquifers.

The confining beds separating these aquifers vary in their distribution, thickness, lithology and hydraulic properties. Figures 5a–e show the position of confining beds with respect to maximum thickness of aquifers, as well as their general distribution over the area.

8.1 FIRST TERTIARY AQUIFER (T1)

The first Tertiary aquifer is defined as the first intersected, saturated and permeable Tertiary sediments, regardless of their stratigraphic age. T1 may therefore consist of several stratigraphic units which vary in lithology and thickness (Table 10). These sediments may include the overlying Carisbrook Sand, which underlies Quaternary clay. This aquifer occupies most of the study are and generally is confined, except where it becomes shallow or outcrops.

Zone 1 – Mount Lofty Ranges

The area immediately to the east of the Eden-Burnside Fault does not contain any Tertiary aquifers. The fractured rock aquifer system (Precambrian age) is the only significant aquifer in this zone.

Zones 2 and 2a

In the area located between Brown Hill Creek and east of the Sturt River the aquifer consists of several layers (Fig. 5a), described as follows:

- Hallett Cove Sandstone (Unit 4). A thin, well cemented, pale yellow to reddish yellow layer of sandstone.
- Port Willunga Formation limestone (Unit 8). Yellow, friable, highly permeable limestone, interbedded with layers of dark yellowish brown silt and rare clay.
- Part of Ruwarung Member. This comprises several metres of dark grey sandy silt and limestone; occasionally contains shell fragments.

- In proximity to the hills, Carisbrook Sand is hydraulically connected to the underlying Port Willunga Formation limestone, which in turn overlies a relatively thick sand.

Figure 17 shows an average thickness of 50 m, which increases to 80 m near the hills. This figure also shows the aquifer base to be generally in the middle of the Ruwarung Member (Unit 9), except in proximity tot he Eden-Burnside Fault, where it is located within the Aldinga Member (Unit 10).

Most individual wells are capable of supplying an average of 15 L/sec, except in proximity to the hills and along the Sturt River, where yields are lower.

In the area along the Sturt River, extending 2 km westward and 1–1.5 km to the east, the aquifer (T1a) consists of Hallett Cove Sandstone and Dry Creek Sand (Unit 4), which Munno Para Clay Member (Unit 7) forming the aquifer base. The aquifer thins towards the south and the east with an average thickness of 3 m, and produces insignificant yields. Most of the production wells in this area are therefore completed in the second Tertiary aquifer (T2).

In the area along the coast west of the Sturt River, the T1 Aquifer occupies a narrow strip approximately 1.5 km wide, and consists of two major subaquifers, Tla and Tlb.

- Subaquifer T1a consists of Carisbrook Sand (Unit 3), Hallett Cove Sandstone and Dry Creek Sand (Unit 4), and the permeable portion of ‘Croydon facies’ sediments (Unit 5).
- Subaquifer T1b consists mainly of Port Willunga Formation limestone (Unit 6), which overlies Munno Para Clay Member (Unit 7).

Munno Para Clay Member (Unit 7) occurs at an average depth of 90 m below ground (Fig. 5b). It consists of an average 8 m of dark grey bluish clay interbedded with two bands of pale grey limestone.

Table 2 describes the lithology of each subaquifer in detail. The depth to the top of subaquifer T1a averages 65 m, while the top of subaquifer T1b lies 85 m below ground.

Figure 5b shows the total thickness, which ranges from 25–50 m; T1a has an average thickness of 30 m and T1b an average thickness of 20 m.

Extended well development is necessary to obtain sand-free water from subaquifer T1a. Information compiled from wells in the area indicates that subaquifer T1b has the potential for supplying a maximum of 6 L/sec (5000 g/hour) of sand-free water.

Zone 3

This zone occupies the area west of the city and is bounded on the east by the Para Fault. The first Tertiary aquifer in this zone consists of two major subaquifers (Gerges, 1986) and three confining beds. They are summarised as follows:

- Confining bed, the grey clay of Quaternary age.
- Subaquifer T1a, which consists of Carisbrook Sand (Unit 3), Hallett Cove Sandstone and Dry Creek Sand (Unit 4), and the permeable portions of ‘Croydon Facies’ (Unit 5).
- Semi-confining bed, the remaining part of ‘Croydon Facies’.
- Subaquifer T1b, which consists of Port Willunga Formation (Unit 6).
- Confining bed, Munno Para Clay Member (Unit 7), which forms the base of the T1 Aquifer.

Confining bed, the grey clay

This clay of Quaternary age separates the T1 Aquifer from the overlying Quaternary aquifers. It attains a maximum thickness of 3 m and is uniformly distributed over the area (Gerges, 1980a; 1982a,b). The clay is typically sticky, dark grey, non-fossiliferous, and slightly calcareous to non-calcareous. In the centre of the area, it becomes dark reddish (oxidised), suggesting a possible more active interconnection between the Quaternary and Tertiary aquifers.

Subaquifer T1a

- The Carisbrook Sand (Unit 3)

This unit is confined to large portions of subzone 3A, mainly in the vicinity of the Little Para River. It consists of cream to yellow and grey to black non-calcareous to slightly calcareous, moderately sorted sand. In some areas (Little Para River) the sand is highly carbonaceous and interbedded with layers of lignite and/or highly carbonaceous silt (Selby and Gerges, 1980). The depth to this unit ranges between 60–80 m below ground.

In subzone 3A the thickness of this sand varies between 100 and 6% of the total thickness of subaquifer T1a, or 70 and 4% of the total thickness of T1 (Fig. 17).

A maximum thickness of 64 m of the unit was intersected along the Little Para River in proximity to the Para Fault.

The potential supply from this aquifer averages 3.7 L/sec (3000 g/hour); however, a few wells are capable of up to 12 L/sec (10 000 g/hour), suggesting a possible interconnection to the underlying aquifer. Most of the reliable supplies are obtained in an area adjacent to the Little Para River.

Low salinity of 600 mg/L occurs along most of the Little Para River. High salinities of up to 3600 mg/L were recorded in the Wingfield (Gerges, 1982b) and Waterloo Corner areas (Selby and Gerges, 1980).

- The Hallett Cove Sandstone, Dry Creek Sand and portion of ‘Croydon Facies’.

These units are well distributed over the area except in small areas along the Little Para River.

They consist of white, yellow and dark grey well cemented, highly fossiliferous sandstone and sand containing an abundance of shell remains. The lower section contains interbedded layers of dark grey glauconitic, shelly sand, silt and clay. The permeable portions of ‘Croydon Facies’ consist of sand, silt and shells with some very dark grey, loose limestone fragments embedded in the sand. The depth to the top of these aquifer units is relatively constant and averages 110 m, but ranges between 130 m near the Para Fault and 60 m in proximity to the Gulf.

The total thickness of subaquifer T1a includes:

- the total thickness of Carisbrook Sand
- the total thickness of Hallett Cove Sandstone and Dry Creek Sand
- the permeable portion of ‘Croydon Facies’ which is estimated to be 40–50% of its entire thickness.

Semi-confining bed, part of 'Croydon Facies'

Information from drilling, geophysical logs and pump tests suggests the presence of a leaky semi-confining bed between subaquifers T1a and T1b. It lies within the 'Croydon Facies' (Unit 5) and consists mainly of sandy, silty clay, interbedded with loose bryozoal fragments. Aquifer testing (discussed later) shows the significance of this layer.

Subaquifer T1b, the upper Port Willunga Formation limestone

Subaquifer T1b is comprised of this unit and is well distributed over the whole zone. It attains a maximum thickness of 60 m at North Glenelg (Gerges, 1980) and thins northward (Gerges, 1982).

It consists of moderately weathered yellow limestone interbedded with thin bands of sand, silt and clay, which overlies a well cemented pale grey to white limestone. The consistent colour change with increasing depth over the whole zone is significant in identifying the subaquifer from rotary drilling cuttings.

Information compiled from wells drilled in the area indicates that T1b has the potential to produce large supplies of sand-free water. The specific capacity of this subaquifer averages 20 m^3/day per metre of drawdown.

Salinity (Fig. 18) ranges from 700 mg/L in the middle of the zone increasing to 900 mg/L towards the south and up to 3110 mg/L in zone 3B (Gerges, 1982).

Confining bed, Munno Para Clay Member

In zone 3 the Munno Para Clay Member consists of 6–10 m of dark grey clay interbedded with two bands of pale grey limestone. In a well drilled at North Glenelg, the first band was reported dry or to contain little supply, while the second was found to contain water with salinity close to the average salinity of the T1 and T2 Aquifers.

Laboratory testing of cores taken from the clay in several locations suggests that the clay is of very low permeability. In the Wingfield area, the vertical permeability averages 1.6×10^{-5} m/day (Gerges, 1982).

Recent drilling at several locations in the Northern Adelaide Plains shows a small variation in vertical permeability, ranging between 1.2×10^{-6} and 2.6×10^{-7} m/day (Gerges, in preparation).

Another core collected from a well near Adelaide Airport (ADE 146) was tested for several months without significant flow through the core, suggesting an abnormal very low vertical permeability.

Zone 4a

Zone 4a is located between the Eden-Burnside Fault and the extension of the 'Hope Valley Fault. It contains one thick Tertiary aquifer and consists of various stratigraphic units.

Information obtained from drilling together with re-interpreting old well data along the Eden-Burnside Fault indicate the presence of a deeply buried Tertiary trough containing up to 130 m of clastic sediments (Figs 7d and 7f). This trough extends along most of the length of the Eden Burside Fault.

The greatest thckness is located along the downthrow side of the Eden-Burnside Fault where palaeontological control is poor and the sand close to the fault could be included as undifferentiated Tertiary sand. These sediments consist mainly of sand, gravel and minor silt.

The hydrogeological significance of the trough is discussed later.

Zone 4

Zone 4 covers large portion of Golden Frove-Adelaide Embayment. The T1 Aquifer is gernerallly thin and consists of several stratigraphic units ranging from Aldinga Member sand to South Maslin Sand. Drilling suggests that supply from this aquifer is very limited and rarely exceeds 2 L/sec.

8.1.1 HISTORIC SALINITY DISTRIBUTION IN THE FIRST TERTIARY AQUIFER

Water quality data from several hundred wells were examined and validated before being used for analysis and interpretation. Approximately 50 to 60% of these data were collected prior to the 1950s and are assumed to represent the historic salinities within this aquifer. Salinity information from both subaquifers T1a and T1b was used in data analysis of the T1 Aquifer.

Figure 18 shows the salinity distribution within T1 Aquifer, which can be summarised as follows.

Zone 4a

Information from the few scattered wells indicates that the best water quality of less than 800 mg/L salinity occurs in proximity to the Eden-Burnside Fault zone. This may be interpreted as representing direct flow from the fractured rock aquifer of zone 1 to the first Tertiary aquifer. This zone contains one thick aquifer which shows evidence of a slight increase in salinity with depth. This may indicate a decrease in vertical hydraulic conductivity with increasing depth.

Low salinity groundwater is restricted to a few small areas particularly along Fourth Creek (project well nos 279, 303, 280, 281, 283, 661 and 757). The high salinity of the Q1 Aquifer along this creek suggests that recharge to the T1 Aquifer occurs as lateral flow from deep Quaternary and Tertiary aquifers in zone 4a, which merge into the Tertiary aquifer of zone 4.

The high salinity of T1 Aquifer along the River Torrens indicates lack of recharge to the aquifer. The general salinity patterns of this zone suggest that groundwater flows towards the River Torrens in a northwesterly direction. During the summer the outflow of high salinity groundwater significantly increases river salinity.

Zone 3

Low salinity groundwater of less than 800 mg/L occurs in two major regions, a northern region surrounding the Little Para River and a southern region located north and south of the River Torrens.

The extent of less than 800 mg/L water is much greater than in any of the overlying Quaternary aquifers, confirming that recharge to the T1 Aquifer does not occur as a result of downward leakage.

Zones 2 and 2a

Low salinity groundwater is restricted to an area between Brown Hill Creek and the Sturt River. Salinity under both surface drainage lines is generally higher than between them, indicating a more complex recharge mechanism than the simple downward infiltration from surface drainage as was earlier proposed (Miles, 1952).

8.1.2 RECHARGE AND FLOW MECHANISMS

Recharge to all aquifers in the sedimentary basin on the downthrow side of the fault occurs through several mechanisms. This includes recharge into the Q1 Aquifer and/ or the Q2 Aquifer through beds of losing streams and as a hidden recharge from the highly permeable recharge zones located at the interface between the Adelaide Hills and the sedimentary aquifer. Alternatively, it occurs as underflow from the adjacent basin and/or the fractured rock aquifer in zone 1.

Water migrateds from fractures (joints, faults, shear zones and other openings in the rocks) of the Adelaide Hills directly into the basin sediments and is also discharged from the Hills springs. The exact rate at which water flows directly from the fractured rock aquifers into the sedimentary basin is not known: an attempt is made to calculate this amount of lateral flow from flow net analysis (Gerges, 1999). In the Tertiary aquifers the reconstructed pre-development potentiometric surface indicates that regional flow was predominantly towards the northwest and/or the west. The direction of this regional flow is similar to the general flow deduced from salinity distribution within the aquifers. It is similar to the regional flow of the overlying Quaternary aquifer. This flow pattern and salinity distribution suggests that major recharge to the Tertiary aquifers occurs from the fractured rock aquifer in zone 1 into the deeply buried thick Tertiary aquifer located along the Eden-Burnside Fault in zone 4a (Figs 5c-d) and also along the Para Fault near the Little Para River in sub-zone 3A.

Chemical information lends support to this premise. Water from fractured rock aquifer wells in the Adelaide Hills and Tertiary aquifer wells on the downthrow side of the fault have a similar dissolved solids concentration generally, and for specific ions including chloride. Furthermore, the seasonal fluctuations of water levels on the upthrow side of the fault are similar to those of the water levels on the downthrow side.

In zones 2, 2a and 3 the extent of less than 800 mg/L groundwater in the T1 Aquifer is much greater than in any of the overlying Quaternary aquifers.

Figures 5a–b show T1 Aquifer salinity from individual wells to be much less than the overlying Quaternary aquifer, even in areas underlying major surface drainage, i.e. recharge to T1 Aquifer did not occur as a result of downward leakage.

The section shown in Figure 5a illustrates the hydraulic continuity of the first Tertiary aquifer across the Para Fault splinters. This indicates that flow in this aquifer is towards the northwest (salinity increases in this direction). Figure 5a also shows the hydraulic connection between the Q4/Q6 Aquifers in zone 2 and the T1 Aquifer in zone 3 across the Para Fault splinters.

<u>It appears that there are two flow mechanisms in the Tertiary aquifer inferred from salinity distributions:</u>

- flow towards the west in the Little Para River (zubzone 3A)

- flow towards the northwest in the area southwest and west of Adelaide (from zone 4a to zones 2 and 3).

In zone 3 the two major low salinity corridors are separated by a zone of relatively higher salinity. This zone, with salinity of more than 2500 mg/L, is undoubtedly located at the extreme edges of recharge and flushing fronts. In addition, the aquifer in this high salinity zone may have a relatively lower horizontal hydraulic conductivity.

8.1.3 PRE-DEVELOPMENT HISTORIC POTENTIOMETRIC SURFACE AND GROUNDWATER FLOW

Using the best available data an attempt has been made to reconstruct the potentiometric surface which existed prior to significant impact by man’s activities.

Figure 19 shows the postulated pre-development potentiometric surface for the first Tertiary aquifer. This map was prepared primarily from water levels recorded on drillers’ logs, early measurements taken from observation wells, and water levels recorded in early reports (Miles, 1952). For these reasons the reconstructed potentiometric surface shown on this map is approximate.

Zones 2 and 3

Prior to significant groundwater development, most wells were flowing, i.e. the potentiometric surface was above ground (Fig. 19). Shut-in head measurements were not taken, except for a few wells. The precision of available measurements is uncertain, but because many of these measurements are consistent with each other, it seems probable that they area accurate to within a few metres. Generally, most water level data collected prior to 1950 were considered reliable.

The historical artesian condition of the T1 Aquifer in these zones strongly suggests that upward leakage from T1 into the overlying Quaternary aquifers was an important component of the flow system. This means that infiltration of surface water along drainage lines does not recharge the first Tertiary aquifer, contrary to the conclusions of Miles (1952).

The boundary conditions at the western extreme of the St Vincent Basin are not well understood. If the Tertiary aquifers are limited by an impermeable boundary, this upward leakage represents the only natural discharge from the system.

The general pre-development flow direction in the River Torrens area is towards the northwest, while in the Little Para River area it is westerly.

The flat hydraulic gradient of 0.5 m/km in the River Torrens area west of Adelaide is due to the combination of high aquifer transmissivity (moderate hydraulic conductivity and thick aquifer), upward leakage to the Quaternary aquifers, and/or the proximity of aquifer discharge boundaries to this zone.

In the Little Para River area, the cause of the relatively steep hydraulic gradient area of 1.8 m/km is that the Carisbrook Sand constitutes up to 70% of the total aquifer thickness. This sand is known for its low to moderate hydraulic conductivity.

Zones 4 and 4a

Because of lack of historic data and the small amount of current groundwater (pumpage) extraction, recent water level measurements were used in part to reconstruct the pre-development potentiometric surface.

On the basis of changes of gradient and the shape of potentiometric contours, several characteristics are identified.

In the area adjacent to the Mount Lofty Ranges, the up-gradient flexures near the River Torrens indicate groundwater discharges into the river. Supporting evidence is the higher salinity near the river, which precludes direct recharge from the river. The closely spaced contours indicate a thinner aquifer (Fig. 19), a low hydraulic conductivity (low yield of the aquifer is indicative evidence), or a combination of both factors.

The hydraulic gradient of 3 m/km indicates a moderate transmissivity. The bulk of this aquifer consists of up to 140 m of sand with low hydraulic conductivity. The general flow direction in this zone is towards the northwest.

In certain areas the aquifer is unconfined, particularly south and north of the River Torrens and in proximity to the Eden-Burnside Fault.

The aquifer is hydraulically connected to the Quaternary aquifers across the Para Fault (Fig. 5e). The general flow is towards the northwest and it appears that much of the groundwater in this aquifer discharged into the River Torrens. The steep hydraulic gradient of 7 m/km is indicative of low aquifer transmissivity. The aquifer consists of sand, silt, clay and chert with an average thickness of 25 m.

8.1.4 SUMMARY OF HISTORIC SALINITY AND POTENTIOMETRIC SURFACE

The reconstructed pre-development potentiometric surface indicates that regional flow in the aquifer was predominantly towards the northwest, but towards the west in the Little Para River area.

The direction of this regional flow is similar to the general flow direction deduced from salinity distribution within the aquifer. It is similar to the regional flow of the overlying Quaternary aquifer.

This flow pattern indicates that the aquifer is recharged from the Eden-Burnside Fault zone and from the fractured rock aquifer in zone 1.

In conclusion, there are two natural lateral flow regimes which have been important in the development of the salinity distribution in the T1 Aquifer:

- flow path (system) towards the northwest, originating in zone 4a in the area bounded approximately by Brown Hill Creek and the Sturt River through to zones 2 and 2a and then zone 3 (salinity less than 1000 mg/L)
- flow path (system) towards the west in the vicinity of the Little Para River (salinity less than 1000 mg/L).

8.1.5 GROUNDWATER EXTRACTION

Most of the groundwater extraction occurs from zones 2, 2a and 3, because of the significant groundwater storage in subaquifers TIa and TIb (zone 3). Groundwater quality is generally suitable for most purposes. The rapid post-war growth of population in a topographically low area, such as zone 3, demanded additional water resources for market gardens, industry and recreation purposes. These resources have been provided primarily from groundwater.

A total of 504 production wells were drilled and only 170 remain in operation today. Most of the drilling occurred west of the para Fault in zone 3 (303 wells, of which only 35% (114 wells) are still operational).

The earliest reliable records of pumping from Tertiary aquifers were provided in Miles (1952). He estimated the amount of pumping from zones 2, 2a and 3 (the River Torrens-Sturt River area) to be between 4500 and 5500 ML/year (Miles, 1952, p.133).

On several occasions during severe drought the E&WS reluctantly supplemented reticulated supplies with groundwater from wells drilled and completed in the top of the first Tertiary aquifer (subaquifer TIa).

It is noteworthy that a total of 41 248 ML were utilised for public water supplies from groundwater sources between 1914 and 1968. Although the yields and salinities of these wells were acceptable, water hardness was relatively high.

The results of the present investigation show extraction from the first Tertiary aquifer to be around 6900 ML/year (Table 11). This amount includes the 638 ML/year pumpage from the Little Para River irrigation area, which has been recently reduced to approximately 200 ML due to urbanisation. Most extraction occurs in zones 2 and 3 (western Adelaide Plains) and is calculated at 6200 ML/year.

In the Thebarton area extraction increased significantly to 750 ML/year in the late 1980s as a result of approximately 500 ML being extracted from the SA Brewery well field.

8.1.6 HISTORIC POTENTIOMETRIC SURFACE DEVELOPMENT AND PUMPAGE

This section summarises the development of the potentiometric surfaces and pumpage during summer (March) and winter (September).

The potentiometric surface maps were constructed from water level measurements taken from the observation wells network (Fig. 20). The number of observation wells has been increased significantly from 15 wells in 1936 to 273 wells in the 1980s.

The terms ‘cone of depression’ and ‘are of influence’ are defined as the area below the zero AHD contour, with the coast being the western boundary and Grand Junction Road the northern boundary. The selection of the northern boundary was based on the lack of water level measurements during the early years of water level observation.

Winter potentiometric surface maps and pumpage

Water level measurements taken during September of every year were considered representative of the winter potentiometric surface. Figure 21 shows the configuration of the potentiometric surface for September 1936, prior to any significant groundwater development.

Measurements were taken from approximately 15 E&WS wells in zones 2 and 3. This map and the 1947 map (Fig. 21) clearly show that the regional flow pattern is towards the northwest from zone 2 to zone 3. Similar flow patterns were deduced previously from the postulated historic potentiometric surface and historic salinity.

Prior to this period, the only known documented pumping records were from E&WS wells during 1914 (568 ML) and 1934 (854 ML). Figure 21 shows that the 4m AHD contour has moved southward, indicating a decline in the potentiometric surface.

Figure 22 shows that the 1948 contours are similar to 1947 contours, while during 1951 and 1952 a cone of depression developed, possibly as a result of late winter pumping. Contours for 1953 show a recovery to the 1947 situation, while 1955 levels (Fig. 23) indicate a recovery to 1937 values. This behaviour was maintained up to 1957 (Fig. 23).

In September 1958 (Fig. 23) there is evidence for development of a small cone near the intersection of the Para Fault and the River Torrens. This cone probably resulted from continuous heavy pumping of 10 030 ML from August 1959 to May 1960 from E&WS wells.

The cone contracted to its minimum size during 1961 and 1963 in response to high rainfall and hence a reduced extraction. From September 1966 to 1975 (Fig. 24) the cone formed in the same area and reached its maximum size during 1968, mainly due to prolonged E&WS pumping of 10 030 ML during the period September 1967 to May 1968.

The extraction of groundwater from subzone 3B (Penrice (ICI) – SAMCOR) began in 1957. The increase in the number of observation wells in the area enables the extent of the cone of depression during 1979 and 1980 (Fig. 25) to be better defined. The centre of the cone reached –8 m AHD.

A comparison between potentiometric surfaces from 1976 to the late 1980s indicates the consistency of pumping rates and the stability in distribution of major pumpage centres during this period.

During the last decade (Fig. 26), the zero potentiometric contour moved southward in proximity to the River Torrens, indicating a slight increase in pumping rate in this region.

The majority of groundwater discharge east of Adelaide in zone 4 is into the River Torrens as base flow. The remainder of flow may move westward across the Para Fault and recharge the laterally continuous Quaternary aquifers.

Northeast of Adelaide, most groundwater flow is towards the River Torrens, with the remainder towards the small pumpage centres of the Golden Grove sand quarries.

Summer potentiometric surface maps and pumpage

Water level measurements taken during March of every year were considered representative of the summer potentiometric surface.

The first reliable summer contour map was constructed from March 1947 water levels (Fig. 27).

The March 1950 contours (Fig. 27) indicate a major pumping centre located immediately north of the River Torrens. The zero potentiometric contour is restricted to an area bounded by the Para Fault.

During 1951 (Fig. 28), the cone of depression spread southward as a result of heavy E&WS pumping of 6280 ML during the period October 1950 to June 1951. The pumping centre was located in the middle of zone 3 and produced a steep cone to –21 m AHD in the central area.

Slight recovery occurred during March 1952 (Fig. 28) and the cone became restricted to zone 3 and partly zone 2a with E&WS pumping of 426 ML from November 1951 to May 1952. The partially recovered cone was less steep with a minimum of –18 m AHD.

During 1953, the cone was reduced in drawdown but extended over most of the area west of Adelaide (zone 3), with its centre near the coast. This cone formed as a result of irrigation pumpage only, as E&WS pumping was only 320 ML.

In 1954, E&WS pumping of 3850 ML during the period October 1953 to April 1954 extended the cone southward across the Para Fault, with a pumping centre similar to those of 1951 and 1952.

In 1955 (Fig. 29), the extensive pumping of 6650 ML (October 1954 to May 1955) from E&WS wells caused the cone to extend southward across the Para Fault. The major extraction centre produced a steep cone extending to –17 m AHD.

In 1956 (Fig. 29), the usual irrigation pumping from zone 3 lowered the potentiometric surface to –6 m AHD in proximity to the coast.

In 1960 (Fig. 30), E&WS pumping of 10 030 ML (August 1959 to May 1960) caused the cone to spread southward across the Para Fault (similar to the 1951 and 1955 cones). However, the shape and the steep gradient of the cone suggest more widespread and intensive pumping.

The 1961 potentiometric surface map (Fig. 30) has a similar pattern to 1956.

The 1962 map (Fig. 31) shows a steep cone restricted to the areas west of the Para Fault and extending to –15 m AHD, produced as a result of E&WS pumping of 2364 ML (December 1961 to April 1962).

In 1968, E&WS pumping of 10 030 ML (September 1967 to May 1968) enlarged the cone of depression to an area similar to the 1955 and 1960 cones.

During 1969 (Fig. 31) and the last decade (Fig. 32), the cone contracted and became restricted to zone 3, with the pumping centre near the coast.

8.1.7 PRESENT DAY POTENTIOMETRIC SURFACE DEVELOPMENT AND PUMPAGE

At present, most groundwater is being used for industrial purposes and irrigation of school ovals, golf courses and recreation grounds.

Figures 33 and 34 show extracted volumes, locations of pumping wells, pumping centres and potentiometric surfaces for summer and winter.

For the purposes of this study, the summer pumping period was estimated at 210 days, during which all irrigation and industrial pumping wells were in full operation.

The winter period of 155 days has industrial wells only in operation. Table 11 shows that total pumping of 7383 ML/year occurs mainly from the first Tertiary aquifer (6920 ML/year) and other hydraulically connected aquifers, such as the Carisbrook Sand (87 ML/year) and the fractured rock aquifer (376 ML/year).

Yearly irrigation usage is 3602 ML/year which is almost equal to industrial usage. However, most pumping occurs during summer, totalling 57 780 ML, of which 3600 ML is used for irrigation and the remainder for industrial purposes. During winter, pumpage from groundwater is restricted to industrial use and totals 1610 ML.

The assessment of groundwater pumpage and the potentiometric surface for each zone is summarised as follows.

Zones 2 and 2a

This area contains a total of 37 irrigation wells, distributed over both zones and pumping a total of 711 ML/210 days, with four industrial wells located in a small area and pumping 138 ML/year (Palm Beach Towel Co. pumping centre, which was recently closed down).

A comparison between summer and winter potentiometric surfaces shows the effect of summer irrigation, which includes shifting of both the 5 m and 10 m contours eastward, steepening of the upflow gradient and initiation of a small cone of depression near the coast as a result of heavy pumping from the Marion golf course well field.

During winter, the movement of contours in response to recovery is variable; the 5 m contour moves 5 km towards the west and 3 km to the north, while the 10 m contour moves only 1.5 km in the same directions.

Zone 3

This zone has five major pumping centres during summer. One of these is for industrial use and therefore is also a major pumping centre during winter.

In addition, the beverage industry located within the zone is expanding to become a major year-round industrial user (~ 500 ML/year).

Subzone 3a, little para river area (irrigation).

This area contains 49 production wells pumping a total of 638 ML during the 210 days of summer. In addition, 13 wells pump a total of 87 ML during summer from the Carisbrook Sand aquifer. This aquifer is known to be hydraulically connected to the underlying first Tertiary aquifer.

Pumping from this centre causes a steepening of the hydraulic gradient in the area and the expansion of both the zero and –10 m AHD contours towards the east and the north.

Pumping from this area also affects the shape of the potentiometric surface in the Penrice (ICI) – SAMCOR pumping centre during summer.

Subzone 3B, Penrice (ICI) – SAMCOR area (industrial)

This northern industrial pumping centre is the largest and most permanent centre in the area. It contains 12 production wells pumping 2689 ML/year (1548 ML/210 days and 1140 ML/155 days). This has created a steep cone of depression for the whole year, which expands during summer to –17 m AHD in the central area and contracts slightly during winter to –12 m AHD.

The large withdrawals during summer produce seasonal variations in the regional flow pattern, creating a groundwater divide between the Penrice (ICI) - SAMCOR permanent cone and the West Lakes seasonal cone.

During winter the West Lakes pumping centre recovers to –2 m AHD and the groundwater divide disappears, with most of the flow directed northward towards the permanent cone.

The line labelled ‘Discharge Boundary’ on Figures 33–34 is in fact partly a no-flow boundary (parallel to flow lines) and party a discharge boundary (Penrice (ICI) – SAMCOR pumping centres). It divides the Penrice (ICI) – SAMCOR core into two essentially equal parts:

- the northern subcone, in which lateral flow originates largely from the east and northeast (Fig. 26).
- the southern subcone, which derives most of its lateral flow from the south, especially during winter (Fig. 26).

Pumpage from each subcone was calculated at 770 ML during summer and 570 ML during winter.

Subzone 3C, West Lakes area (irrigation)

This seasonal irrigation pumpage centre located near the coast contains 20 production wells servicing golf courses and other recreation grounds. Total pumping from this centre is 1232 ML during the 210 day summer season. The result of this intensive pumping from a small area is a steep cone of depression which extends to –22 m AHD in the central area (Fig. 32). This cone recovers during winter to –2 m AHD (Fig. 26). During summer, the regional flow is radial towards the centre of the cone, while during winter flow is to the north and northwest.

Subzone 3D, Torrens Valley area (irrigation)

This pumping centre consists of 23 production wells scattered north and south of the River Torrens. They produce 500 ML during the 210 days of summer pumping. One industrial well pumps 40 ML/year. The summer potentiometric surface shows a gentle gradient towards the northwest, which swings towards the north during winter.

Subzone 3E, Thebarton area (industrial)

This centre is located along the River Torrens in proximity to the Para Fault. Total pumpage is 258 ML/year from five wells (148 ML during summer and 110 ML during winter). The effect of this pumping centre on the potentiometric surface can be observed from the shape of the zero contour (Fig. 32), which does not change significantly from summer to winter. It is expected that pumping of 500–900 ML/year for the Southwark Brewery will expand this small pumping centre to become the largest permanent pumping centre in the area. Figures 33–34 (summer, winter) show the development of the new cone as a result of this intensive pumpage, which began in 1989.

Zones 4 and 4a

A total of 25 industrial and irrigation wells pump 1015 ML/year from both Tertiary and shallow fractured rock (hydraulically connected to the overlying Tertiary aquifer) aquifers. The locations of pumping centres divide both areas into two subareas.

The northeastern area with total pumpage of 619 ML/year is divided such that:

- 483 ML/year is pumped from four wells for dewatering the Tertiary sand quarries of the Golden Grove area.
- 136 ML/year is pumped from three irrigation wells completed in the fractured rock aquifer.

Pumping from the area south of the River Torrens with total pumpage of 396 ML/year is distributed as follows:

- 1159 ML/year is pumped from one industrial well (Schweppes Co.). This well is completed in the fractured rock aquifer.
- 237 ML/year is pumped from 17 irrigation wells during the summer period. Most wells are completed in the shallow fractured rock or Tertiary aquifers.

The small amount of pumpage from this area means that the present day and historic potentiometric surfaces are similar.

8.1.8 SUMMARY OF POTENTIOMETRIC SURFACES

Winter potentiometric surface

Permanent loss of head from the aquifer has occurred since 1936 or earlier.

The 1951 potentiometric surface map shows the first indications of developing cones of depression. The major cone of depression always occurs north of the River Torrens and west of Adelaide, except during droughts and heavy E&WS pumping.

The location of the recent permanent cone of depression in zoned 3 corresponds to the location of recently developed pumping centres. At present, the cone of depression decreases to its minimum size at the end of winter but the potentiometric surface never recovers to his historic levels for the following reasons:

- There is continuous industrial pumping during winter.
- The duration of the recovery period is short in comparison to the pumpage period.

The effect of cumulative residual drawdown over years of pumping, particularly during summer, has led to a significant loss from elastic storage, which shows as a continuous decline in water level.

Summer potentiometric surface

The present day potentiometric surface is severely modified by present day pumping, and shows steep cones of depression increasing to their maximum levels in summer. These permanent cones evolved during the mid 1950s as a result of heavy industrial pumping from Penrice Soda (ICI) in the northern parts of the zone, and seasonal (from November to March) irrigation pumping elsewhere.

Extensive and continuous pumping from zone 3 has created a regional cone of depression in the aquifer, which has changed the local flow patterns.

The major new flow direction are summarised as follows:

- Flow from the east to the Penrice (ICI) – SAMCOR pumpage centre.
- Flow from the north and northwest to the Penrice (ICI) – SAMCOR PUMPAGE CENTRE, AND FROM THE NORTH TO THE West Lakes pumpage centre.
- Flow from the west (from under Gulf St Vincent) to the Penrice (ICI) – SAMCOR and West Lakes pumpage centres.

The location of the zero contours is always south of the River Torrens and has rarely progressed south of the Para Fault northern splinter in the past, except during E&WS

pumping periods, particularly from zones 2 and 2a. This indicates that the northern splinter of the para Fault represents a recharge boundary.

The almost flat area between major pumpage centres Penrice (ICI – SAMCOR and West Lakes implies an artificial groundwater divide which develops only during summer months.

The consistency in size of cones of depression during several different period indicates a constant yearly pumping for each period (e.g. from 1947–50 and from 1951–1990s).

8.1.9 CHANGES IN WATER LEVEL

Selected hydrographs with long term records (Figs 36–40) show seasonal fluctuations and overall decline during the period of records. These were caused primarily by extensive pumping from the production aquifer (TI), which may have induced leakage from overlying and/or underlying aquifers. Extensive pumping induces an increase of hydraulic gradient in the production aquifer, which promotes increased lateral flow. This increased lateral flow and possible leakage have implications for the long term salinity of T1.

The principal factors which contribute to a long term decline in water level are the increase of pumping rate over the whole area during the period of record, and the long term effect of cumulative residual drawdown over the whole area, which represents a loss from elastic storage.

An examination of hydrographs shows that the trend of winter peaks is different from that of summer troughs.

The first stage shows a sharp decline in water level in response to initial heavy pumping. The second and third stages represent an almost constant pumping from the aquifer, ranging between 4500–5600 ML/year and establishing a new equilibrium, while the fourth stage trend indicates increases in total extraction.

The trend of summer troughs indicates the following:

- Some stages are similar to the winter peaks pattern, indicating a constant pumping from these areas over each stage.
- Other stages show a continuous but steady decline in water level, indicating slight increases in summer pumping over the period of development.

Changes in water level over the last 50 to 70 years

Figure 41 shows water level changes between historic and winter 1985 water levels. An average decline of 8 m has occurred in both zones 2 and 3 and south of the groundwater divide-discharge boundary. In contrast, a major decline of 22 m has occurred in the permanently stressed Penrice (ICI) – SAMCOR area as a result of continuous industrial usage and stressing of the aquifer. Miles (1952, p.132) reported that water level decline over the early 30–40 years of development was between 6–9 m.

This evidence of early and major water level decline and depletion was supported by comparing the pre-development potentiometric surface data with data from later years. Comparison with September 1936 water levels indicates an average decline of 4 m, and with September 1947 levels an average decline of 6 m.

However, September 1948 water levels indicate an average decline of only 5 m, which represents a recovery of 1 m from the previous year.

These observations are critical as they suggest that most of the sharp decline in water levels occurred during the initial years of pumpage and up to 1947.

This suggests that the aquifer has never recovered to its original level following the initial pumpage, which may in part be due to residual drawdown, but may also be related to poor well completions in the early days, which allowed confined aquifer flow into the overlying Quaternary aquifers to dissipate aquifer pressure.

Zones 4 and 4a show only small changes in water levels (storage), suggesting a negligible amount of pumpage.

8.1.10 ANNUAL CHANGES IN PRESENT DAY CONE OF DEPRESSION WEST OF ADELAIDE

Figures 42–43 show the development of the cone of depression and its monthly changes during one year.

The cone develops to a maximum during March, with the zero contour parallel to and in proximity to the para Fault.

In April, the cone is similar to that in march but in May the zero contour moves northward and is coincident with the River Torrens.

During the period from July to September, the zero contour moves north of the River Torrens and west of the para Fault. In October, the cone of depression begins to expand southward and by January moves partially south of the River Torrens. During February, it approaches its maximum size.

The movement of the zero contour confirms that lateral flow into the aquifer is towards the northwest, as deduced from historic salinity and potentiometric surface maps.

During winter, the northward migration is in response to lack of pumping from the West Lakes pumping centre, i.e. it represents a recovery phase.

8.1.11 LONG TERM CHANGES IN SIZE OF AREA OF INFLUENCE DUE TO PUMPING

Figure 44 shows the size of the area of influence (defined as the area below the zero AHD potentiometric contour), during summer and winter, which has developed during pumping since 1947, mainly from zone 3 and sporadically from zone 2. It shows the known annual pumping rate from private wells and occasional pumping from E&WS wells (the latter prior to 1968). The change in size of the area of influence indicates a change in pumping rate from the aquifer.

The summer graph shows the following periods:

- In the first period (1947–50), the average size of the area is 55 km^2 with an average pumping rate of 4550 ML/year (Miles, 1952).
- In the second period (1951–84), the average size of the area is 85 km^2. The annual pumping rate remained almost constant during the period, despite changes in the location of major pumping centres. Annual pumping was estimated between 4550 ML (Miles, 1952) and 5630 ML (this report), averaging 5000 ML, which is only marginally lighter than the pre-1950 average.

The increase in average size may be partly due to the occasional high pumpage from E&WS wells. Spikes on the graph (averaging 125 km^2) during the years 1954, 1960 and 1967–68 are generated by E&WS pumping.

The winter graph shows almost full recovery to zero km^2 up to 1959, except during E&WS pumping during 1950 and 1954. From 1959–63, the size of the area became larger and fluctuated between 10–50 km^2, indicating the beginning of moderate industrial pumping and the effect of 1960 and 1962 E&WS pumping.

From 1962–84, the size of the area of influence increased to an average 50 km^2, suggesting a new period of extensive and continuous pumping for industrial usage (e.g. Penrice ICI) – SAMCOR) from the Northern Adelaide Plains irrigation area. The 1967–68 E&WS pumping shows as a spike extending the area of influence to 75 km^2 and also affecting the 1971 and 1972 area of influence.

8.1.12 SUMMARY OF WATER LEVEL CHANGES

The similarity between patterns shown on the hydrographs, and the variation in the area of influence, support the view that, in the period from 1900–50, a major decline in water level averaging 8 m occurred in response to extensive pumping, particularly during 1934 and 1949. This will be the subject of further assessment. Miles (1952) reported that 4550 ML/year was extracted during 1948–49.

The period 1951–84 was one of almost constant pumping, from both zones 2 and 3, which allowed the establishment of a new equilibrium with respect to recharge and discharge conditions. An average pumping rate of 5000 ML/year is believed to have applied to this phase.

From 1984 to the present, a notable decline in water levels and increase in area of influence has occurred in both zones 2 and 3, which is attributed to an increase in annual pumping to an estimated 16 300 ML/year.

This increase is attributed to an increasing demand for groundwater, particularly for industrial usage such as the Southwark Brewery.

8.1.13 FIRST TERTIARY AQUIFER PARAMETERS

Aquifer and confining bed parameters were determined from aquifer test data by the type curve matching (log/log) and Jacobs straight line (semi-logarithmic) methods.

Flow net analysis methods were used where possible to calculate the apparent transmissivity of the aquifer. Average values of aquifer parameters were determined and they are summarised in Table 12.

The first Tertiary aquifer in zone 3 was previously described as one homogenous aquifer with an average thickness of 100 m and transmissivity of 60 m^2/day (Shepperd, 1975).

The present study has identified T1 to be a multilayered aquifer with two significant subaquifers T1a and T1b. Aquifer testing was undertaken to estimate the hydraulic properties of the system. The results suggest the presence of an effective confining bed separating T1a and T1b. These results also suggest that the transmissivity value ranges between 120 and 175 m^2/day, and the storage coefficient between 2.5 x 10^{4} and 5 x 10^{-4}.

These transmissivity values are approximately two to three times higher than the value of 60 m^2/day, calculated by Shepperd (1975), from the Northern Adelaide Plains.

8.2 SECOND TERTIARY AQUIFER (T2)

This aquifer is defined as the second intersected, saturated and permeable Tertiary sediments, regardless of their stratigraphic age.

It is well distributed over the whole area and consists of various stratigraphic units.

Zone 2

In the area located between Brown Hill Creek and the Sturt River the aquifer consists mainly of Aldinga Member sand (Unit 11) and Chinaman Gully Formation sand (Unit 13).

The salinity in this area (Fig. 45) varies between 1100–10 000 mg/L. Supply is expected to average 5 L/sec.

Information interpreted from cross sections suggests that the aquifer in this area is not hydraulically connected to the T2 Aquifer within the para Fault splinters to the north. Most of the groundwater from this area flows towards the west-northwest, but not into the T2 Aquifer which contains better quality water (600–900 mg/L).

In the area west of the Sturt River, the aquifer attains a thickness of up to 95 m near the coast (Fig. 5b).

The dominant stratigraphic unit is the lower Port Willunga Formation limestone (Unit 8).

Salinity (Fig. 45) varies between 950–3600 mg/L. Lower salinities are found near the coast. The most reliable records suggest a maximum supply of 10 L/sec can be obtained from the aquifer near the coast, where the aquifer is thicker and consists mainly of moderately to well cemented limestone. The anticipated groundwater flow in this area is towards the west.

Zone 2a

In this zone the aquifer consists of lower Port Willunga Formation. Its thickness is not well known but it could be up to 80 m.

It contains the best water quality in the T2 Aquifer in the metropolitan area. T2 here is hydraulically connected to the T1 Aquifer south of the Para Fault (zone 2) and to T1 and T2 north of the Para Fault (zone 3).

Zone 3

The T2 Aquifer occurs throughout this entire zone. It consists of well cemented limestone of lower Port Willunga Formation (Unit 8). The formation is relatively flat lying and is uniform in thickness, ranging between 80 and 110 m. It is hydraulically connected to the T2 Aquifer to the south of zone 2a.

Salinity distribution (Fig. 45) shows that a low salinity zone of less than 1000 mg/L occurs in the middle of the zone. A high salinity value of more than 1300 mg/L was intersected in the proximity of the River Torrens and Para Fault intersection on the western boundary of Adelaide.

It suggests that most of the recharge to this aquifer occurs as a result of lateral flow of better quality water from the area within the Para Fault splinter (zone 2a), and not as concluded in previous studies (Miles, 1952).

Evidence of salinity stratification within the second Tertiary aquifer suggests the presence of subaquifers T2a and T2b.

This salinity difference suggests that they are probably separated by a thin semi-confining layer which consists of silt and weathered limestone.

In the North Glenelg Well (Gerges, 1980a) and the Wingfield Well (Gerges, 1982) both subaquifers are well recognised.

Subaquifer T2a is a white to pale grey well cemented limestone/sandstone, with groundwater of salinity between 1200 mg/L (North Glenelg) and 3590 mg/L (Wingfield).

Subaquifer T2b is well recognised as a pale yellow to orange brown friable to moderately cemented limestone/sandstone, occasionally interbedded with highly calcareous, fossiliferous sand. It contains groundwater inferior to the overlying subaquifer T2a and ranges in salinity between 4840 mg/L (at Wingfield) and 8000 mg/L (at North Glenelg).

In the middle of the zone, salinity stratification possibly does not exist, as determined during the drilling of Allenby Gardens Well (Gerges, 1980b).

This evidence of salinity stratification within the high salinity zones and the lack of stratification in the middle of the area, where lower salinity occurs, supports the revised recharge mechanism (Gerges, 1986), in which recharge to the deep Tertiary aquifer occurred as a lateral flow from another deep aquifer.

The extent of salinity stratification within this essentially unexploited water resource suggests that development should be treated with caution. It requires further investigation. In the Little Para River area (subzone 3A), low salinity groundwater of less than 1000 mg/L occurs in proximity to the Para Fault and the River. Initial interpretation suggests that recharge to the aquifer occurs as a result of downward movement of low salinity water from the River through the overlying Quaternary and Tertiary aquifers. However, careful examination of the salinity profile suggests that the salinities of the overlying shallow aquifers are relatively higher than in the underlying Tertiary aquifer. This supports a revised recharge mechanism (Gerges, 1986).

In conclusion, it appears that there are two historic recharge (flow) mechanisms which occurred in this aquifer and which are responsible for the observed salinity distribution.

- A northwestern flow occurred from the Tertiary aquifer in zones 2 and 2a through the para Fault splinters and into the T2 Aquifer in the area west of Adelaide (subzone 3D).
- A western flow occurred from the fractured rock aquifer into the T2 Aquifer in the Little Para River area (subzone 3A).

These historic recharge mechanisms are similar to those which occurred in the T1 Aquifer. These two major low salinity corridors are separated by a region of relatively higher salinity.

8.2.1 HISTORIC POTENTIOMETRIC SURFACE

Using the best available data an attempt has been made to reconstruct the potentiometric surface which existed prior to significant impact by development.

Figure 46 shows the inferred historic potentiometric surface prior to any groundwater development in the area. Most of the wells prior to the 1950s were flowing, particularly west of the Little Para River in the vicinity of the coast, and because many of the water level measurements are consistent with each other to 'within a few metres', water level data collected prior to the 1950s are considered reliable.

The earliest information was recorded from the Croydon deep well drilled in 1889 (Miles, 1952) and the most recent data was compiled from the Allenby Gardens Well (Gerges, 1982). Water level data from both wells show a permanent decline of 6 m over the last 93 years.

The general pre-development flow directions in the River Torrens area are towards the northwest, while in the Little para River area flow is westerly. These flow directions are similar to those deduced from the overlying T1 Aquifer.

In the River Torrens area the hydraulic gradient is moderate in comparison to the steeper hydraulic gradient in Little Para River area.

The direction of this regional flow is similar to the general flow direction deduced from the salinity distribution within both this aquifer and the overlying T1 Aquifer.

8.2.2 PRESENT DAY PUMPAGE AND POTENTIOMETRIC SURFACE

At present there is no significant pumping from this aquifer in the Adelaide Metropolitan Area. Only three production wells were drilled into the aquifer, at Regency Park golf course, Riverside golf course, and at Penrice Soda Osborne. The latter is not used at present, while the extraction from the other two wells is insignificant and unlikely to cause impact on the regional groundwater flow.

Figure 47, constructed from three production wells and observation wells drilled by MESA, shows that regional flow is now predominantly towards the north.

This indicates that the potentiometric surface has been significantly modified by present day pumping from the same T2 Aquifer in the Northern Adelaide Plains area, some 20–30 km north of the Adelaide Metropolitan Area. As a result, the zero potentiometric contour is located at the northern end of the study area.

This observation is important as it indicates that the T2 Aquifers in the Adelaide Metropolitan Area and the Northern Adelaide Plains are hydraulically connected.

8.2.3 CHANGES IN WATER LEVEL AND STORAGE OVER THE LAST 40 YEARS

Figure 48 shows water level changes between historic and present day potentiometric surfaces.

The permanent loss of head is the result of:

- upward leakage to the overlying heavily pumped T1 Aquifer in the area west of Adelaide
- reduction in lateral flow from the Tertiary aquifers in the area within the Para Fault splinters and southeast of Adelaide (zone 2)
- heavy extraction from the Northern Adelaide Plains area.

However, the heavy extraction from the Northern Adelaide Plains will contribute in the long term to the following:

- decline in water level and steepening of the hydraulic gradient in subzone 3A
- modification of the direction of flow towards the north.

The rate of change in elastic storage over the entire area (160–300 km^2) during the last 40 years can be calculated, using an average storage coefficient of 2.4×10^{-4}, at 6–21 ML/year and a range of water level changes of 6–12 m.

This amount is considered to be very small in comparison with the total amount in elastic storage and/or unconfined storage.

8.2.4 SEASONAL WATER LEVEL DECLINE AND FLUCTUATIONS

Selected hydrographs with relatively long term records (Fig. 49) show the seasonal fluctuations and overall decline during the period of record.

The rate of decline in water level was calculated at 0.35 m/year and the most recent seasonal fluctuation was measured at 0.5 m/year.

8.3 THIRD TERTIARY AQUIFER (T3)

This aquifer is defined as the third intersected, saturated permeable Tertiary sediments, regardless of their stratigraphic age.

Zone 2

In this zone the aquifer consists mainly of South Maslin Sand (Unit 15).

This aquifer is intersected at 190 m below ground and attains a maximum thickness of 10 m, with standing water level of 3 m. Salinity ranges between 2400–15 850 mg/L. The lignitic layer of Clinton Formation, and the clay of the weathered rock or the confining bed, separate T3 from the underlying fractured rock aquifer.

In the area west of the Sturt River, T3, at a depth of 275 m, is hydraulically connected to T2 west of the River (Fig. 5b). A selected hydrograph, ADE 140 (Fig. 50), shows the seasonal fluctuations. Near the coast the aquifer consists of Aldinga Member sand (Unit 11) and Chinaman Gully Formation sand (Unit 13). The confining bed separating T3 from the overlying T2 Aquifer consists of 60 m of chert and clay of Ruwarung and Aldinga Members.

The marl and clayey layer of Blanche Point Formation separates T3 from the underlying T4 Aquifer (South Maslin Sand).

Table 13 summarises aquifer information in this zone.

Zone 3

The distribution of T3 in this zone is insignificant except in the Northern Adelaide Plains area.

The only record of T3 is in the Allenby Gardens Well, where 12 m of Chinaman Gully Formation sand was intersected at 427 m below ground.

8.4 FOURTH TERTIARY AQUIFER (T4)

This aquifer is defined as the fourth intersected, saturated permeable Tertiary sediments, regardless of their stratigraphic age.

Zone 2

The aquifer is limited to a narrow strip along the coast (Fig. 5b). It was intersected in the Minda Home Well (no. 773). It consists of 26 m of carbonaceous South Maslin Sand and was intersected at 414 m below ground. Salinity was measured at 40 700 mg/L and the well was flowing at 4 L/sec with 21 m head above ground.

The overlying confining bed consists of 82 m of marl siltstone and clay of Blanche Point Formation.

Zone 3

The aquifer is well distributed over zone 3 (Fig. 5e) and extends northward into the Northern Adelaide Plains area.

It consists mainly of South Maslin Sand (Unit 15) and occasional North Maslin Sand (Unit 17).

In the Allenby Gardens Well, T4 consists of 39 m of dark grey highly calcareous sand intersected at 532 m. Samples collected during a pump test had a salinity of 140 000 mg/L and a standing water level of 22 m below ground (Gerges, 1982). Figure 51 shows the seasonal fluctuation and decline in water level.

In Grange a well was drilled by Beach Petroleum Co. and intersected 39 m of South Maslin Sand at 500 m, overlying a 31 m sequence of North Maslin Sand.

Since this deep Tertiary aquifer contains high salinity, little is known of its hydraulic properties.

Penrice Soda drilled two investigation production wells, in the Dry Creek and Port Gawler areas, with a potential supply of 20 L/sec.

Both wells were completed as production wells in either the South Maslin Sand (Dry Creek Well) or in both the South and North Maslin Sands (Port Gawler Well). Preliminary results from both wells show the transmissivity ranges between 120 and 400 m^2/day.

In the Dry Creek Well 60 m of South Maslin Sand were intersected at 438 m, with salinity averaging 80 000 mg/L and water levels 6–18 m above ground.

The Port Gawler Well intersected 17 m of South Maslin Sand 300 m below ground. Measured water levels were 2–5 m above ground and samples had a salinity of 55 000 mg/L. The anticipated yield is 20 to 40 L/sec.

Table 14 summarises the aquifer information.

9. FRACTURED ROCK AQUIFER (P)

This aquifer is the Precambrian (Adelaidean) fractured rock aquifer which forms the scarp face of the Adelaide Hills and underlies the St Vincent Basin.

This fractured rock aquifer is believed to be the primary source of recharge to the lower Quaternary aquifers and the deeper Tertiary aquifers.

9.1 SALINITY

Figure 52 shows the generalised salinity distribution within this aquifer.

The fractured rocks in zone 1 and adjacent to the Eden-Burnside Fault exhibit low salinity as a result of the active recharge occurring from high rainfall and surface water drainage.

Salinity distribution indicates that low groundwater salinity of under 1500 mg/L is associated with the highly fractured rock (quartzite, dolomite and sandstone). The high salinity of over 1500 mg/L is associated with tillite and siltstone.

The zone is believed to be the prime source for recharge of the sedimentary aquifers in St Vincent Basin (Gerges, 1986).

In the fractured rocks underlying the sediments in zone 4a, low salinities are found adjacent to the Eden-Burnside Fault. At St Peters Girls School, low salinity of 755 mg/L was intersected at 285 m below ground, with water level measured at 105 m. The salinity distribution in this zone suggests that direct recharge occurs from the adjacent hills and the fault zone. The salinity gradually increases towards the northwest, indicating a groundwater flow in this direction.

In Zone 4 the lowest salinities are found along the River Torrens and in the vicinity of the Hope Valley Fault. The aquifers in this area are shallow and/or outcropping and were used extensively for irrigation during the 1950s and 1960s.

In Zone 2, two wells drilled in proximity to the Eden-Burnside Fault zone show high salinity ranging between 13 000–22 000 mg/L. Therefore it is anticipated that the remaining area of the zone contains groundwater of high salinity.

In the area west of Adelaide, no information is available apart from the early documented records from the Croydon Well and the Michell Well, both indicating salty water. In addition, the overlying T4 Aquifer contains groundwater of a high salinity.

9.2 POTENTIOMETRIC SURFACE AND GROUNDWATER FLOW

The few existing water levels obtain prior to extensive groundwater development are believed to be of great value for reconstructing the pre-pumping potentiometric surface (Fig. 53).

The flow direction is towards the northwest, which is similar to the general flow direction deduced from salinity distribution within the aquifer.

This flow direction is also similar to that deduced from the overlying historic potentiometric surface of Quaternary and Tertiary aquifers.

This indicates that the multi-aquifer groundwater system was in equilibrium prior to development. This also supports the revised recharge mechanism to all aquifers (Gerges, 1986), with lateral inflow from the fractured rock aquifer of the Mount Lofty Ranges being a significant component.

The base flow from this aquifer, where it outcrops, sustains some of the flow in the River Torrens (effluent stream) during dry periods. Selected hydrographs (Figs 54–56) show both a seasonal fluctuation in response to summer pumping and the effects of winter recharge. Some of the observed water level decline is due to the compartment nature of this aquifer.

10. CONCLUSIONS

The area under consideration is divided into two sub-basin areas, the Golden Grove-Adelaide Embayment and the Adelaide Plains Sub-basin.

During this study eleven aquifers were recognised, six Quaternary aquifers, four Tertiary aquifers and one Precambrian fractured rock aquifer.

The 'boundary' separating the Adelaide Metropolitan Area and the Northern Adelaide Plains is based on a high salinity zone which has been created by differences in flushing and recharge mechanisms between the two areas.

Information from the historic potentiometric surfaces of the aquifers indicates that the groundwater system was in equilibrium prior to development. Groundwater flowed towards the northwest, and an upward hydraulic gradient was maintained during this equilibrium.

Most recharge to the deep sedimentary aquifers occurs from the fractured rock aquifer of the Adelaide Hills, not as previously thought via the Quaternary sediments connected to present day drainage lines.

The first Quaternary aquifer (Q1) was previously regarded as unconfined, but careful examination of water cut data has revealed that, in the majority of wells, confined conditions exist. This observation is important as it implies that, as long as the aquifer is fully saturated, changes in head are elastic responses (i.e. large changes in head for small changes in volume of water in storage).

The observed continuous decline in water level is a result of factors other than rainfall. The possible factors contributing to the decline are:

- urbanisation
- lining of surface drainage with concrete, thus reducing recharge to the aquifer
- extensive local pumping from Q1
- continuous downward leakage and elimination of historic recharge to this aquifer as a result of reversing historic head gradient; this is caused mainly by extensive pumping from the underlying Tertiary aquifer
- continuous leakage into the old corroded sewage pipes, as occurs in the Port Adelaide area.

The water quality of the Q1 Aquifer is dominated by surface water drainage and possibly by lateral flow from fractured rock aquifers of the hills. Summer salinity increases in the River Torrens are caused by inflow from this aquifer.

In the second Quaternary aquifer (Q2) the lowest salinities (500 mg/L) are found adjacent to Brown Hill Creek and the Sturt River, indicating direct recharge. The salinity distribution pattern is similar to Q1. The most obvious difference between the two aquifers is the areal extent of the less than 1500 mg/L salinity zone, which is more extensive in Q2 than in Q1.

The extent of less than 1500 mg/L water beneath the River Torrens in Q2 is, however, much greater than in Q1, suggesting that lateral flow of better quality water from another aquifer is more important than direct downward recharge.

An overall comparison between salinity distribution in the Q3 and Q2 Aquifers indicates that the extent of lower salinity zones in Q3 is much greater than in Q2, suggesting that recharge is more complex than downward leakage.

In the fourth Quaternary aquifer (Q4), salinity increases towards the northwest. Several recorded salinity values are significantly lower than those of the overlying Quaternary aquifer. This indicates that downward leakage is not the prime mechanism responsible for flushing the salt out of this system.

As there is no pumping from this aquifer, the recently observed decline in water level is believed to be due to downward leakage in response to pumping from the underlying aquifer.

Salinity distribution in the deep Quaternary aquifers (Q5 and Q6) in zone 3 shows that high salinity of up to 1900 mg/L occurs along the River Torrens in proximity to the Para Fault. This indicates that recharge from surface water drainage does not reach these aquifers in this area, contrary to the conclusions of previous studies.

In some wells salinity values in the Q6 Aquifer are lower than values in the Q5 Aquifer, suggesting a recharge from the better quality water of the underlying first Tertiary aquifer.

Historic water level data suggest that the deeper Quaternary aquifers had a higher head than overlying aquifers. This upward hydraulic gradient is characteristic of the discharge side of the groundwater cycle. Upward flow (leakage) within the Quaternary aquifers would result in increasing salinity near the surface and discharge from the system, either by evaporation from overlying confining beds or by flow in the shallower aquifer to surface streams flowing into the Gulf. This explains the gradual decrease in the size of the less than 1500 mg/L salinity zone from Q6 towards the Q1 Aquifer.

As the historic system was in equilibrium, the better quality water leaked upward, and evaporation concentrated the salt in the first Quaternary aquifer and/or the soil profile. The evidence from the present head relationships indicates that the present day downward vertical gradient is not consistent with the observed water quality. Flowing wells from deep aquifers are an indication of a low permeability discharge boundary, which restricts lateral groundwater outflow and enhances upward leakage.

The bulk of extracted groundwater is obtained from the T1 Aquifer; consequently it is recognised as the superior aquifer in terms of salinity and yield It is also the shallowest and therefore the most easily developed of the four Tertiary aquifers.

Salinity distribution in the T1 Aquifer suggests two flow mechanisms. The first is a flow to the west in the Little Para River area, while the second is a flow originating in the area southeast of Adelaide adjacent to the Eden-Burnside Fault. This recharge flows towards the northwest through the area southwest and west of Adelaide. This zone of fresh water suggests that either the Tertiary formation has high permeability and/or it represents an ancient narrow buried Teriary channel (possible predecessors to Brown Hill Creek and the Little Para River) flowing towards the northwest and discharging into the Gulf. This inferred narrow channel could have been part of a wider channel which may have played an important role in flushing the salt out of the Tertiary sediments.

The two major low salinity corridors are separated by an area of relatively higher salinity. This area is undoubtebly located at the extreme edge of recharge and flushing fronts. The reconstructed pre-development potentiometric surface indicates that regional flow in the aquifer is similar to the general flow direction deduced from salinity distribution within the aquifer. It is similar to the regional flow of the overlying Quaternary aquifer.

The present day potentiometric surface shows that a permanaent loss of head from the aquifer has occurred since 1936 or earlier. This potentiometric surface is severely modified by present day pumping and shows steep cones of depression. These cones are at their maximum level in summer, and recover variously towards their original levels during winter.

Cones of depression located under industrial areas (e.g. Penrice Soda) never recover to their original levels as a result of continued pumping during winter. Cones of Depression located under irrigation areas (e.g. West Lakes golf course) recover substantially but not completely during winter. This is a result of the short duration of the recovery period and also the effect of cumulative residual drawdown over years of pumping, which has lead to a significant loss from elastic storage, indicated as a continuous decline in water level.

The decline is also partly related to the possibility of poor well completion in the early days, which allowed confined aquifer flow into the overlying Quaternary aquifers to dissipate aquifer pressure.

In the irrigation areas, water level declined by 8 m over the last 50 years, and by 22 m over the same period in the industrial area. This apparent severe decline is a result of continuous pumping during winter. Hydrographs show that the major dedcline occurred prior to the 1950s. This was followed by a period of near-equilibrium. Recently 0.5–1 m decline has been observed in some areas but it is anticipated that equilibrium will be reached in the near future. It is recommended that monitoring should continue.

Salinity stratification within the second Tertiary aquifer suggests that development of this essentially unexploited water resource should be treated with caution.

Water level information shows a total decline of 6 m over 90 years. The permanent loss of head from this aquifer over the last 40 years ranges between 4–12 m, as a result of heavy extraction from the Northern Adelaide Plains irrigation area. The recent decline in water level was calculated at 0.35 m/year.

The third Tertiary aquifer contains water of varying salinity.

The fourth Tertiary aquifer contains a large storage of highly saline water. Utilisation of this resource can be promoted for the following reasons:

- to utilise the large supply of salt water in this aquifer to meet the demand for the brine and fishery industries
- to reduce upward leakage from this highly saline aquifer into the overlying T3 and T2 Aquifers
- to create a storage for future injections of fresh water and/or reclaimed effluent. This new resource may be useable by future generations.

The fractured rock aquifer in the Adelaide Hills is the prime source of recharge to the sedimentary aquifers. It contains a vast amount of fresh water.

11.RECOMMENDATIONS

This report concludes that the hydrogeology of the Adelaide metropolitan area is complex with recharge of the various aquifers generally by vertical recharge from rainfall and surface water being relatively minor in significance.

The main current uses for groundwater in the Adelaide region are:

- industrial, both low and high saline water
- irrigation of parks, gardens and recreation grounds.

The threats to the Adelaide region groundwater are from:

- over use
- pollution, diffuse and point source
- mixing of groundwater from different aquifers through 'leaky' wells.

The future potential uses for groundwater will increase, as the cost of mains water increases. The greatest increase in groundwater demand will occur particularly for irrigation of recreational areas and large industrial users of water.

Whilst this report provides the best estimates of extractions and demonstrate the continuous decline in water levels in heavy extraction areas—regular water levels and salinities monitoring is required to confirm the long term trend. It will also be necessary to regularly assess the extraction rates of groundwater from various aquifers.

A review of the condition of water wells for integrity to prevent 'leakage' between aquifers is an important issues that should be addressed. This should be particularly considered where the higher quality aquifers are under threat from a neighbouring contaminated or higher salinity aquifer.

Aquifer storage and recovery (ASR) provides an opportunity for the conjunctive use of stormwater, which generally has low salinity, and the relatively safe storage in the local aquifer ready for demand. ASR can be used to enhance groundwater degraded by pollution or by increased salinity due to over a past over commitment.

Continue upgrading and monitoring observation wells networks in particularly in areas under heavy and continuous stress such as industrial pumping centres.

A comprehensive water and salt balance studies are essential for a sound future management of the area. A fully integrated model is currently being developed to assist in future predications.

11.1 TERTIARY T1 AQUIFER

There are some significant extractions from the T1 Aquifer in sub zone 3d by industrial users and this is creating a new cone of depression. This will require careful management or aquifer enhancement to ameliorate the impact of extractions. It is also possible that 'leaky wells' may be suggesting that impact on T1 is greater than it should be, due to losses on to a 'thief zone', particularly during the winter period.

Sub zone 2 appears to have an opportunity for additional sustainable extractions of up to 2000 megalitre per year from the T1 aquifer.

Continue ongoing monitoring programs for subzones 3b, c and e.

11.2 TERTIARY T2 AQUIFER

The Tertiary T2 Aquifer is an opportunity to protect a relatively high quality and lowly used aquifer for future generations. Any access to T2 should be under the tight controls associated with well construction and allocations and with an associated ongoing monitoring program or, it could be reserved for special purposes.

11.3 TERTIARY T3 AND T4 AQUIFERS

These aquifers are highly saline and the mining of brines could be encouraged. This process would create future storage opportunities for ASR projects.

11.4 BEDROCK P

There are significant opportunities to utilise the high quality groundwater of the fractured rock systems, particularly those on the western ridge of the Mt Lofty Ranges. This geological unit also provides potential for ASR, utilising stormwater in the regions of First and Second Creeks, particularly in the regions neat the River Torrens.

Under the sedimentary basin of sub zone 4, similar opportunities exist, but in the sub zones 2 and 3, the groundwater is very saline. In sub zone 3, the salinity averages about 30 000 mg/l, but can be as high as 100 000 mg/l.

TABLES

Table 1 Adelaide area – generalised stratigraphy

Age	Lithology	Hydraulic Characteristics
Quaternary	Mainly fluvio-lacustrine clay with minor sands and gravel.	Sand and gravels form thin aquifers, usually high in salinity and low in supply.
Tertiary	Fossiliferous, glauconitic, partly carbonaceous sand, sandstone, limestone, chert, marl and shell remains. Thick clay layers and thin lignitic beds.	Sand, sandstone and limestone form aquifers with potential supplies. Clay, chert and marl form leaky confining beds. The Late Tertiary sediments contain the better quality and quantity of water.
Precambrian	Slate, phyllite, quartzite and dolomite.	Where highly fractured (near faults) high supplies of low salinity.

Table 2 Summary of stratigraphic age sequence

Unit Name and Age	Average Thickness (m)	Lithology and Occurrence	Environment of Deposition
St Kilda Formation (Q)	4	Sand and silt, numerous shell remains. Occurs adjacent to present coast.	Marine
Pooraka Formation (Q)	4	Clay – light brown, gravelly and sandy in base deposits. Occurs over most of the area.	Alluvial
Glanville Formation (Q)	6	Highly fossiliferous limestone containing silt and sand. Occurs adjacent to present coast in the northwest area.	Marine
Keswick Clay (Q)	5	Mainly green clay with small percentage of sand. Occurs in isolated areas.	Non-marine
Hindmarsh Clay (Q)	16	Clay – mottled, brown, pale olive-grey. Thin layers of gravel, sand and silt occur over whole area. A green-grey clay 3-5 m thick occurs at the base of this unit.	Fluviatile, estuarine
Carisbrook Sand (Q)	20	Yellow find sand with thin layers of clay and silt. Occasionally carbonaceous. Occurs in vicinity of large palaeo-rivers and adjacent to fault zones.	Fluviatile, estuarine
Burnham Limestone (T)	2	Limestone – white and clayey. Occurs in association with Hallett Cove Sandstone.	Marine
Hallett Cove Sandstone and Dry Creek Sand (T)	50	Shelly dark grey to brownish-grey sand, silt and clay. Highly fossiliferous sandstone. Occurs over whole area west of Para Fault in a restricted area between Brown Hill Creek and the coast.	Marine, warm shallow environment
'Croydon facies' (T)	10-45	Fossiliferous sand and silt, glauconitic. Thin shelly and sandstone interbeds occur over whole area west of para Fault.	Shallow marine
Port Willunga Formation – upper unit (T)	35	Yellow fossiliferous sand, limestone grading to white hard limestone. Occurs over area west of para Fault and west of Sturt River as a thin strip along the coast.	Shallow warm marine shelves
Munno Para Clay Member (Port Willunga Formation) (T)	12	Dark grey, stiff, calcareous clay. Comprises beds of clay separated by two bands of white to grey limestone.	Warm marine
Janjukian unit (Port Willunga Formation) (T)	20	Sand, pale grey to yellow, silty, occasional limestone-environmental bands. Glauconitic. Occurs west of para Fault and in Golden Grove-Adelaide Embayment possibly south of River Torrens.	Warm marine

Unit Name and Age	Average Thickness (m)	Lithology and Occurrence	Environment of Deposition
Janjukian unit (Port Willunga Formation) (T)	20	Sand, pale grey to yellow, silty, occasional limestone-environmental bands. Glauconitic. Occurs west of para Fault and in Golden Grove-Adelaide Embayment possibly south of River Torrens.	Warm marine
Ruwarung Member (Port Willunga Formation) (T)	78	Pale grey interbedded chert-limestone and siltstone. Glauconitic, pyritic. Occurs over the whole area except north of River Torrens in Golden Grove-Adelaide Embayment.	Marine
Aldinga Member (Port Willunga Formation) (T)	36	Clay, stiff, grey to dark grey, carbonaceous. Glauconitic, pyritic. Shell remains grading to sand and silt. Occurrence similar to overlying member. Change to sandy silty facies in an area near Eden-Burnside fault zone.	Marginal marine
Chinaman Gully Formation (T)	12	Grey to black carbonaceous silt and clay. Highly pyritic, lignitic. Sand at the base.	Marginal marine
Blanche Point Formation (T)	50-70	Grey, friable shelly siltstone grading to alternating hard and soft siltstone bands (cherty). Glauconitic, large Turritella shells. Moderately cemented greenish to pale grey, highly glauconitic limestone at the base.	Deep marine
Tortachilla Limestone (T)	3-5	Brown and green, weakly cemented glauconitic limestone.	Marine
South Maslin Sand (T)	20	Dark grey carbonaceous sand and silt. Pyritic and glauconitic.	Marginal marine
Clinton Formation (T)	16	Pale grey, white clay, sandy. Pyritic. Highly carbonaceous, lignite layers.	Marine to non-marine
North Maslin Sand (T)	15	Pale grey, yellow and brown, clayey, silty and gravelly pyritic sand.	Fluviatile, estuarine
Adelaidean (P)	Not known	See Table 3.	Various

Q = Quaternary sediments T = Tertiary Sediments P = Precambrian

Table 3 Summary of Precambrian stratigraphic units

Unit Name	Lithology
Wilmington Formation	Silstone, sandstone, pebbly limestone.
Brighton limestone	Limestone.
Tapley Hill Formation	Dark laminated siltstone; basal Tindelpina Shale Member, black shale, dolomite.
Sturt Tillite	Bouldery sandy siltstone and quartzite.
Mitcham Quartzite	Siltstone, sandstone and quartzite at base.
Saddleworth Formation and Beaumont Dolomite	Slate, dolomite and quartzite.
Stonyfell Quartzite	Feldspathic quartzite, arkose and siltstone.
Woolshed Flat Shale	Laminated siltstone, phyllite and quartzite.
Balhannah Shale Member	Black slate.
Skillogalee Dolomite	Dark chert, sandstone, phyllite and grey dolomitic rock.
Aldinga Sandstone	Feldspathic sandstone, arkose and conglomerate.
Barossa Complex	Schist and micaceous gneiss.

Table 4 Hydrogeological units

Unit No.	Unit Name	Hydrogeological Properties	Approximate Maximum Thickness (m)
1	Quaternary (including Hindmarsh Clay)	Confining bed; up to six, thin confined aquifers	Various
2	Blue to brown clay	Confining bed	10
3	Carisbrook Sand	Aquifer	60
4	Hallett Cove Sandstone and Dry Creek Sand	Confined aquifer	48
5	'Croydon facies'	Semi-confining bed	?40
6	Upper Port Willunga Formation	Confined aquifer	47
7	Munno Para Clay Member	Confining bed	12
8	Lower Port Willunga Formation	Confined aquifer	110
9	Ruwarung Member	Confining bed	70
10	Aldinga Member – clay	Confining bed	49
11	Aldinga Member – sand	Confined aquifer	20
12	Chinaman Gully Formation – lignite and clay	Not known	18
13	Chinaman Gully Formation sand	Confined aquifer	30
14	Blanche Point Formation	Confining bed	105
15	Tortachilla Limestone and South Maslin Sand	Confined aquifer	?5 60 or ?100
16	Clinton Formation	Confining bed	38
17	Undifferentiated Tertiary sand	Confined aquifer	125
18	Weathered Precambrian – clay	Confined bed	55
19	Unweathered Precambrian (basement)	Aquifer (fractured rock)	Not known

Table 5 Summary of aquifer distribution

Hydro-geological Units	Zones and associated aquifers									
	1	2	2a	3A	3B	3C	3D	3E	4	4a
1	X	Q1-Q5	Q1-Q4	Q1-Q5	Q1-Q5	Q1-Q6	Q1-Q6	Q1-Q6	Q1-Q?	Q1-Q5
2	X	X	X	NK	NK	C	C	C	X	X
3	X	?Q5	Tla	Q4 or Q5	Q5	X	X	X	Q5	T1
4	X	Tla	Tla	Tla	Tla	Tla	Tla	Tla	X	X
5	X	C(1)	C(1)	C(1)	C(1)	C	C(1)	C(1)	X	X
6	X	Tlb(1)	Tlb	Tlb	Tlb	Tlb	Tlb	Tlb	X	X
7	X	C(2)	C(2)	C(2)	C(2)	C(2)	C(2)	C(2)	X	X
8	X	T1	T2	T2	T2	T2	T2	T2	X	X
9	X	T1-C	C	C	C	C	C	C	T1	X
10	X	C	C	C	C	C	C	C	C	X
11	X	T2-T3	T3a	T3a	T3a	T3a	T3a	T3a	T1	T1

Hydro-geological Units	Zones and associated aquifers								
12	X	T2-C	C	C	C	C	C	C	C	T1
13	X	T2-T3	T3b	T3b	T3b	T3b	T3b	T3b	T1-T2	T1
14	X	C	C	C	C	C	C	C	C	T1
15	X	T3-T4	T4	T4	T4	T4	T4	T4	T1,T2,T3	T1
16	X	C	C	C	C	C	C	C	C	T1
17	X	NK	NK	NK	NK	T4	NK	NK	T1	T1
18	C	C	C	C	C	C	C	C	C	C
19	P	P	P	P	P	P	P	P	P	P

Q1-Q6 = first to sixth Quaternary aquifers
T1a = first Tertiary aquifer (subaquifer A)
T1b = first Tertiary aquifer (subaquifer B)
T1b(1) = upper Port Willunga Formation, present near the coast only
T2 = second Tertiary aquifer
T3 = third Tertiary aquifer
T4 = fourth Tertiary aquifer
P = fractured rock aquifer
C = confining bed
X = not significantly present
C(1) = 'Croydon facies': partly acts as a semi-confining bed
C(2) = Munno Para Clay Member: confining beds interbedded with thin layers of limestone
NK = not known

Table 6 Summary of Quaternary aquifers

Aquifer Name/No.	Range of Depth (m) in Zone 3	Location in Zones
First/Q1	3 to 15	2, 2a, 3, 4 and 4a
Second/Q2	16 to 30	2, 2a, 3, part of 4 and 4a
Third/Q3	31 to 45	2, 2a, 3, part of 4 and 4a
Fourth/Q4	46 to 60	2a, 3 and part of 4a and 2
Fifth/Q5	65 to 80	3 and part of 4a and 2
Sixth/Q6	90	3

Table 7 Laboratory hydraulic conductivity tests (ADE 190)

Cb. No.	Depth (m)	Lithology	K_V (m/day)	K_H (m/day)
Cb 1	6.40-6.50	Brown silty fine sand, clayey.	1.56×10^{-4}	4.06×10^{-4}
Cb 2	22.40-22.70	Brown silty sand – clayey with bands of clayey sand and course sand.	1.00×10^{-3}	6.04×10^{-3}
Cb 3	36.61-36.87 37.96-38.21	Not tested, but similar to 38.43-38.62m interval.	NK	NK
Cb 3	38.43-38.62	Brown silty clay, and weakly cemented silt patches with organic staining.	5.79×10^{-5}	7.17×10^{-5}
Cb 4	51.42-51.62	Not tested, but similar to 51.20-51.36 interval.	NK	NK
Cb 5	62.33-62.50	Silty clay. Grey stained with brown.	4.84×10^{-5}	5.36×10^{-5}
Cb 5	63.04-63.25	Silty fine sand, slightly clayey, micaceous, occasional siltstone.	2.90×10^{-4}	3.02×10^{-3}
Cb 6	68.79-69.00	Clay – silt, some fine sand micaceous, rare siltstone fragments. Brown.	3.63×10^{-5}	6.60×10^{-5}

Cb. No.	Depth (m)	Lithology	K_V (m/day)	K_H (m/day)
Cb 6	71.31-71.50	Clayey silt with seams of fine white sand. Brown stained with grey.	5.27×10^{-5}	1.38×10^{-4}
Cb 6	72.62-72.80	Clay. Brown stained with grey.	5.96×10^{-6}	7.08×10^{-6}
Cb 6 and/ or Cb 7	92.50-92.80	Clayey sand. Brown stained with yellow.	3.10×10^{-5}	5.60×10^{-6}

KV = vertical hydraulic conductivity (m/day) KH = horizontal hydraulic conductivity (m/day) NK = not known

Table 8 Laboratory hydraulic conductivity tests (YAT 123)

Cb No.	Depth (m)	Lithology	K_V (m/day)	K_H (m/day)
Cb 3	44.30-44.60	Sandy silt with grey clay. Yellow sandy patches and pockets of organic matter. Brown.	1.64 x 10-3	3.46 x 10-5
Cb 4	59.00-59.17	Silty sand. Patches of friable grey clay. Brown mottled with grey.	1.81 x 10-4	1.47 x 10-4
Cb 5	61.80-62.10	Clay, grey mottled with brown.	7.78 x 10-6	7.78 x 10-6
Aquifer	80.25-80.45	Silty sands and grey clay.	1.30 x 10-3	NK
Cb 6	89.40-89.70	Clay, grey mottled with brown.	1.20 x 10-6	6.48 x 10-6
Cb 6	89.70-90.00	Clay, grey stained with brown.	8.64 x 10-7	NK

KV = vertical hydraulic conductivity (m/day) KH = horizontal hydraulic conductivity (m/day) NK = not known

Table 9 Tertiary aquifer distribution in each zone.

Zone	Aquifer Distribution
2	Only three aquifers (T1 to T3), T4 Aquifer is well developed only near the coast.
2a	T1 and T2 are recognised, while T3 and T4 Aquifers are anticipated.
3	All four aquifers (T1 to T4) are well developed in this zone.
4	Only one or two thin aquifers (T1 and T2).
4a	Only one thick sandy aquifer containing several stratigraphic units.

Table 10 Summary of first Tertiary aquifer information

Zone	Equivalent Stratigraphic Units	Average Thickness (m)	Main Lithological Description
4a	3, 10, 11, 12, 13, 14, 15, 16 and 17	120	Fine to medium sand with occasional thin gravel beds and thin clayey and lignitic layers.
4	3, 9, 10, 11, 12 and 13	25	Fine sand, silty and clayey.
2	4 (thin), 6 (near the coast), mainly Unit 8 and part of 9	50+	Some thin sandstone, limestone grading downwards to course sand and silt. Sandstone, sand and limestone.
2a	4, 6, 8 and part of 9	25	Sandstone, sand and limestone.
3	3, 4, part of 5 and 6	80	Sand, sandstone, shells and silty sand and limestone.

Table 11 Estimated well discharge mainly from the T1 Aquifer (1982–84)

Zone and Pumpage Centre	Yearly irrigation	Yearly Industrial	Summer Irrigation	Summer Industrial	Winter Irrigation	Winter Industrial	Total Yearly /zone
2 and 2a	711	138 14	711	79 8	NIL	59 6	863
3E Thebarton area	NIL	258	NIL	143	NIL	110	258
3D Torrens Valley	500	40	500	23	NIL	17	540
3C West Lakes	1232	NIL	1232	NIL	NIL	NIL	1232
3B Penrice (ICI) – SAMCOR	62	2689	62	1548	NIL	1141	2751
3A Little Para River	638 87 (c)	NIL	638 87 (c)	NIL	NIL	NIL	725
4 and 4a	104-.6 217 (P)	483 159 (P)	104.6 217 (P)	278 92 (P)	NIL	205 67 (P)	1014
Seas. Tertiary total	3298	3622	329	2084	NIL	1538	6920
Seas. Bedrock sand total	217	159	217	92	NIL	67	376
Seas. Carisbrook Sand total	87	NIL	87	NIL	NIL	NIL	87
Seas. Total pumpage	3602	3781	3602	2176	NIL1605	7383	

c = Carisbrook Sand aquifer P = Fractured rock aquifer

Both ‘c’ and ‘P’ aquifers are hydraulically connected to Tertiary aquifers

Seas. = seasonal pumping either winter or summer.

Table 12 Average values of T1 Aquifer parameters

Zone	T m^2/day	S	Average b (m)	Average K (m/day)	Remarks
2	200	5.5×10^{-4}	50	3.5	Bailey Reserve
3	120-175	2.5 x 10-4	60-80	2.5	Kidman Park and Grange golf course aquifer tests and flow net analyses
4a	130-360	-	120	2-3	Hazelwood Park pump test
4	?25-40 (estimated)	-	25	1.0	

T = Transmissivity S = storage coefficient B = aquifer thickness K = hydraulic conductivity

Table 13 Summary of T3 Aquifer information (zone 2)

Well Location and Number	Depth to Top of Aquifer (m)	Aquifer Thickness (m)	Salinity (mg/L)	Water level (m)	Supply (L/sec)	Remarks
Edwardstown No. 755	186	9	15850	3	<1	Investigation well completed – South Maslin Sand (Unit 15)
Mitcham Railway Station No. 16	238	4-26	4500	52	?	Investigation well completed – South Maslin Sand (Unit 15)
St James Reserve No. 17	226	5	8410	–	–	Investigation well completed – South Maslin Sand (Unit 15)

Table 14 Summary of T4 Aquifer information

Well Name	Depth to Top of Aquifer (m)	Aquifer Thickness (m)	Salinity (mg/L)	Water Level (m)	Supply (m^3/day)	Remarks
Allenby Gardens	532	39	100 000 to 140 000 see full analysis	25	61 tested 38 tested	Max DD ~ 5 m; unable to test this well at high yield because of casing size restriction (3") max DD ~ 1.8m
G M Michell	~432	15	~ 30 000 to 40 000	3.5	~ 160	Bedrock salinity in order of 50 000 mg/L
Grange	500	39 SMS	Not known	Not known	Not known	Drilled by Beach Petroleum Co.
Elizabeth Oval	345	7	16 100	14	12.5 L/sec	
Dry Creek	~438	25-62	79 000 to 88 000	Flowing 6-18m above ground	10 L/sec	Investigation/ production well
Port Gawler MESA investigations	254	36	~21 000	Flowing 9 m above ground	Flowing ~5 L/sec	Bedrock salinity 50 000 mg/L at 318m below ground
Port Gawler Penrice	300 330	17 SMS 15 NMS	55 000	Flowing ?2-5m above ground	~ 40 L/sec	Completed as production well in both South and North Maslin Sands
Minda Home No. 773	414	26	40 700	Flowing 21m above ground	Flow 4 L/sec	Investigation well, completed in South Maslin Sand (Unit 15)
Fish Farm Pelican Point	?356	?9	~ 2800	Flowing ?10m above ground	1-2 L/sec	located on the up ---- side of Red Bank Fault extension poor supply large drawdown aquifer material are very poorly sorted and contains large amount of clay and lignitic clay

NMS = North Maslin Sand SMS = South Maslin Sand

FIGURES

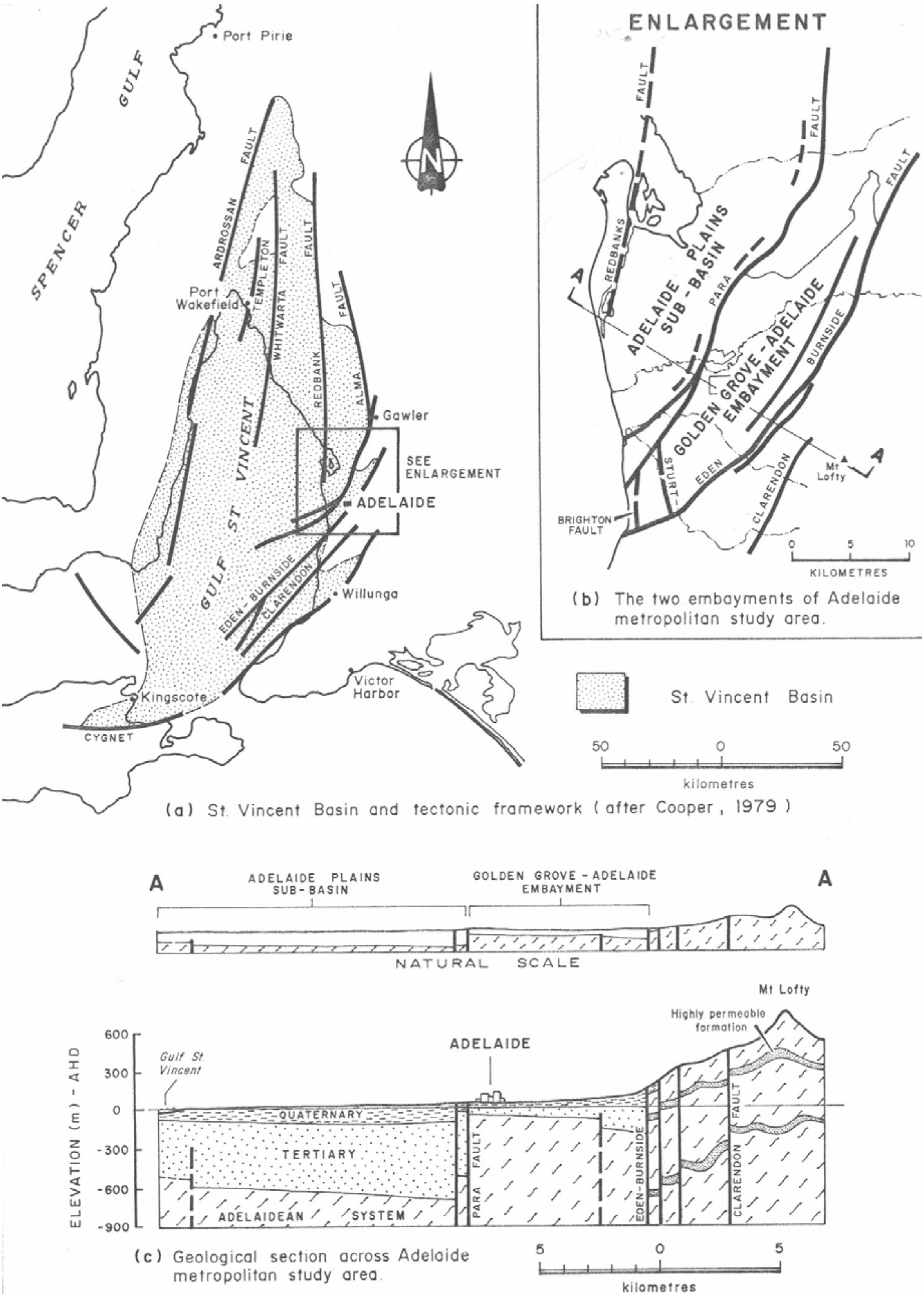

Figure 1 Physiographic features of study area

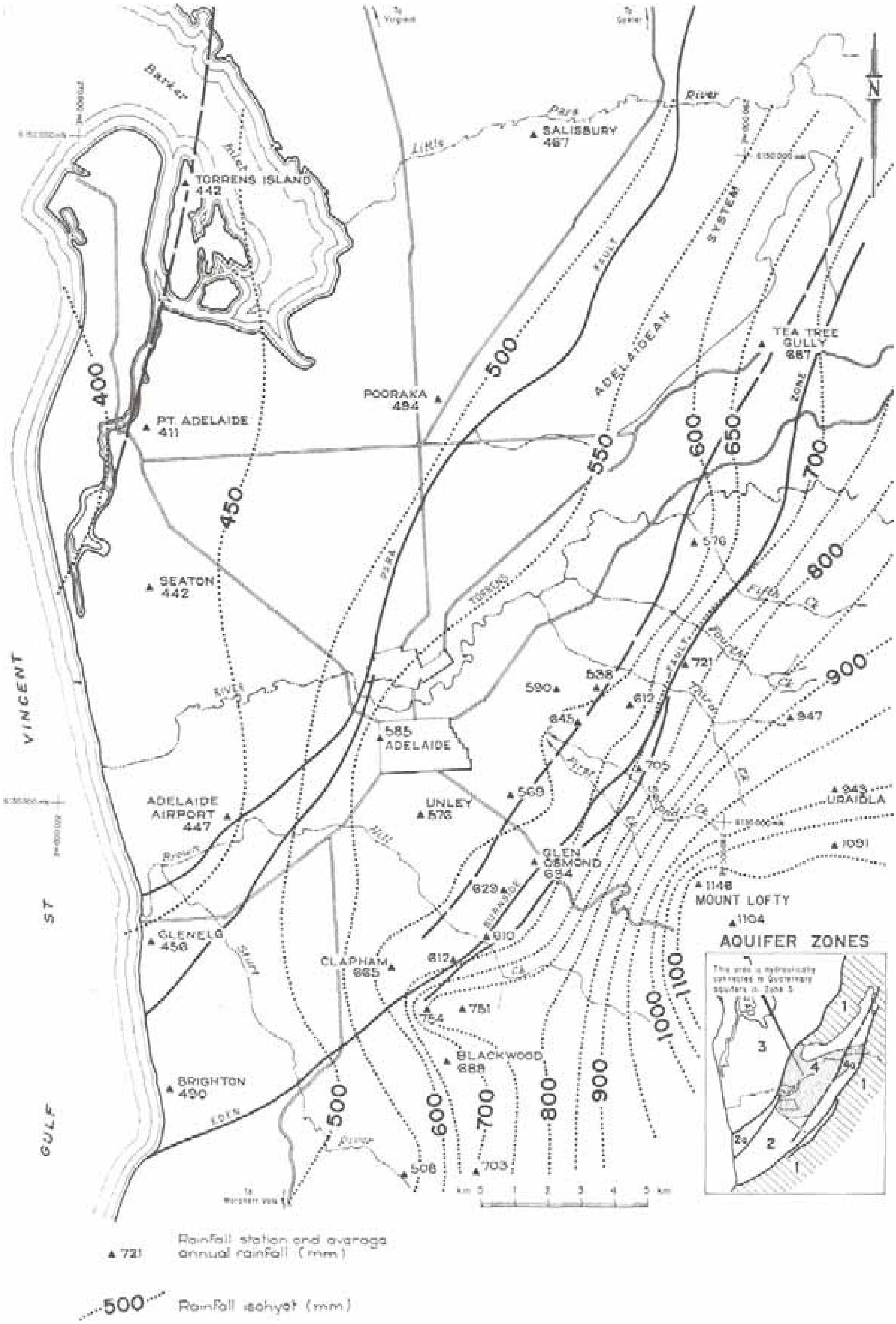

Figure 2 Average Annual Rainfall Isopyets

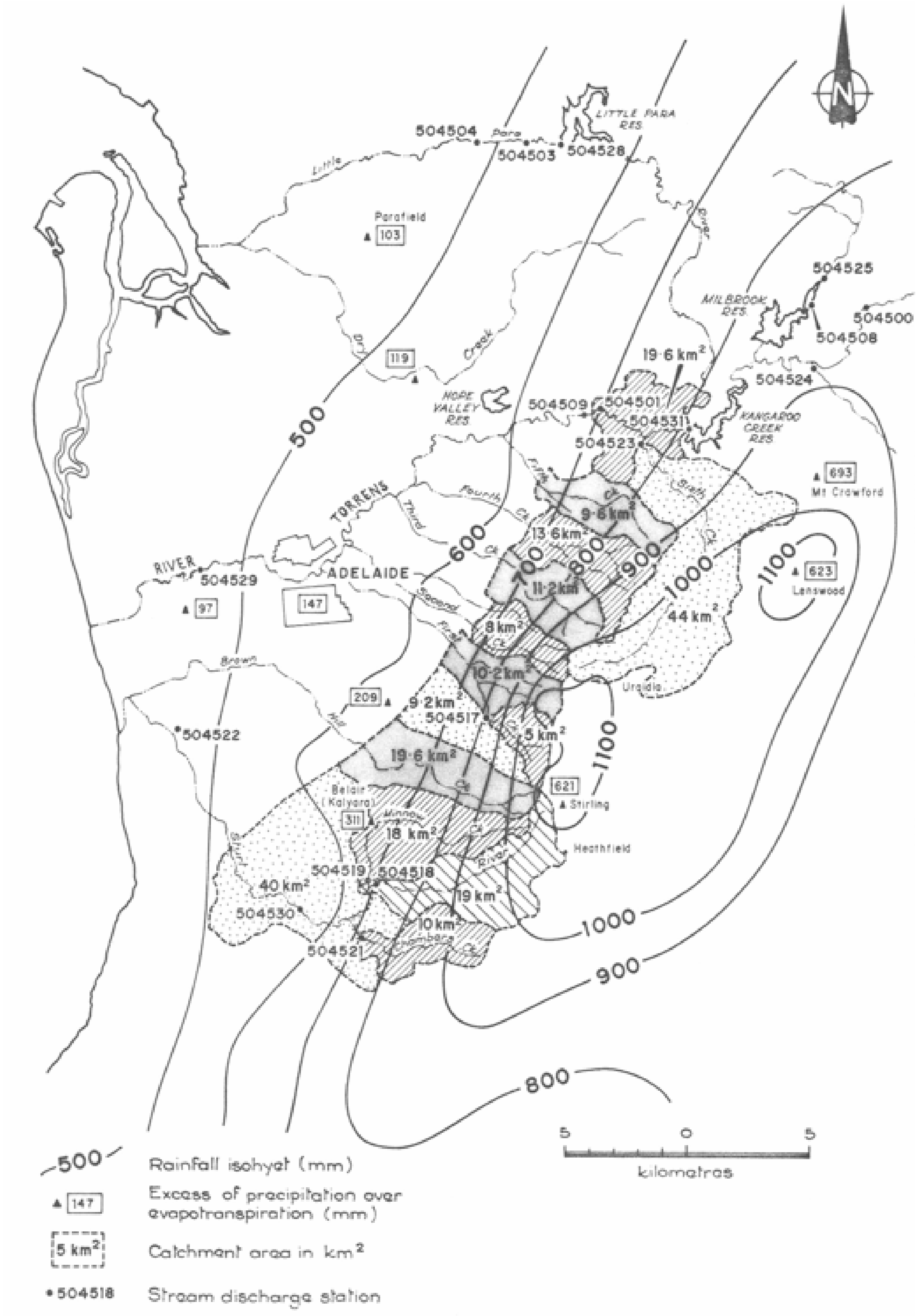

Figure 3 Surface Water Drainage from Hills Catchment Area

FIGURES

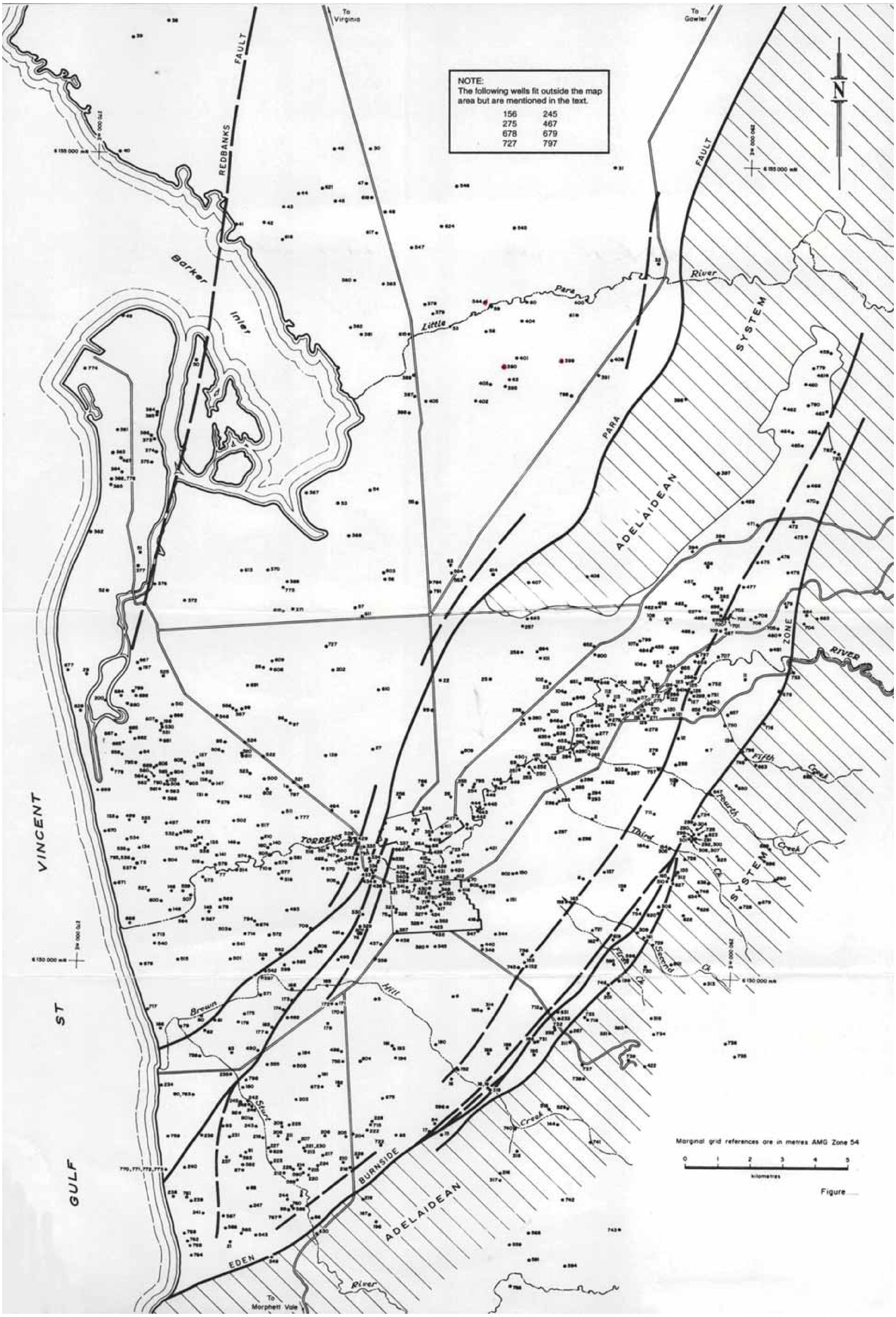

Figure 4 **Location of Data Points**

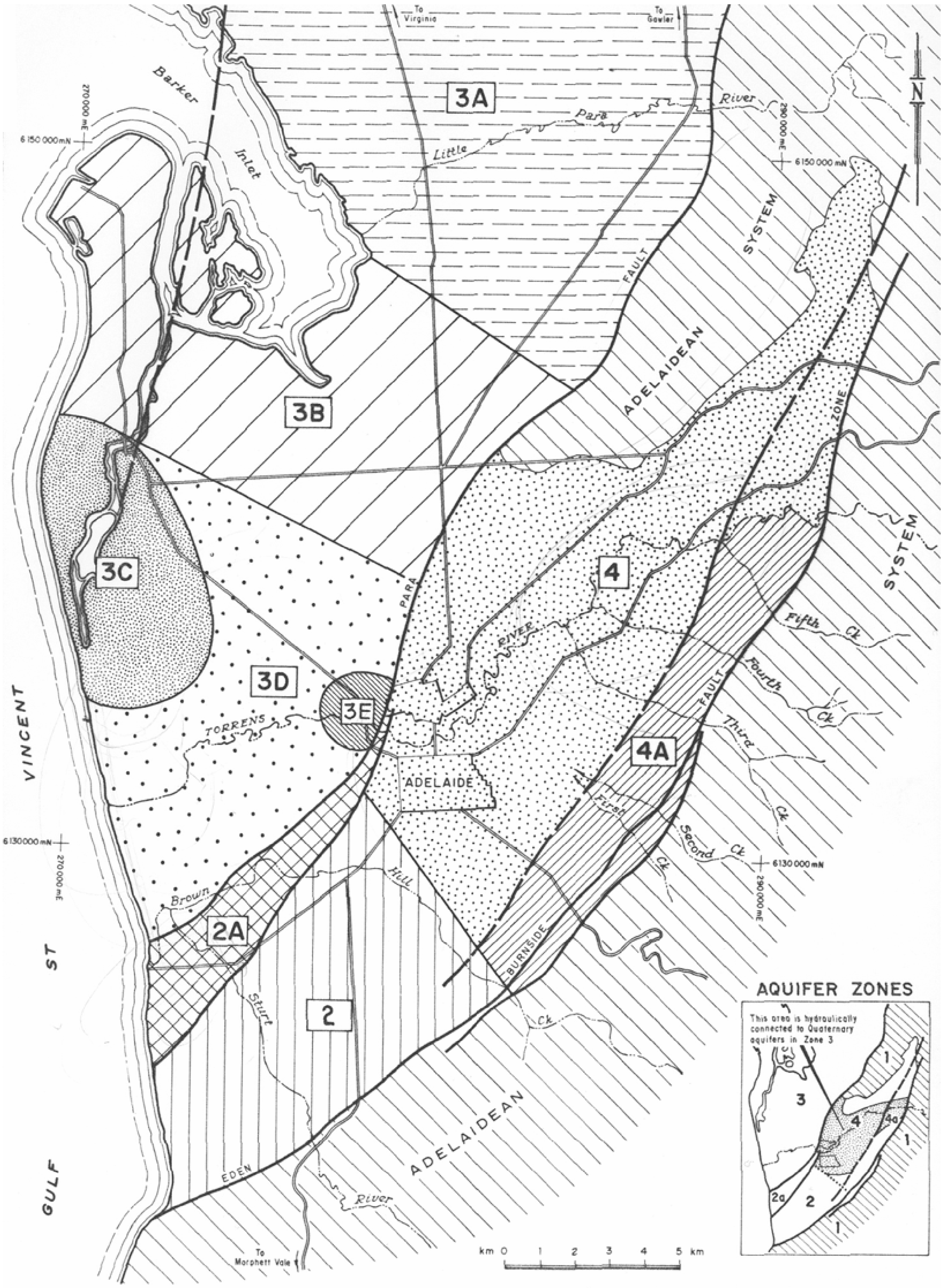

Figure 5 Hydrogeological Zones

Reference

Age	Formation	No.	Unit	Hydrogeology
PLEISTOCENE		1	HINDMARSH CLAY: Clay with interbedded sand and gravel layers	Generally confining bed: contains up to six thin gravel aquifers
PLEISTOCENE		2	LOWER QUARTERNARY CLAY: Dark grey clay to reddish brown, sandy clay	Confining bed
PLIO-PLEISTO		3	CARISBROOKE SAND: Fine yellow sand	Aquifer
PLIOCENE		4	HALLET COVE SANDSTONE AND DRY CREEK SAND: Shelly dark grey	Aquifer
PLIOCENE		5	CROYDON FACIES: Fossiliferous, glauconitic silt, sand and clay	Semi - confining bed
EARLY-MIDDLE MIOCENE	PORT WILLUNGA FORMATION	6	UPPER PORT WILLUNGA FORMATION: Yellow and light grey limestone	Aquifer
EARLY-MIDDLE MIOCENE	PORT WILLUNGA FORMATION	7	MUNNO PARA CLAY: Stiff dark grey clay	Confining bed
EARLY-MIDDLE MIOCENE	PORT WILLUNGA FORMATION	8	LOWER PORT WILLUNGA FORMATION: Light grey to yellow limestone, silty and clayey	Aquifer
OLIGOCENE	PORT WILLUNGA FORMATION	9	RUWARUNG MEMBER: Clay, chert, limestone, silt and sand	Confining bed (clay, chert) Aquifer (sand, silt and limestone)
OLIGOCENE	PORT WILLUNGA FORMATION	10	ALDINGA CLAYEY MEMBER: Dark grey clay	Confining bed
OLIGOCENE	PORT WILLUNGA FORMATION	11	ALDINGA SANDY MEMBER: Light grey to yellow sand - fossiliferous	Aquifer
OLIGOCENE	PORT WILLUNGA FORMATION	12	CHINAMAN GULLY FORMATION: Lignitic - clay	Confining bed
OLIGOCENE	PORT WILLUNGA FORMATION	13	CHINAMAN GULLY FORMATION: Sand and silt	Aquifer
LATE EOCENE		14	BLANCHE POINT FORMATION: Clay - chert, marl, Tortachilla Limestone included	Confining bed
MIDDLE-LATE EOCENE		15	SOUTH MASLIN SAND - Dark grey carbonaceous sand	Aquifer
MIDDLE-LATE EOCENE		16	CLINTON FORMATION: Lignite and clay	Confining bed
		17	UNDIFFERENTIATED TERTIARY: Sand	Aquifer
PRE-CAMBRIAN		18	ADELAIDEAN (weathered): Mostly clay and 'clay-bound' gravel	Confining bed
PRE-CAMBRIAN		19	ADELAIDEAN (unweathered): Phyllite, slate, quartz, dolomite and others	Fractured rock aquifer

QUARTERNARY AQUIFERS

- First........................ 01
- Second.................. 02
- Third........................ 03
- Fourth..................... 04
- Fifth........................ 05
- Sixth........................ 06

TERTIARY AQUIFERS

- First T1
- Second T2
- Third T3
- Fourth T4

BEDROCK AQUIFER

CONFINING BED

Figure 5 continued Geological and hydrogeological section key

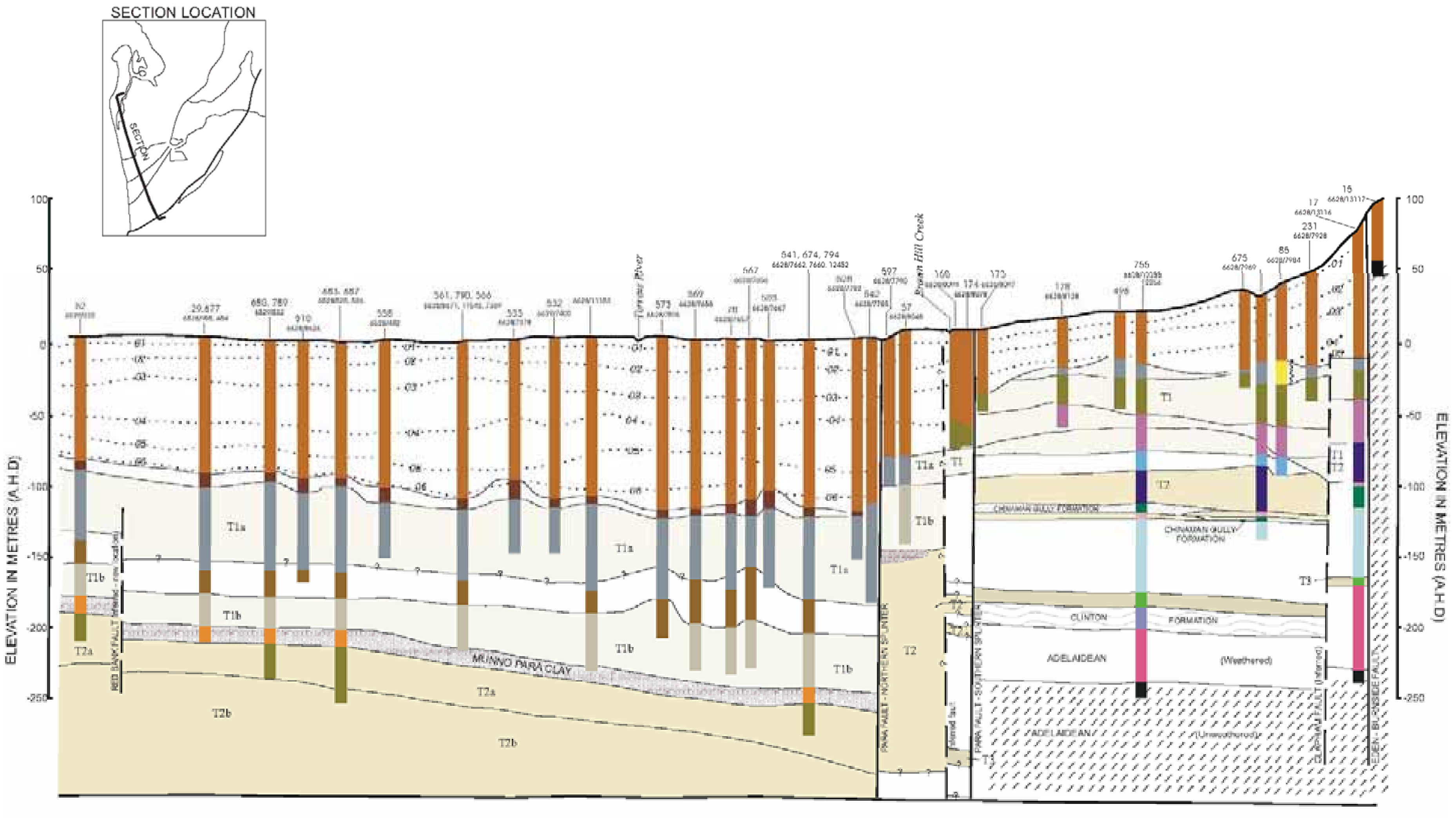

Figure 5a Geological and Hydrogeological Section

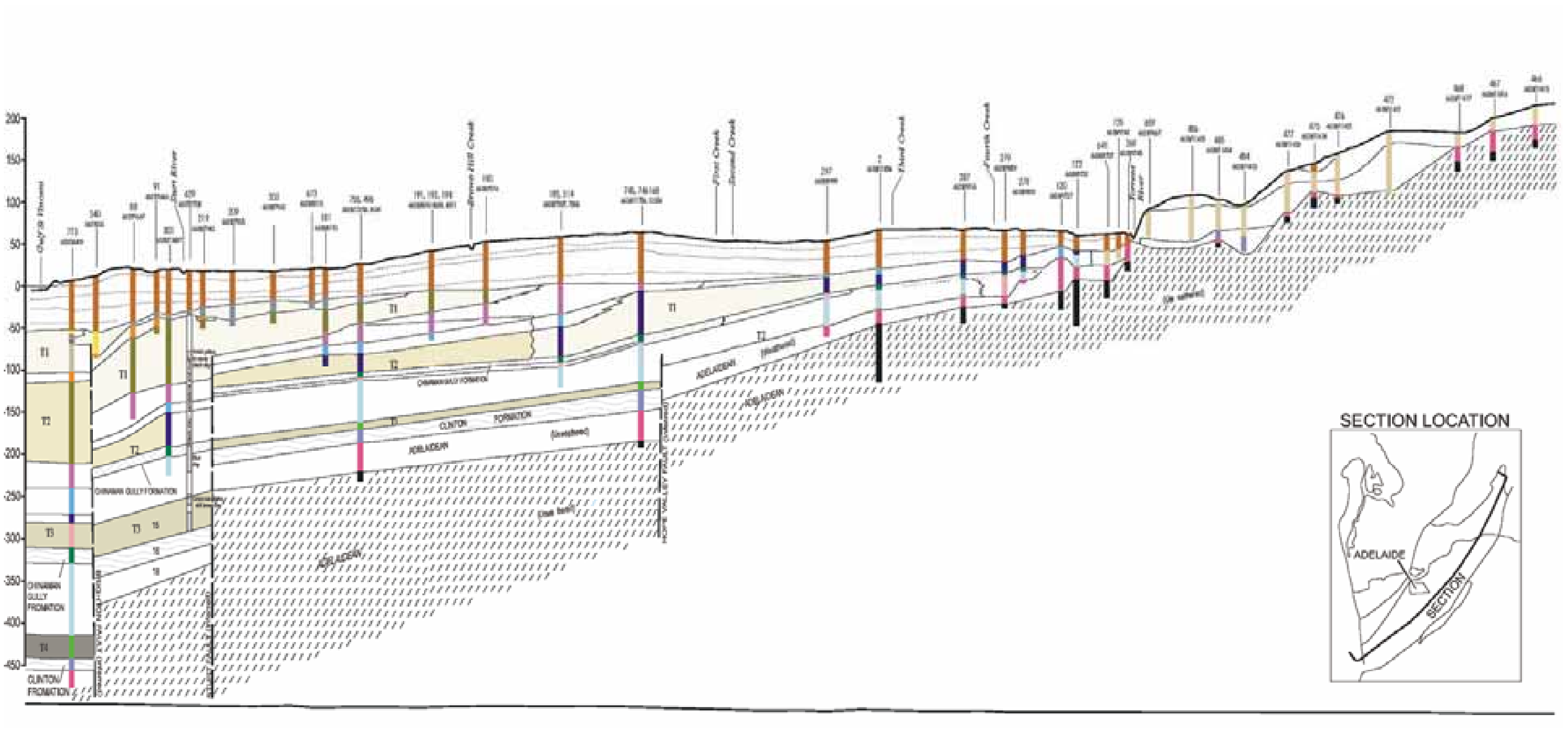

Figure 5b **Geological and Hydrogeological Section**

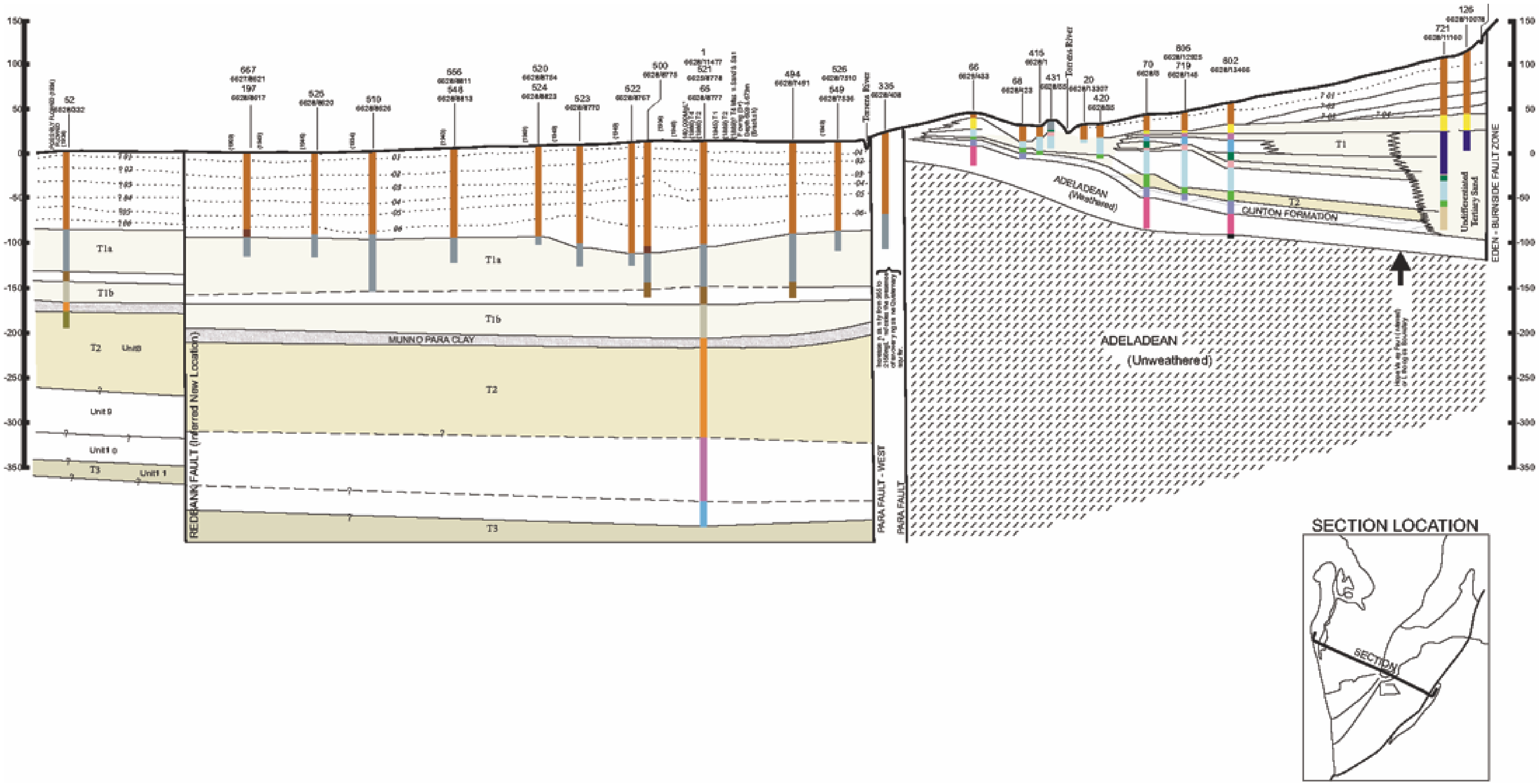

Figure 5c Geological and Hydrogeological Section

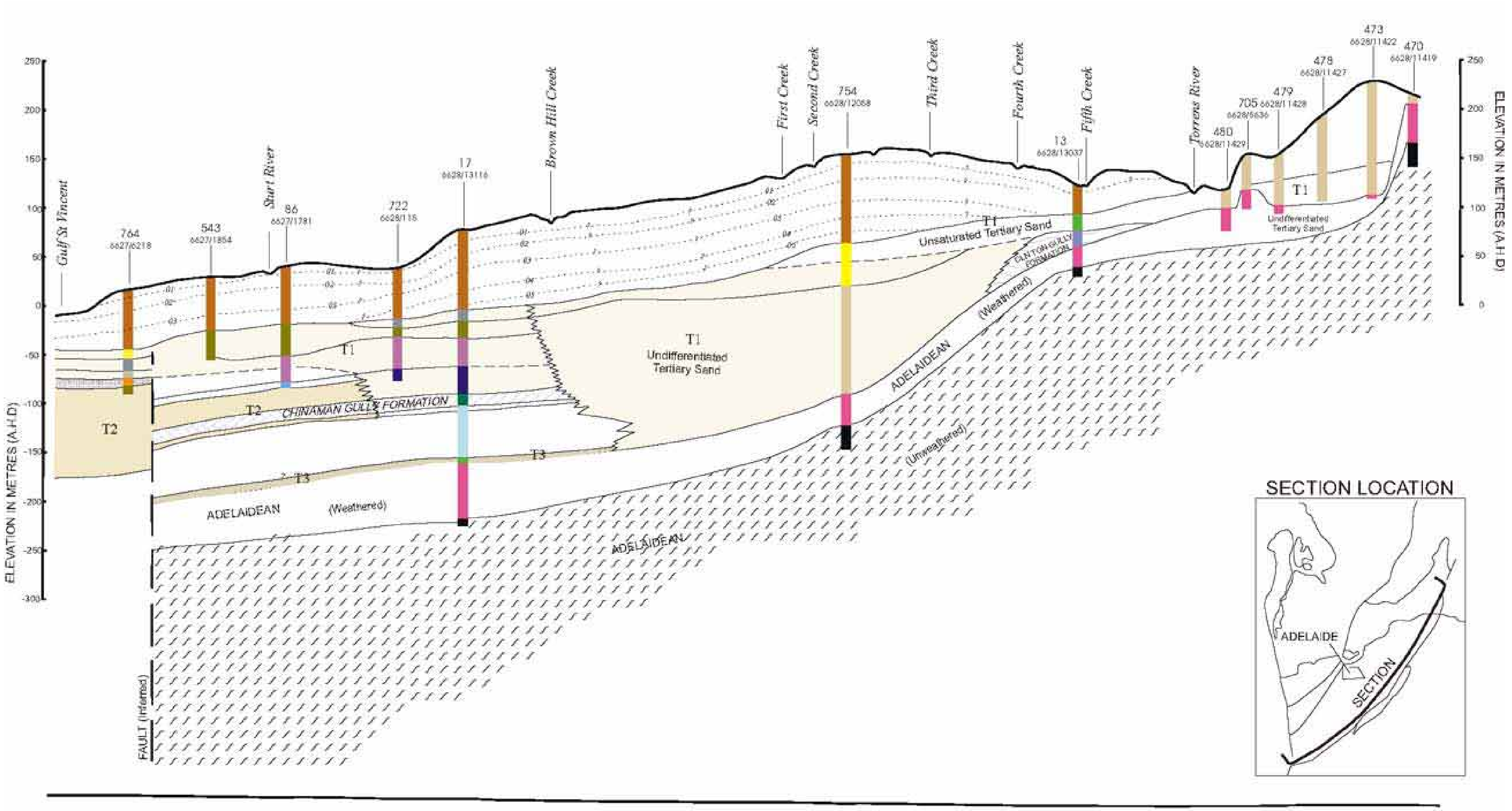

Figure 5d Geological and Hydrogeological Section

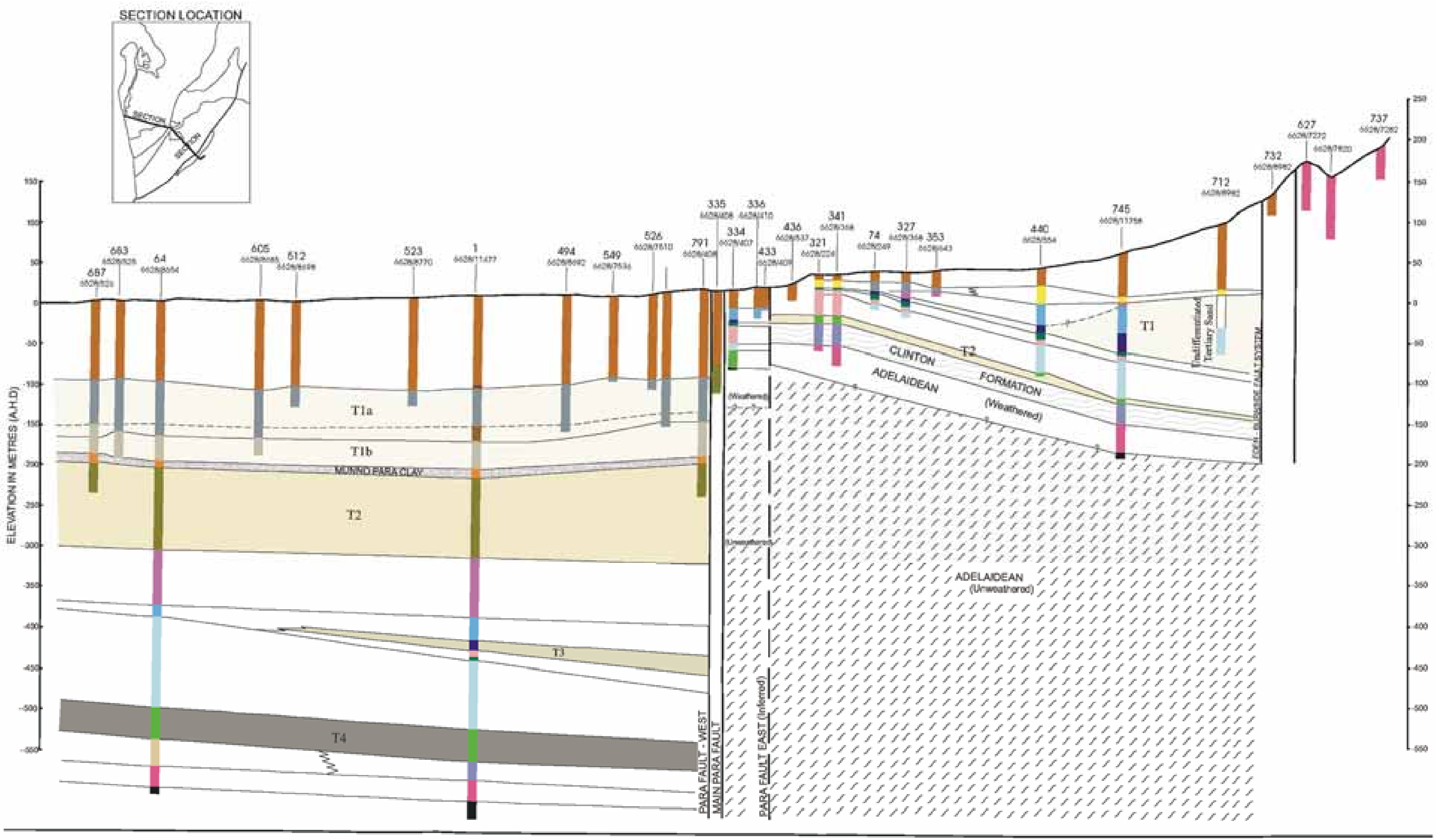

Figure 5e Geological and Hydrogeological Section

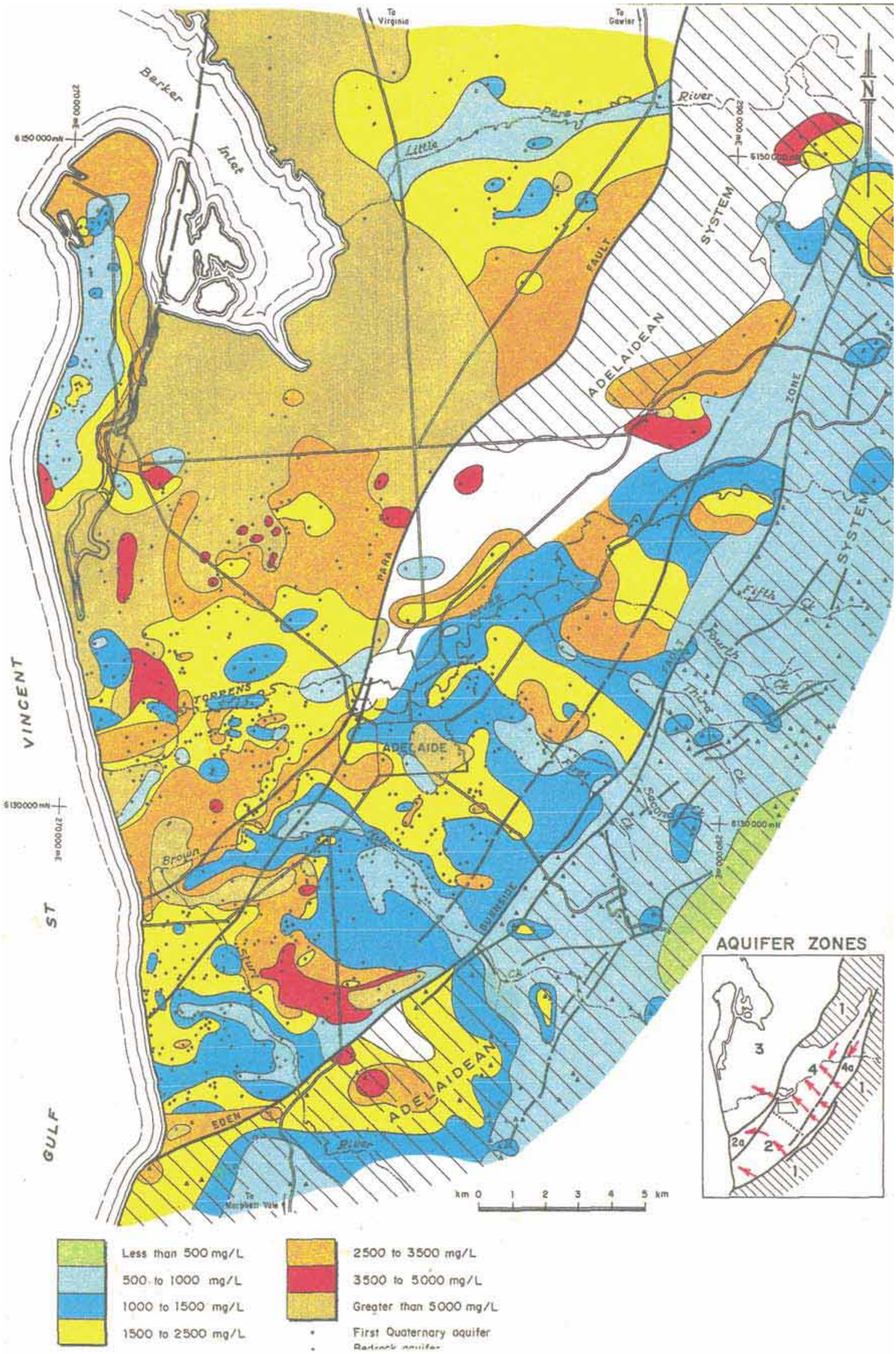

Figure 6 Fractured Bedrock and First Quaternary Aquifer Salinity Plan

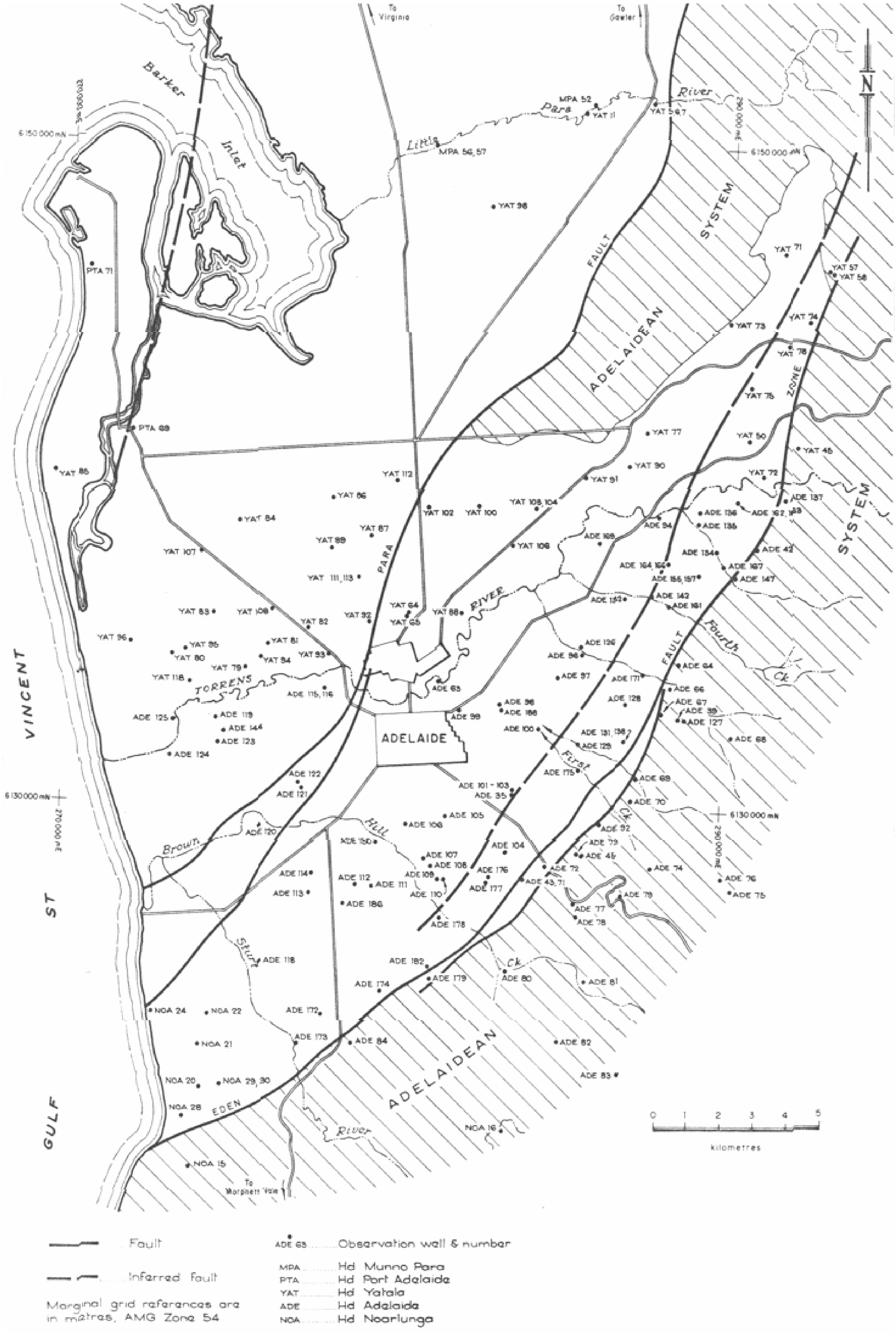

Figure 7 Fractured Bedrock and First Quaternary Aquifer Observation Well Network

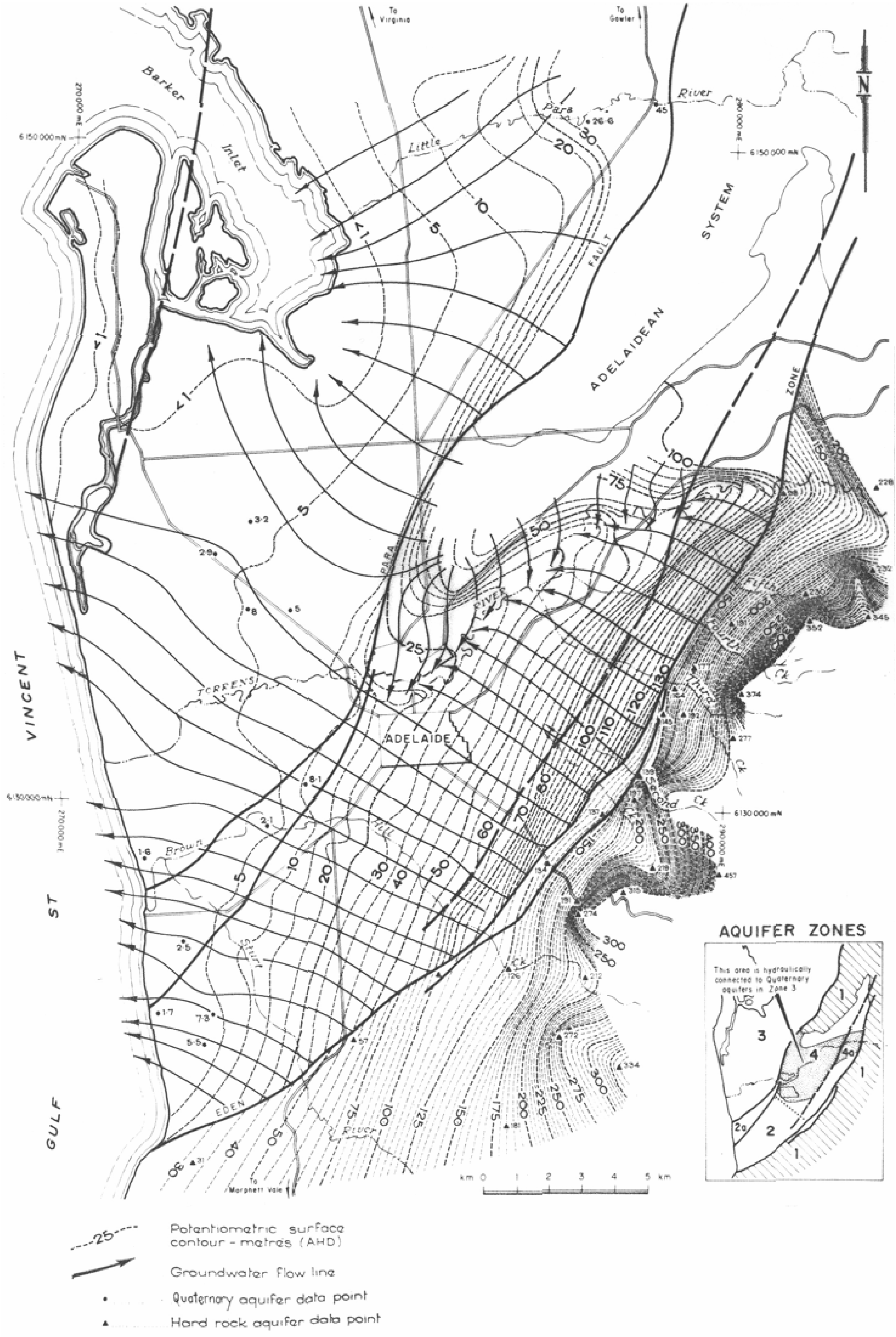

Figure 8 **First (uppermost) Quaternary Aquifer (Q1) and Bedrock Aquifer Potentiometric Surface**

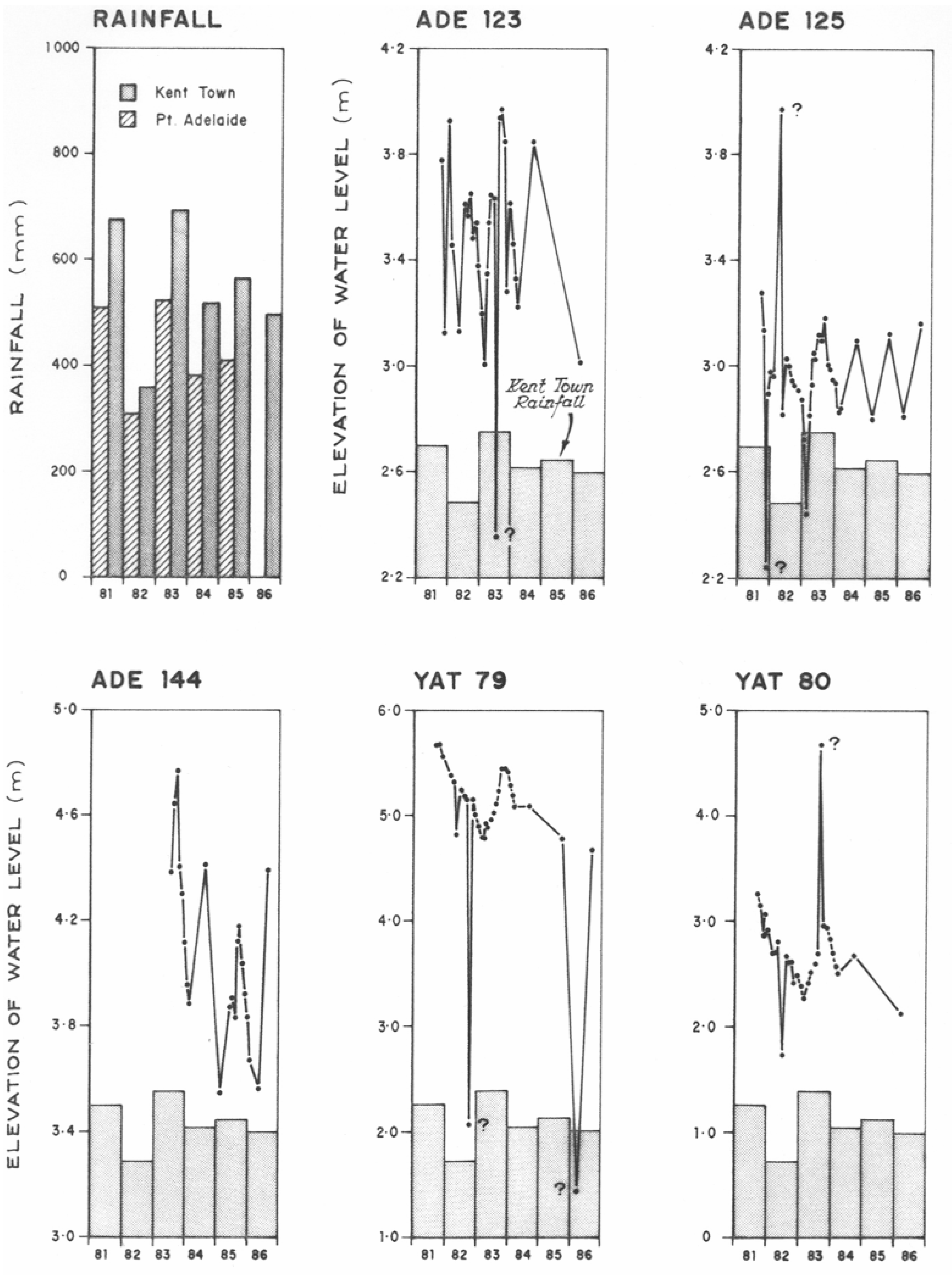

Figure 9 Quaternary Aquifer Hydrographs ADE 123, 125, 144 and YAT 79, 80

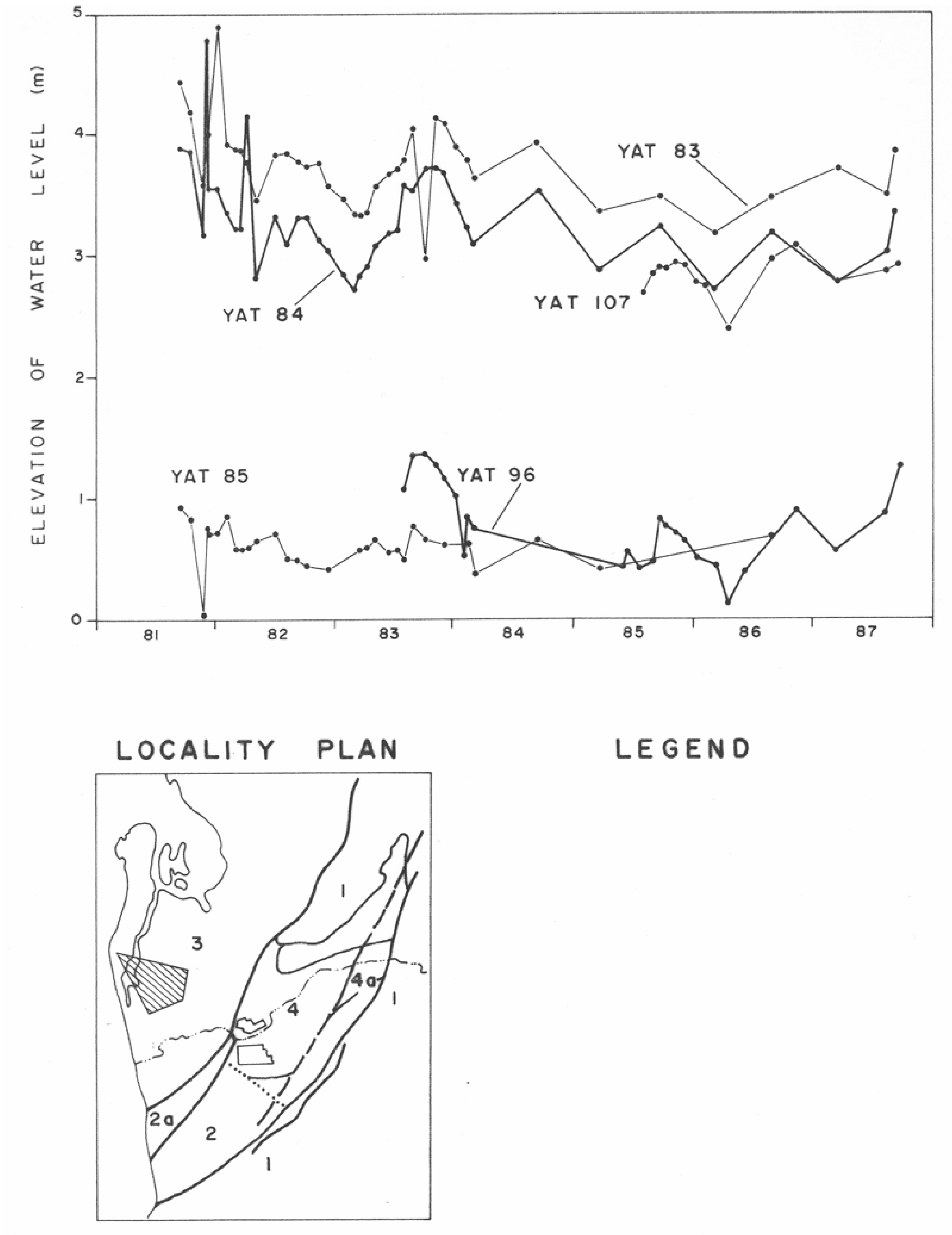

Figure 9a First Quaternary Aquifer Hydrographs Zone 3

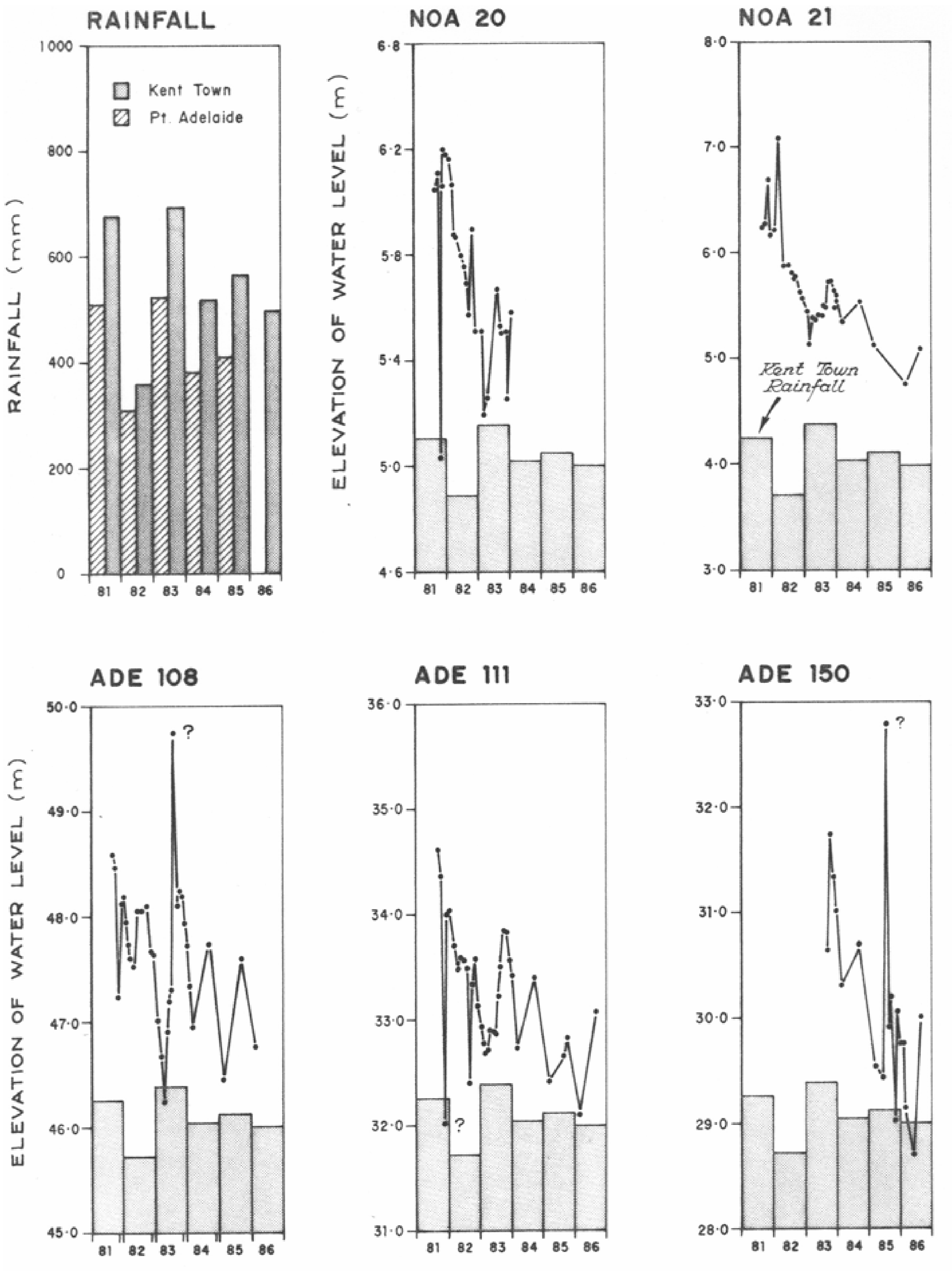

Figure 9b Quaternary Aquifer Hydropgrahs Observation Wells NOA 20, 21 and ADE 108, 111, 150

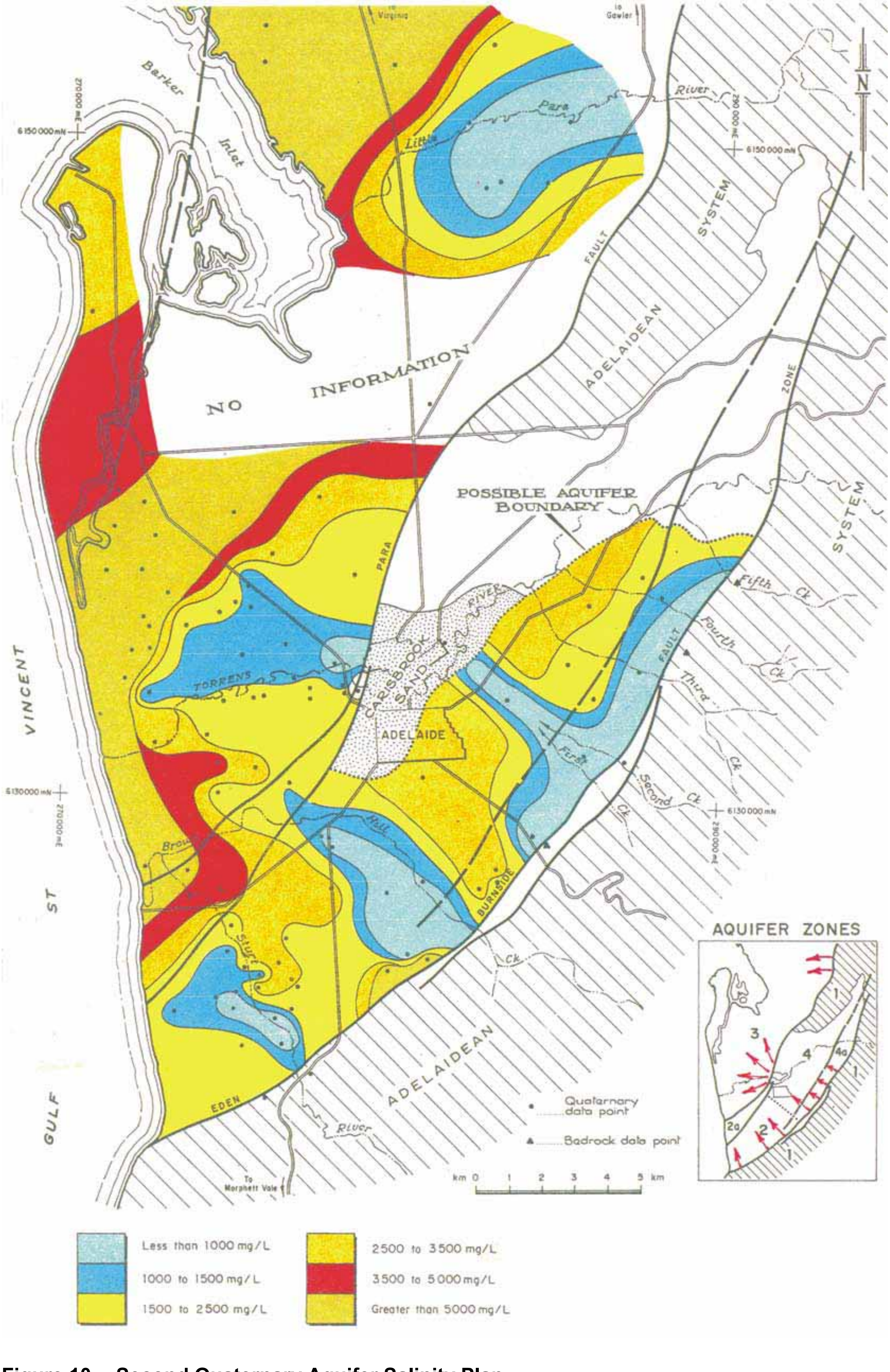

Figure 10 Second Quaternary Aquifer Salinity Plan

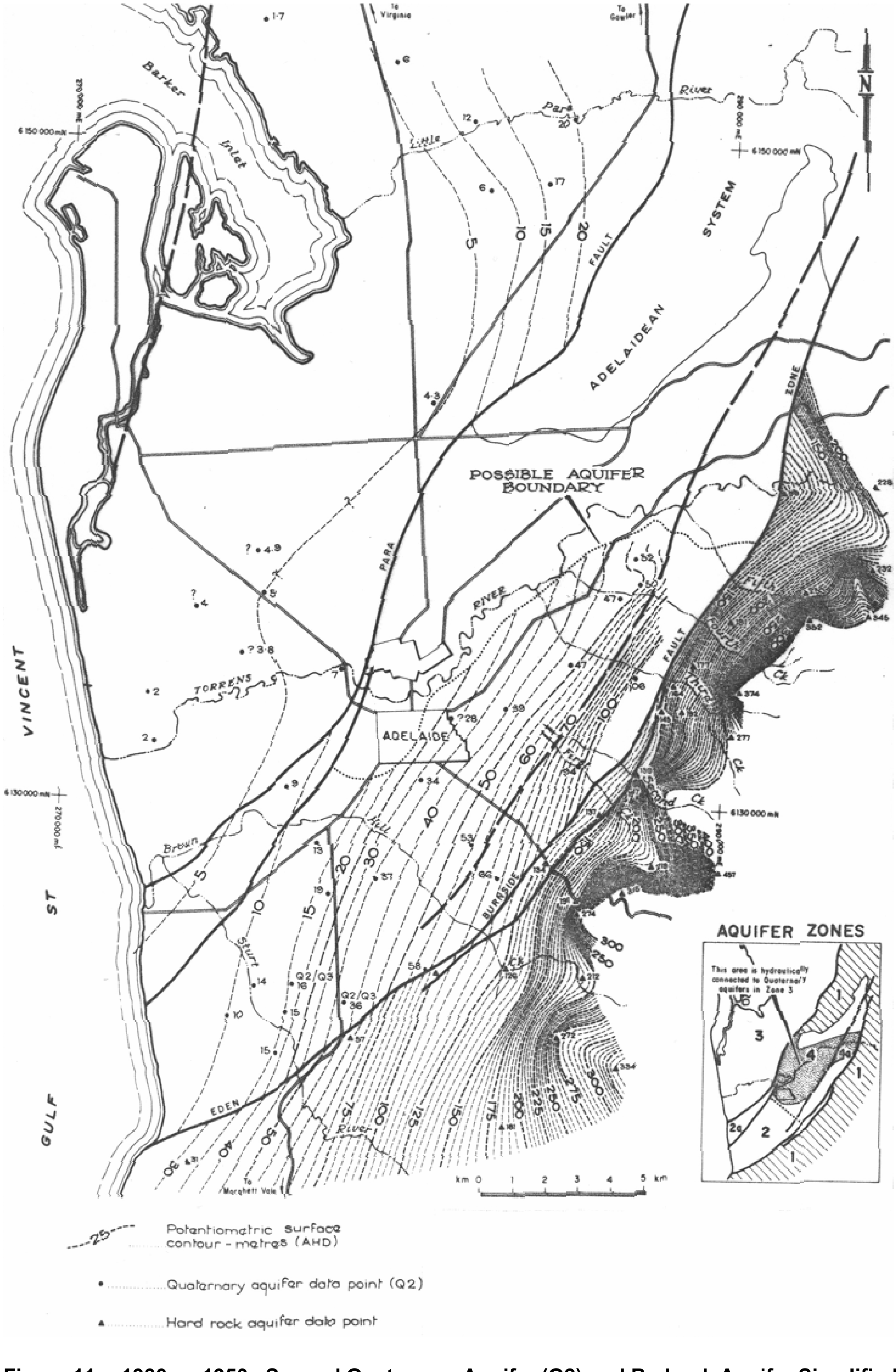

Figure 11 1930s – 1950s Second Quaternary Aquifer (Q2) and Bedrock Aquifer Simplified Potentiometric Surface

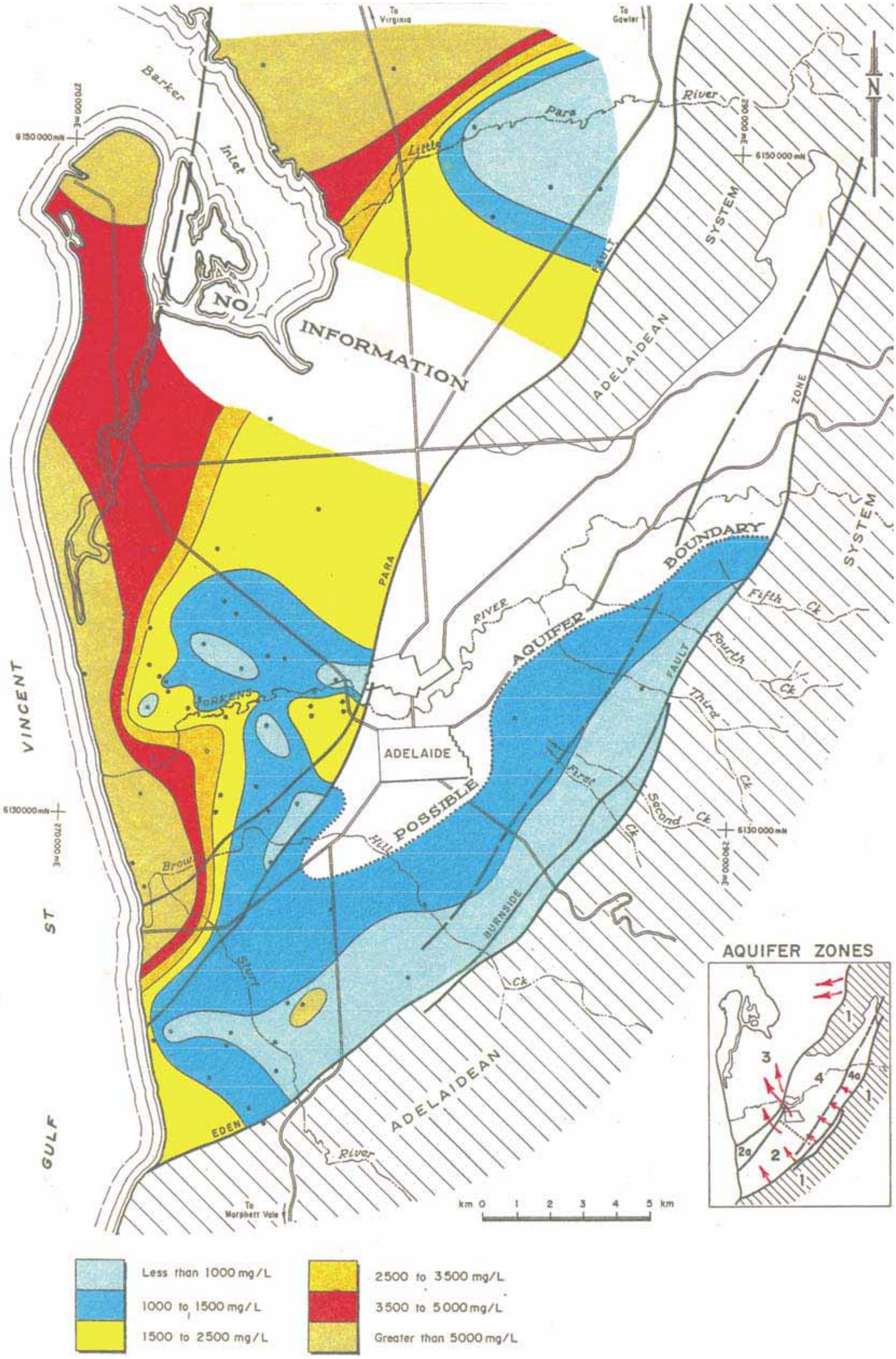

Figure 12 Third Quaternary Aquifer Salinity Plan

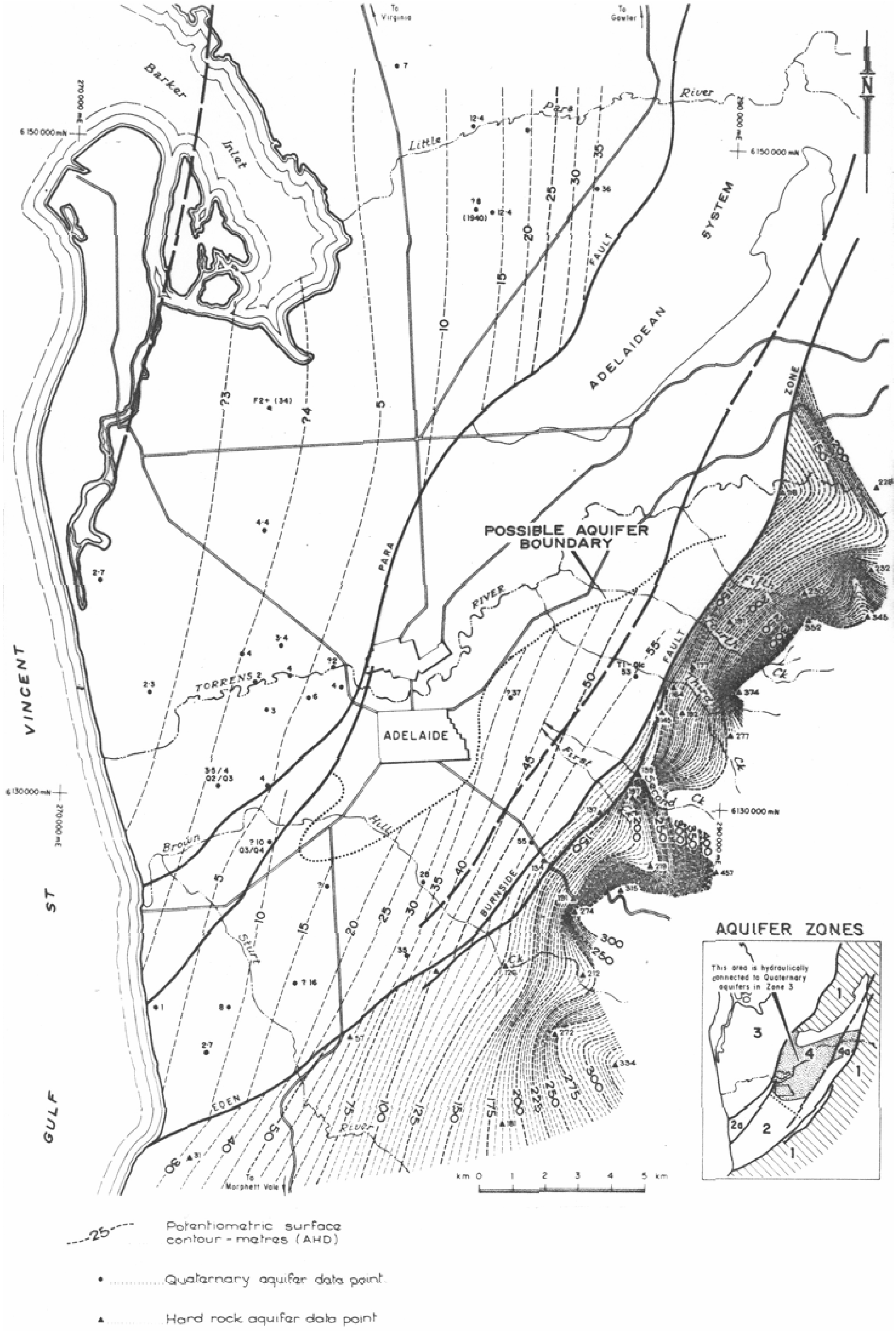

Figure 13 Early 1950s, Third Quaternary (Q3) and Bedrock Aquifers Simplified Potentiometric Surface

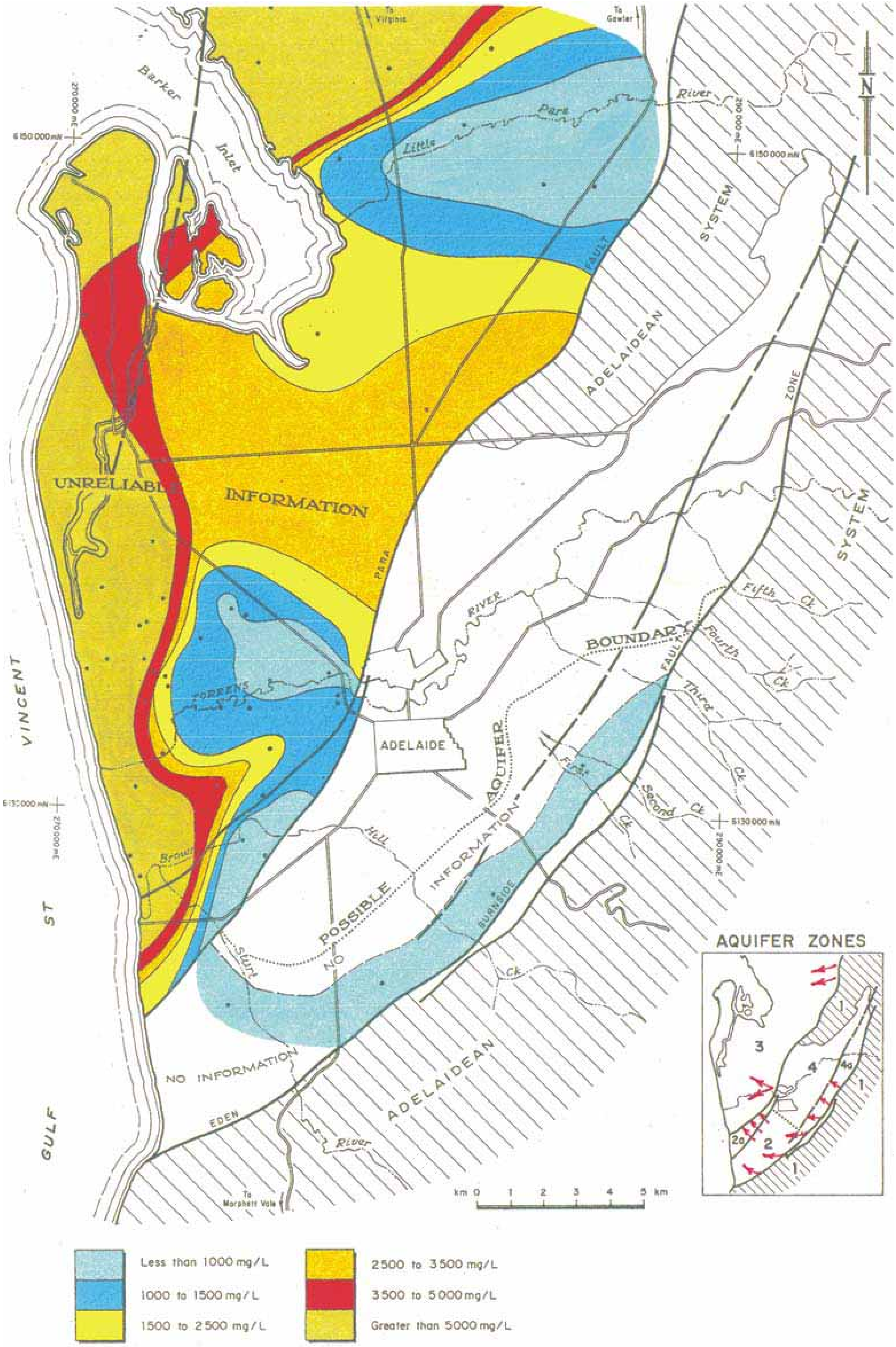

Figure 14 Fourth Quaternary Aquifer Salinity Plan

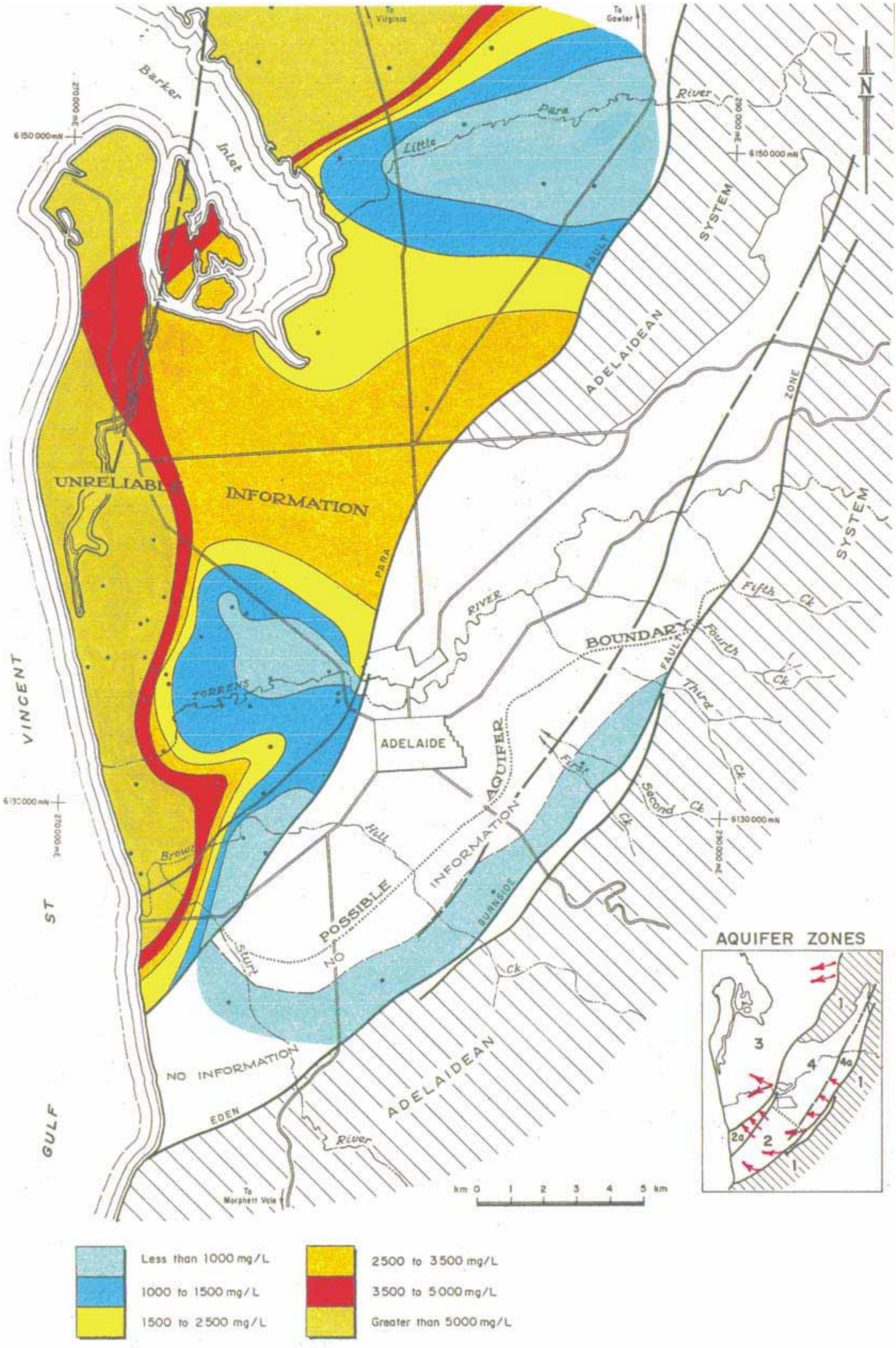

Figure 15 Fifth Quaternary Aquifer Salinity Plan

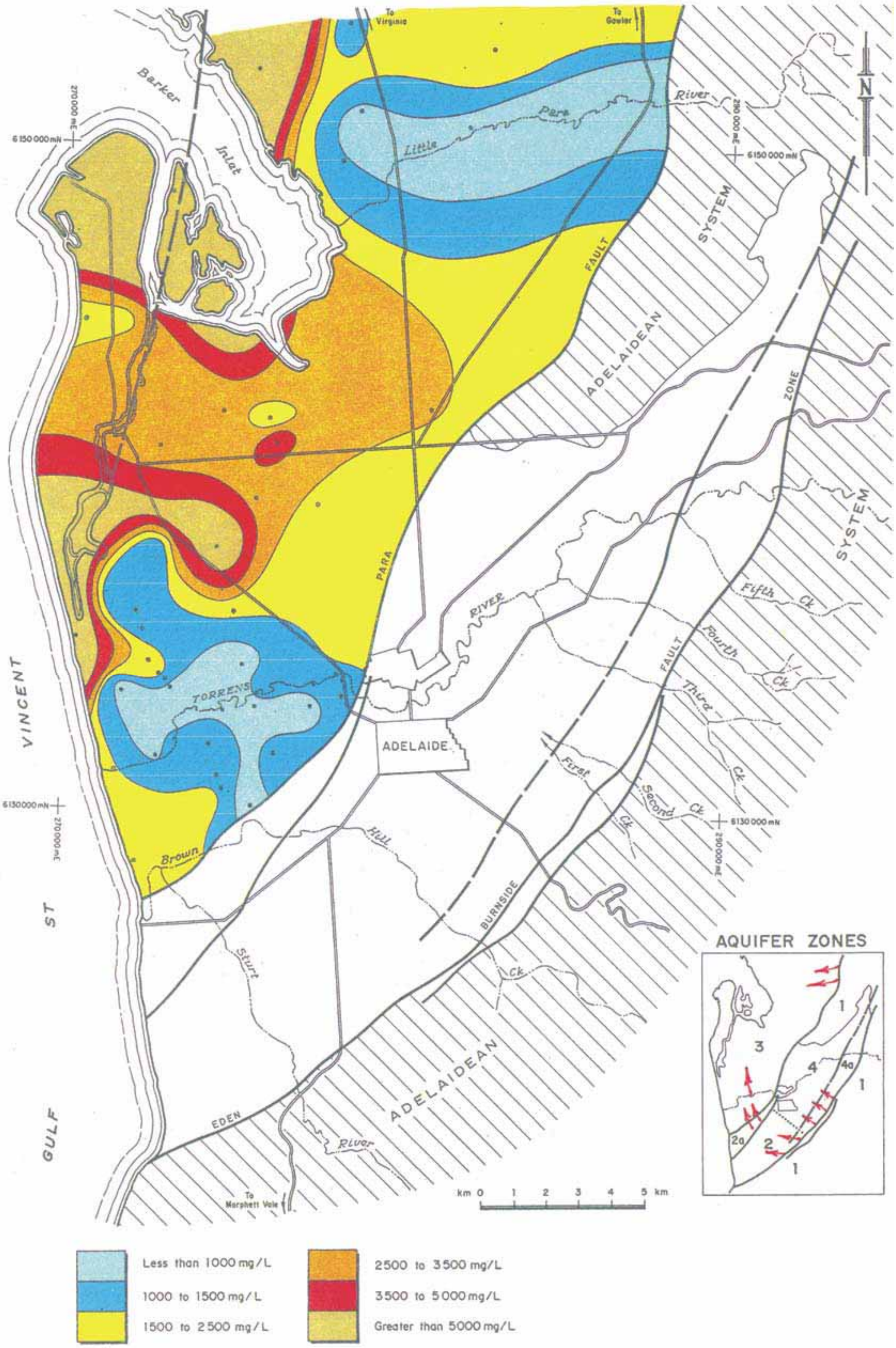

Figure 16 Sixth Quaternary Aquifer Salinity Plan

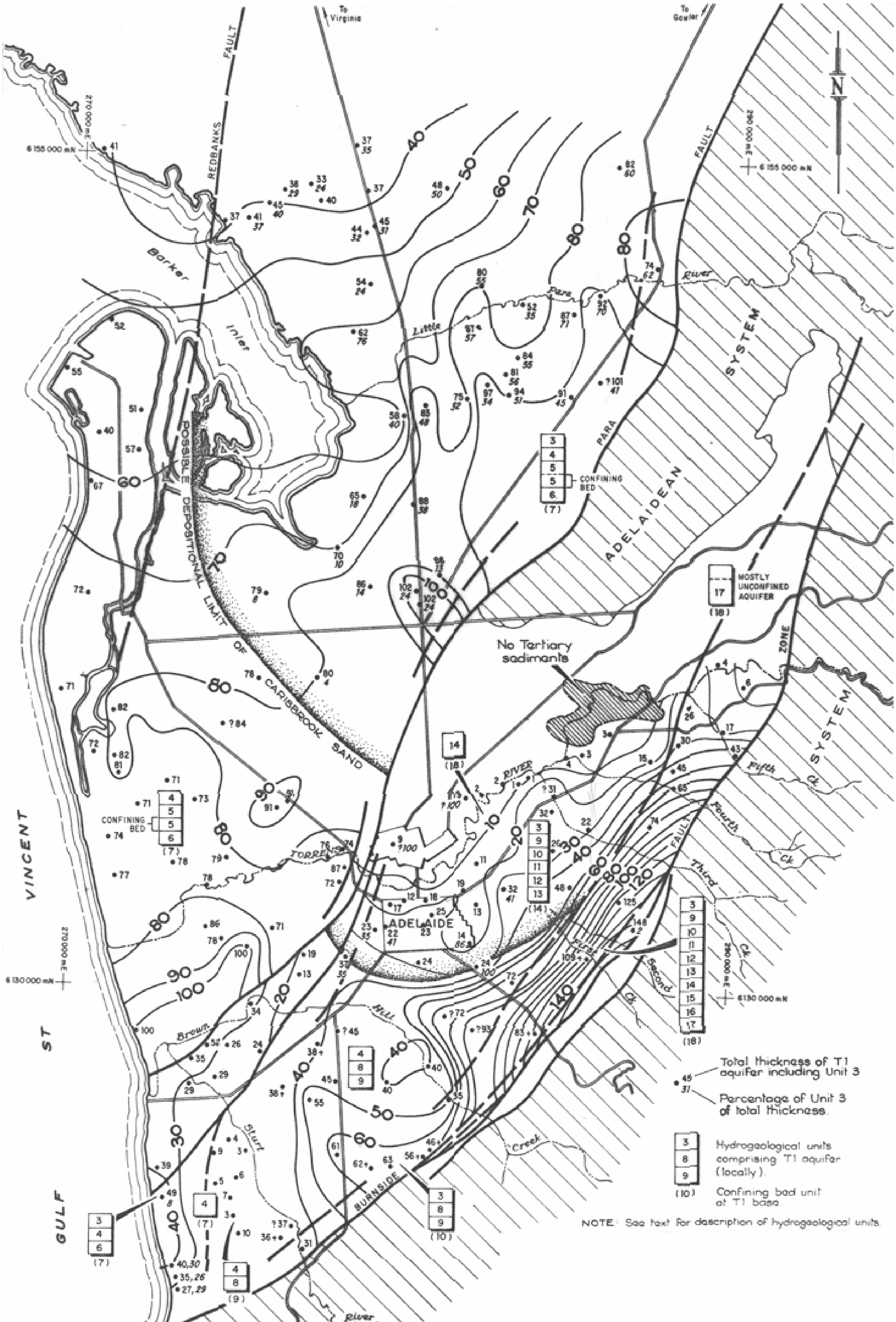

Figure 17 First Tertiary Aquifer (including Carisbrook Sand) Isopach Plan

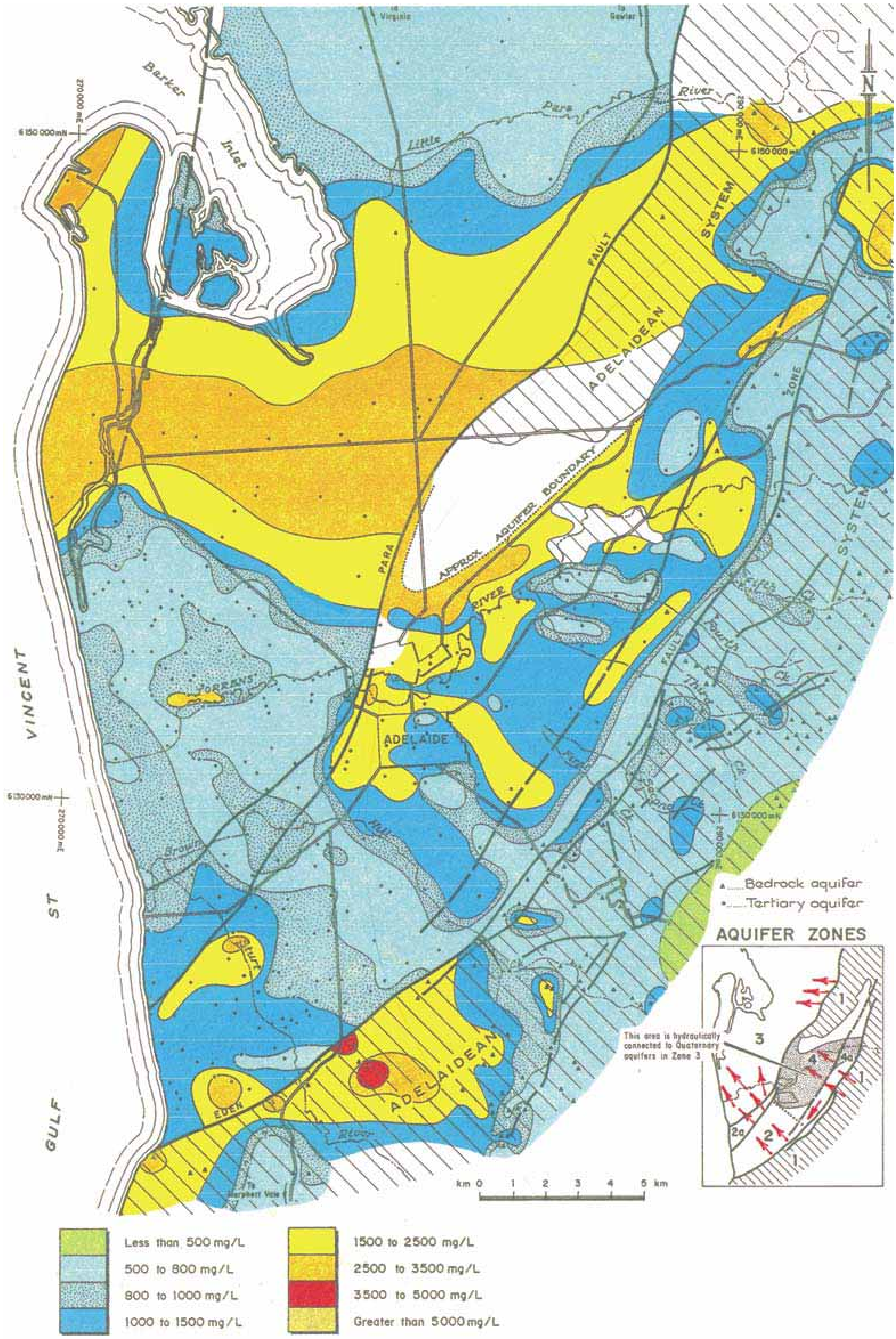

Figure 18 Fractured Bedrock and First Tertiary Aquifer Salinity Plan

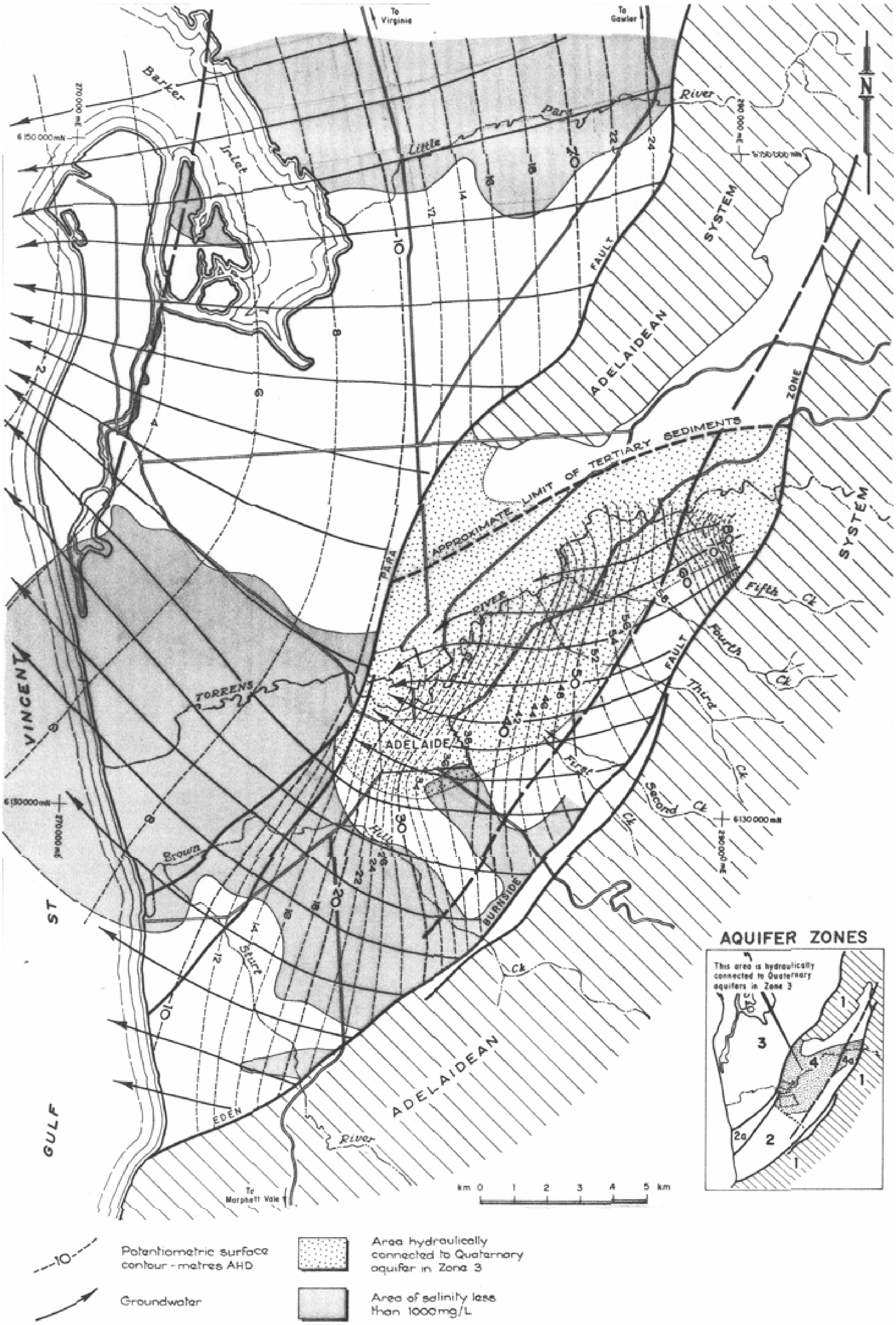

Figure 19 First (Uppermost) Tertiary Aquifer, Pre-Development (Historic) Potentiometric Surface (early 1900s)

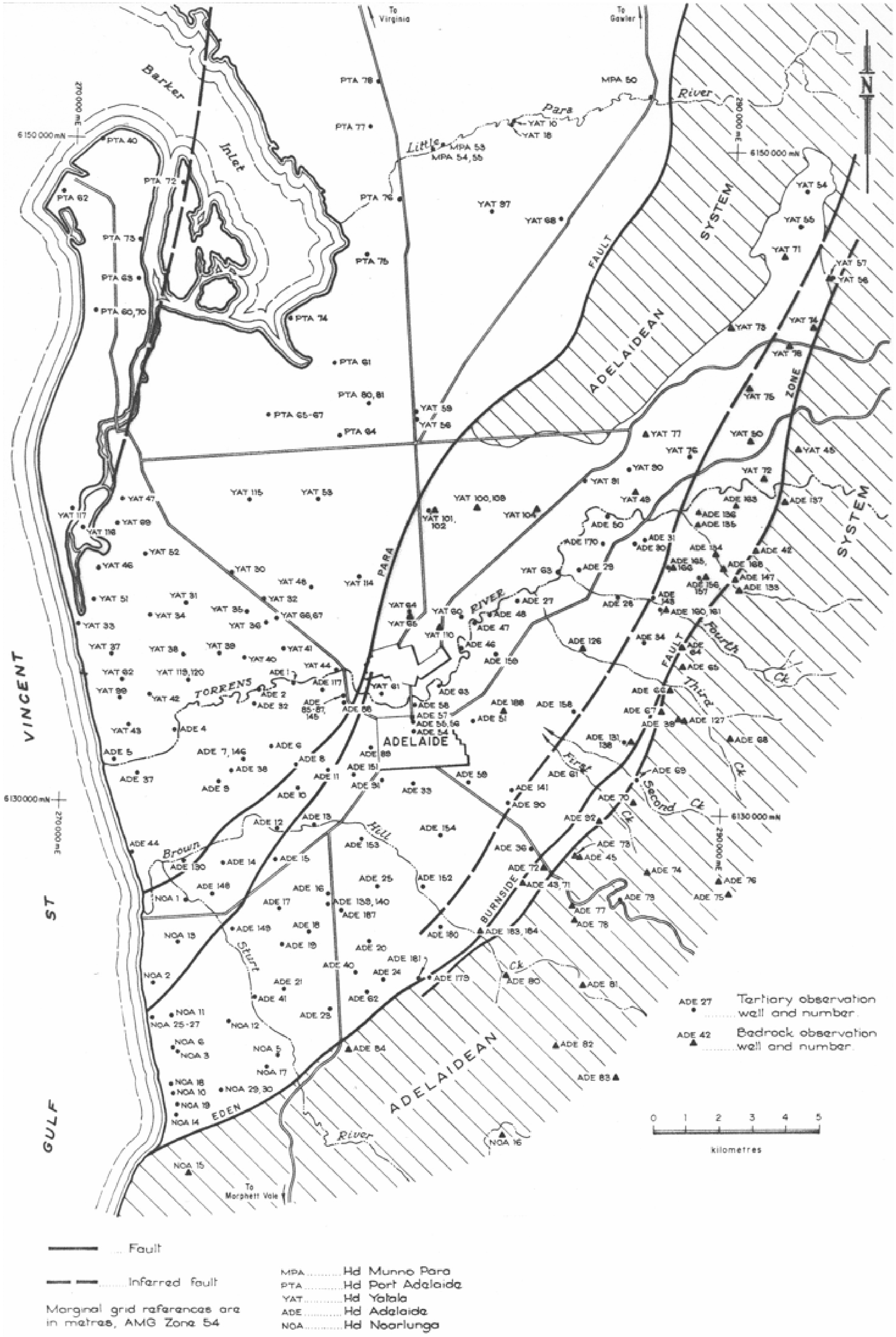

Figure 20 Fractured Bedrock and First Tertiary Aquifers Observation Wells Network

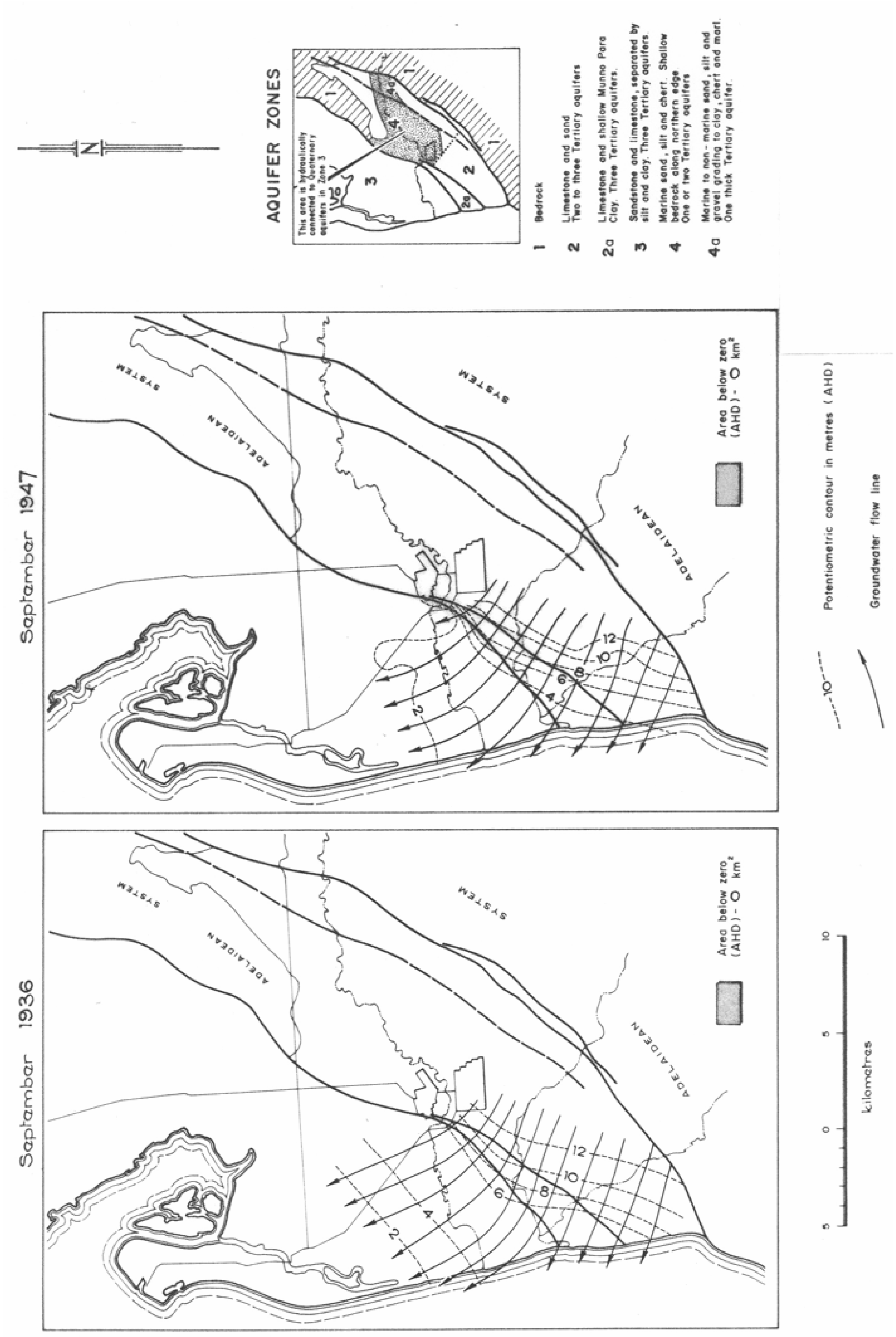

Figure 21 First Tertiary Aquifer, Potentiometric Surface September 1936 and 1947

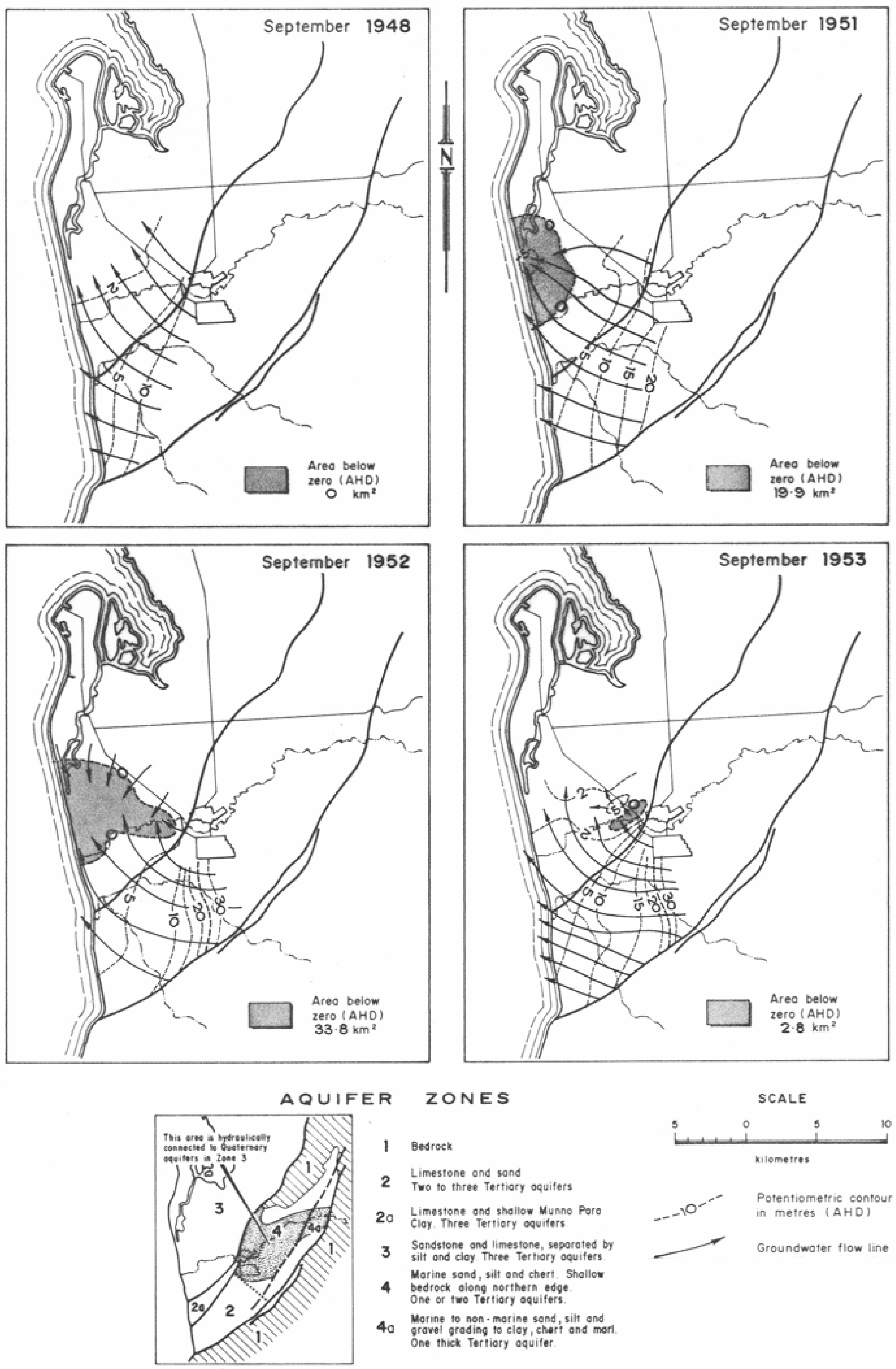

Figure 22 First Tertiary Aquifer, Potentiometric Surface September 1948, 1951, 1952 and 1953

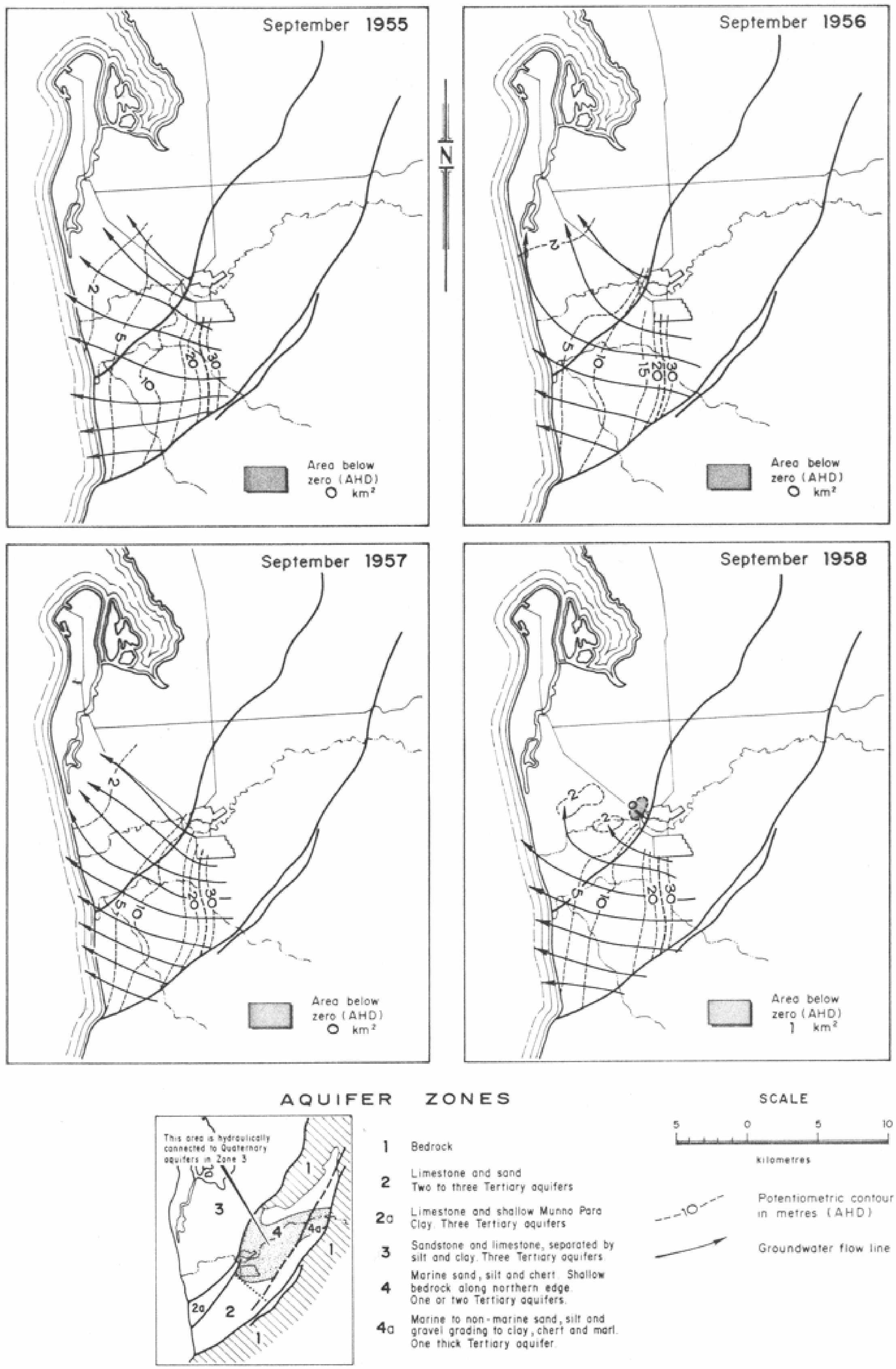

Figure 23 First Tertiary Aquifer, Potentiometric Surface September 1955, 1956, 1957 and 1958

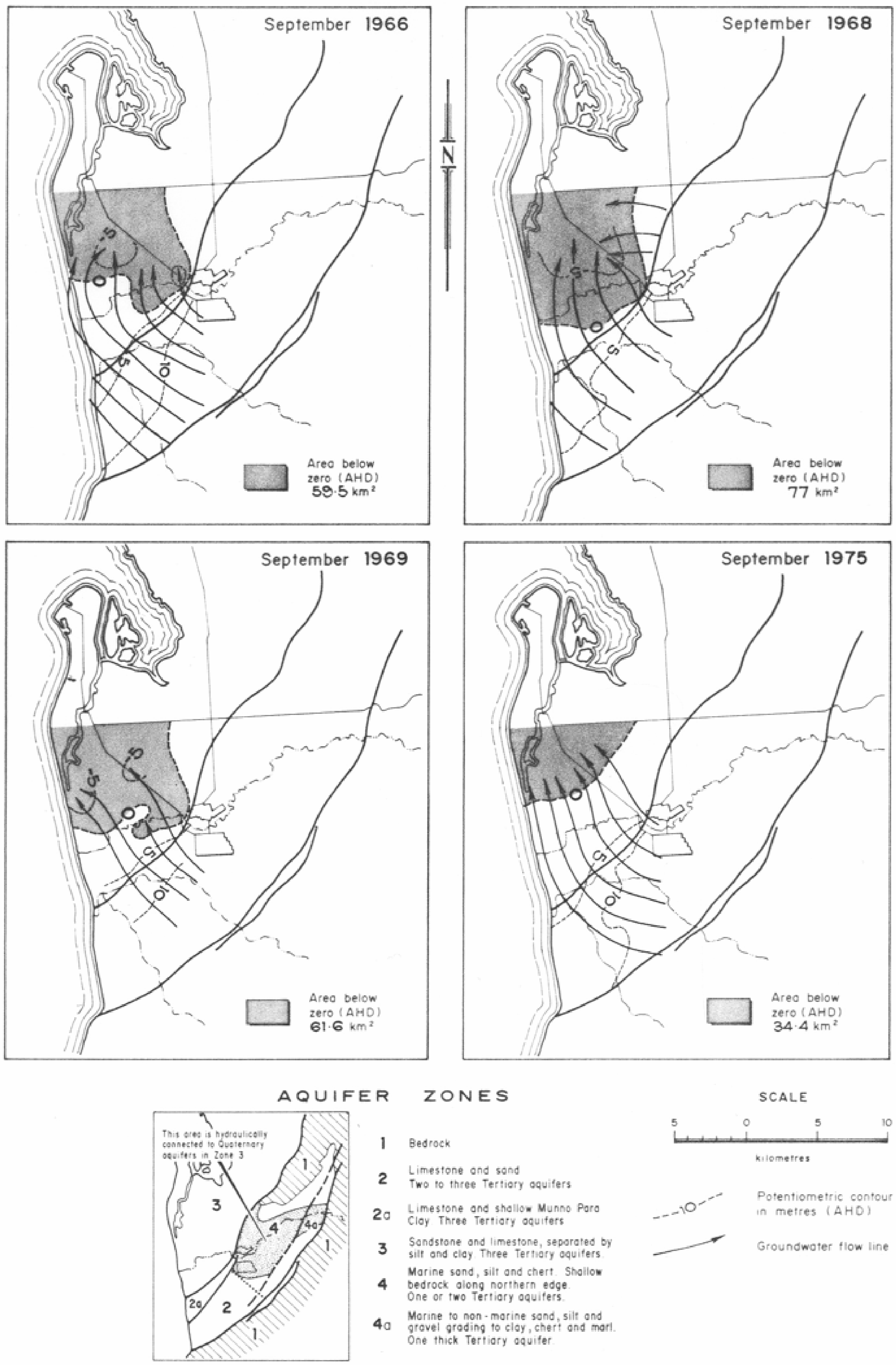

Figure 24 First Tertiary Aquifer, Potentiometric Surface September 1966, 1968, 1969 and 1975

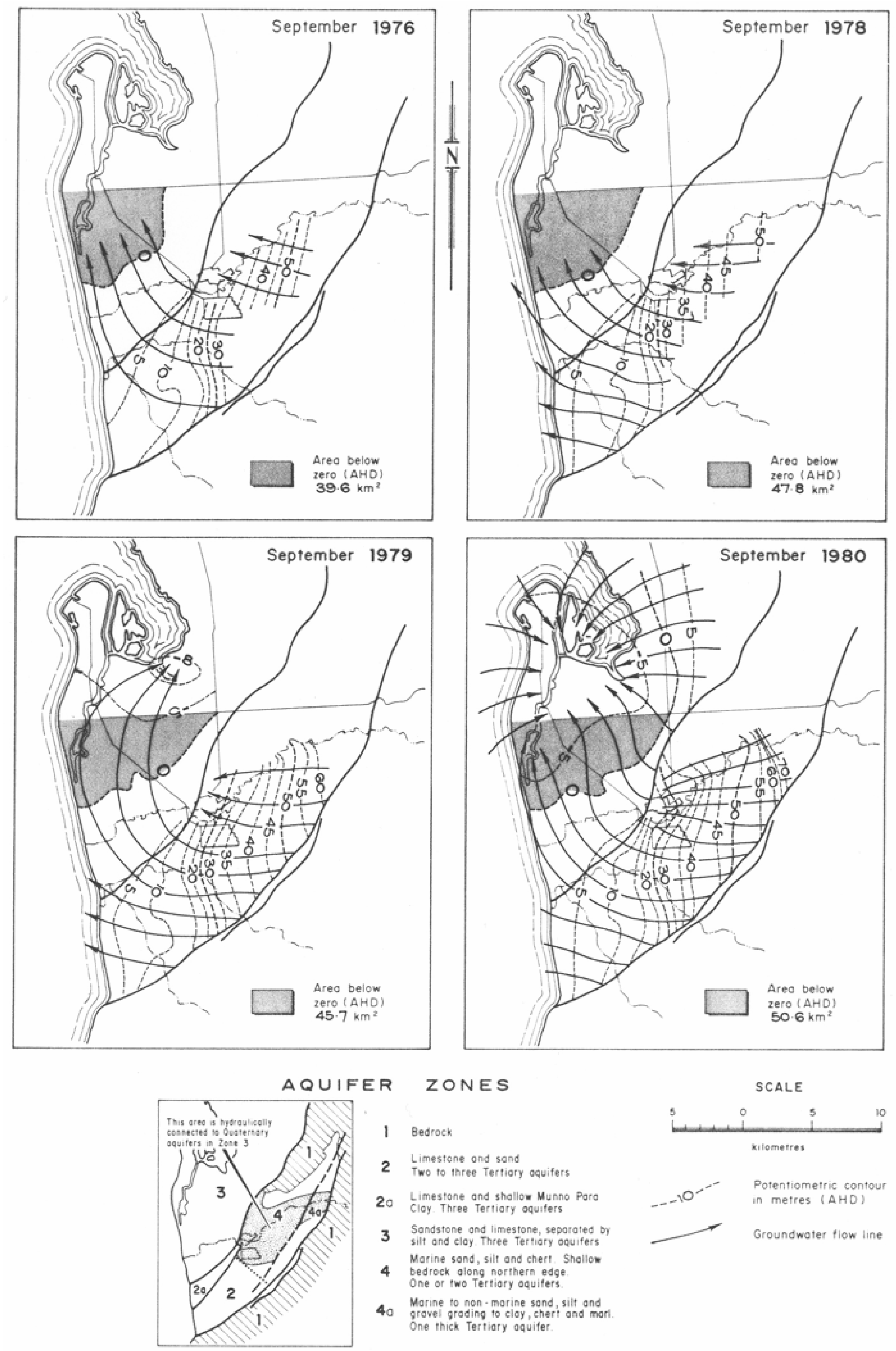

Figure 25 First Tertiary Aquifer, Potentiometric Surface September 1976, 1978, 1979 and 1980

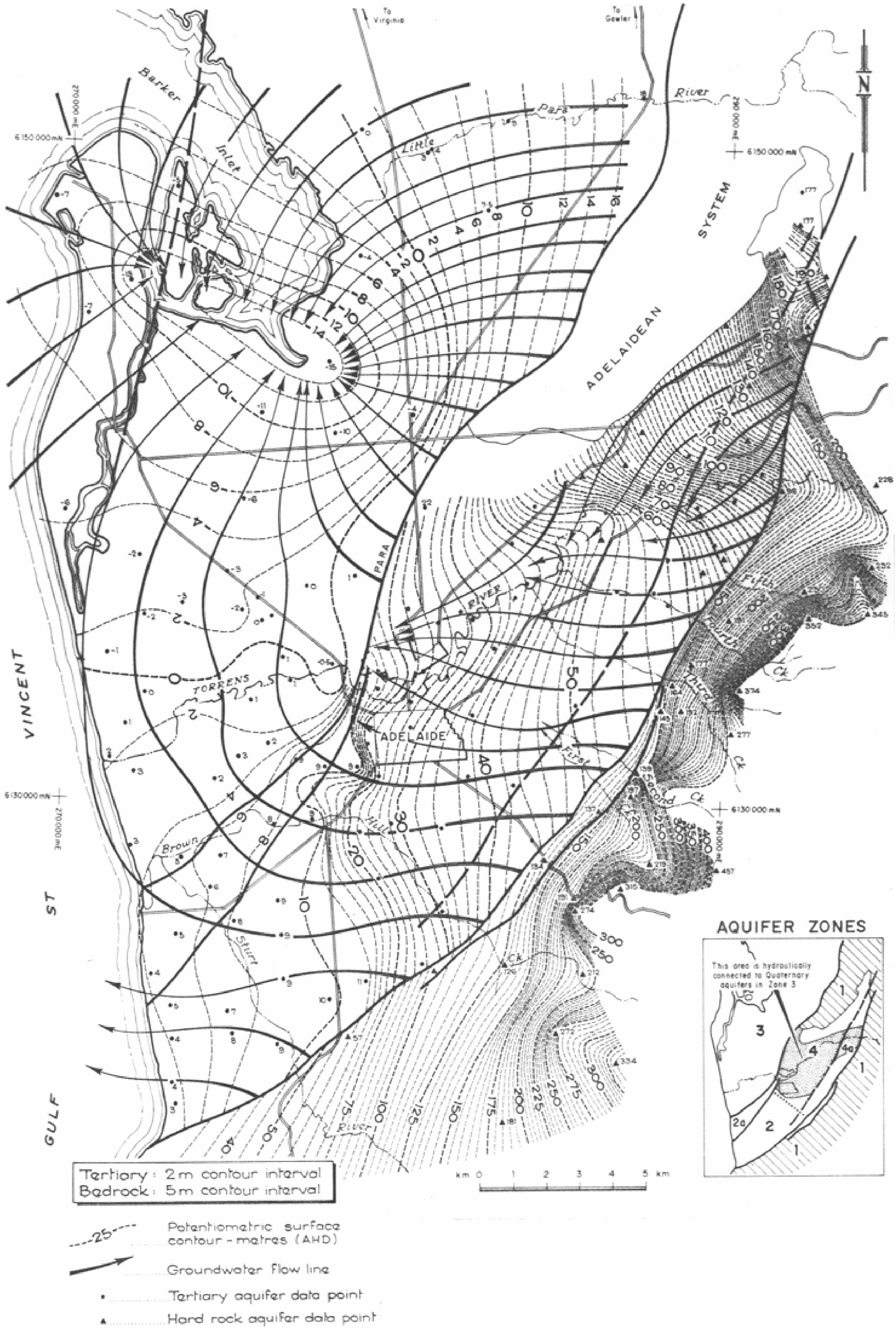

Figure 26 First Tertiary and Fractured Bedrock Aquifers, Potentiometric Surface September 1988

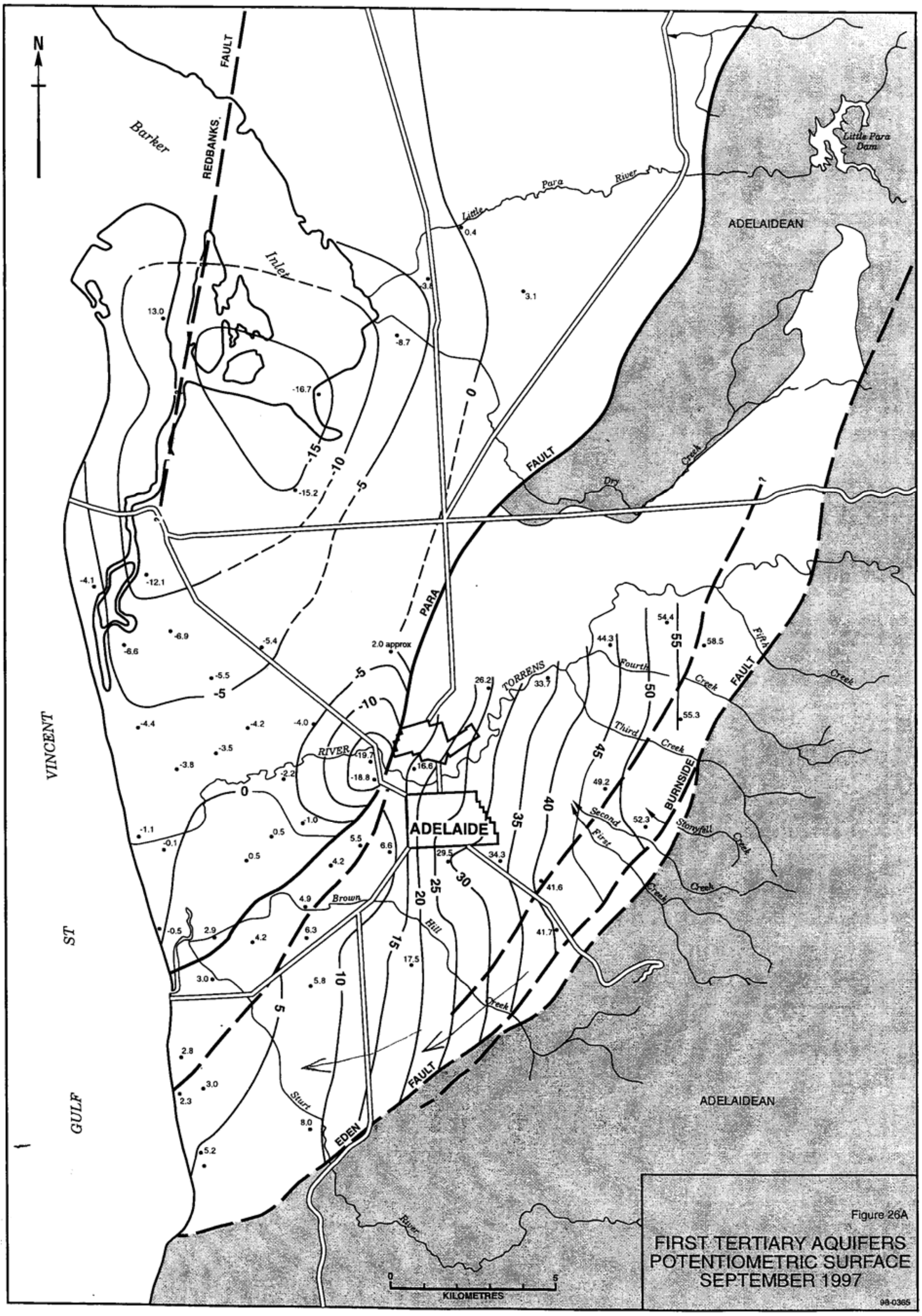

Figure 26a First Tertiary Aquifers Potentiometric Surface, September 1997

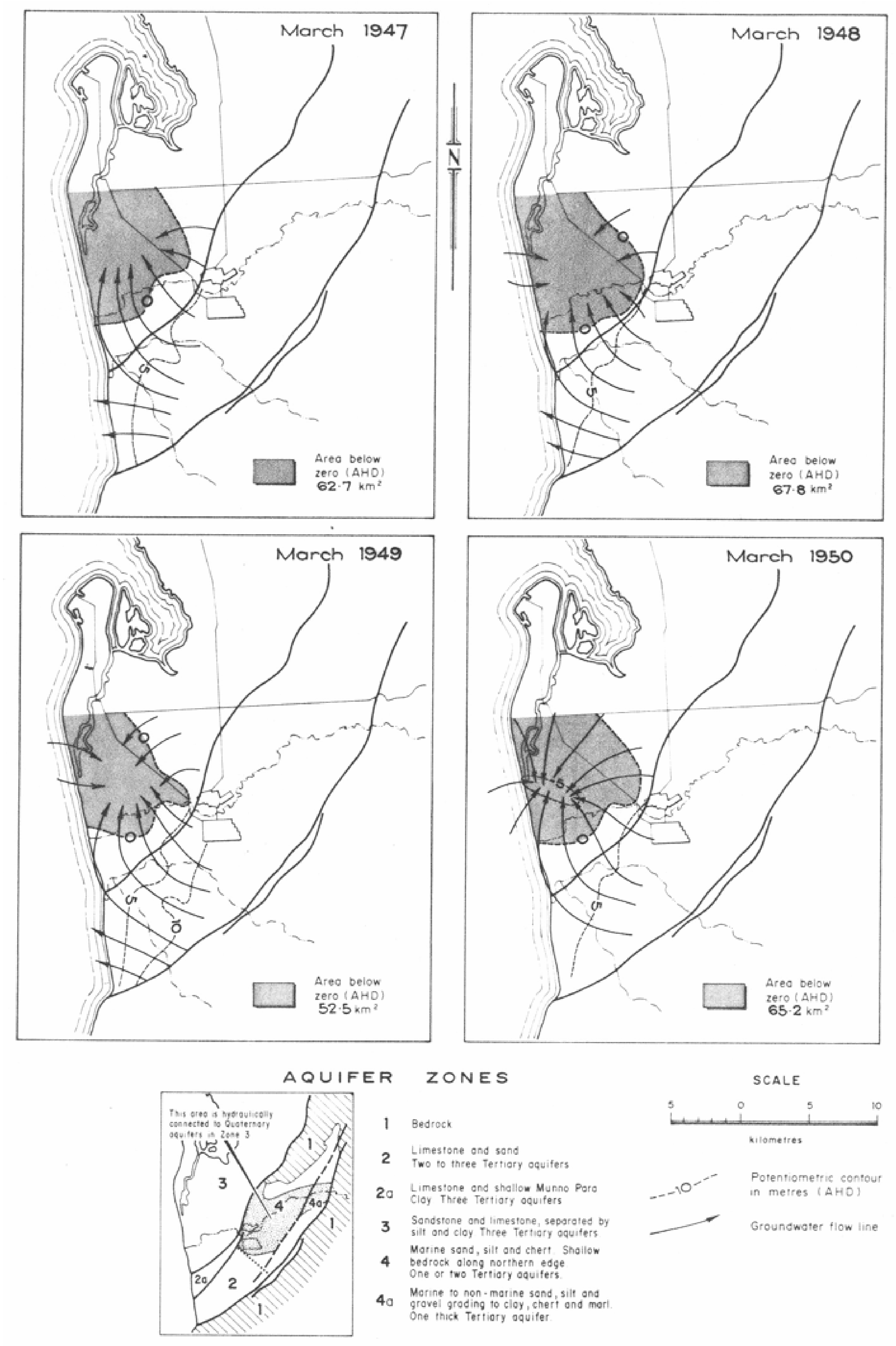

Figure 27 First Tertiary Aquifer, Potentiometric Surface March 1947, 1948, 1949 and 1950

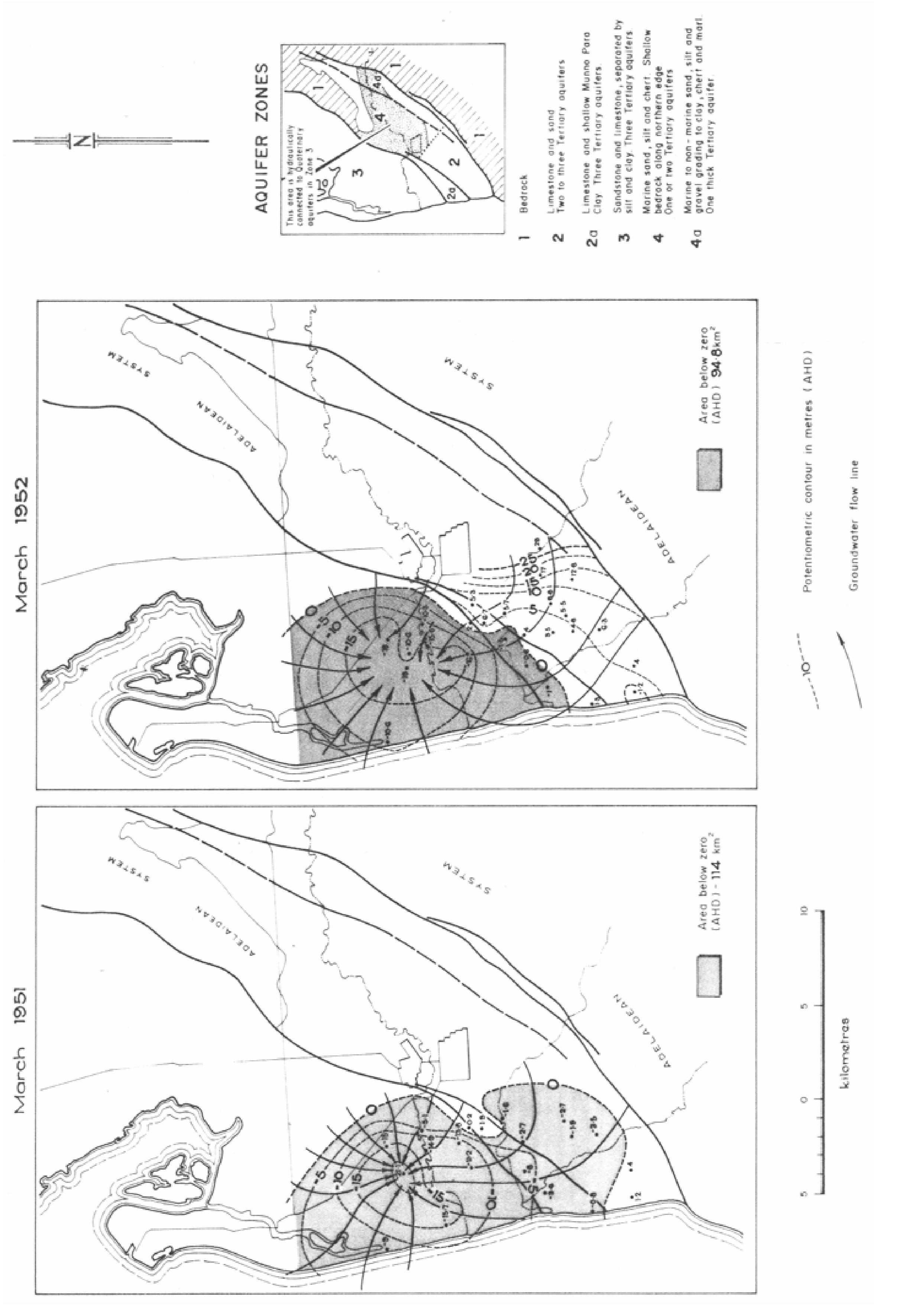

Figure 28 First Tertiary Aquifer, Potentiometric Surface March 1951 and 1952

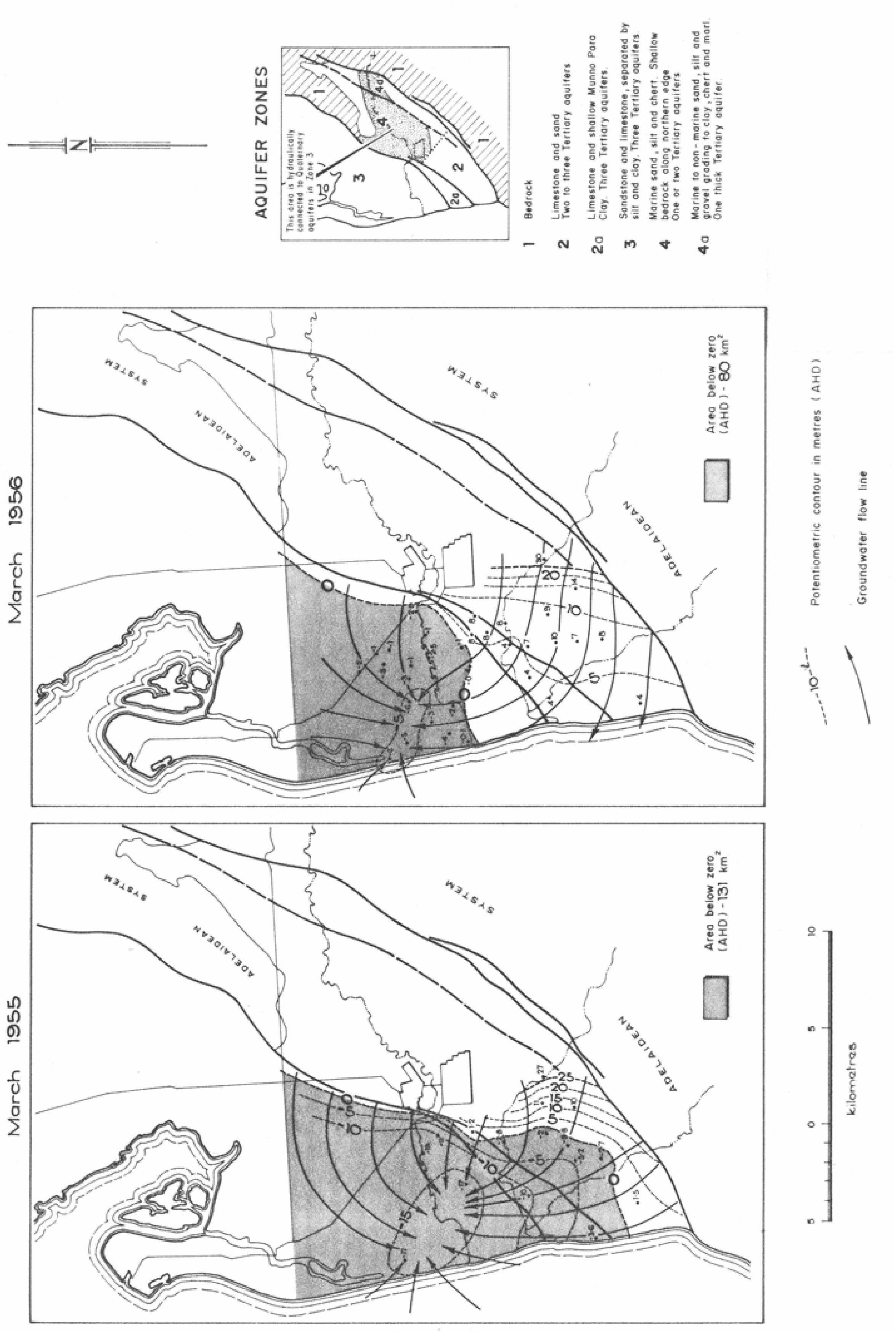

Figure 29 First Tertiary Aquifer, Potentiometric Surface March 1955 and 1956

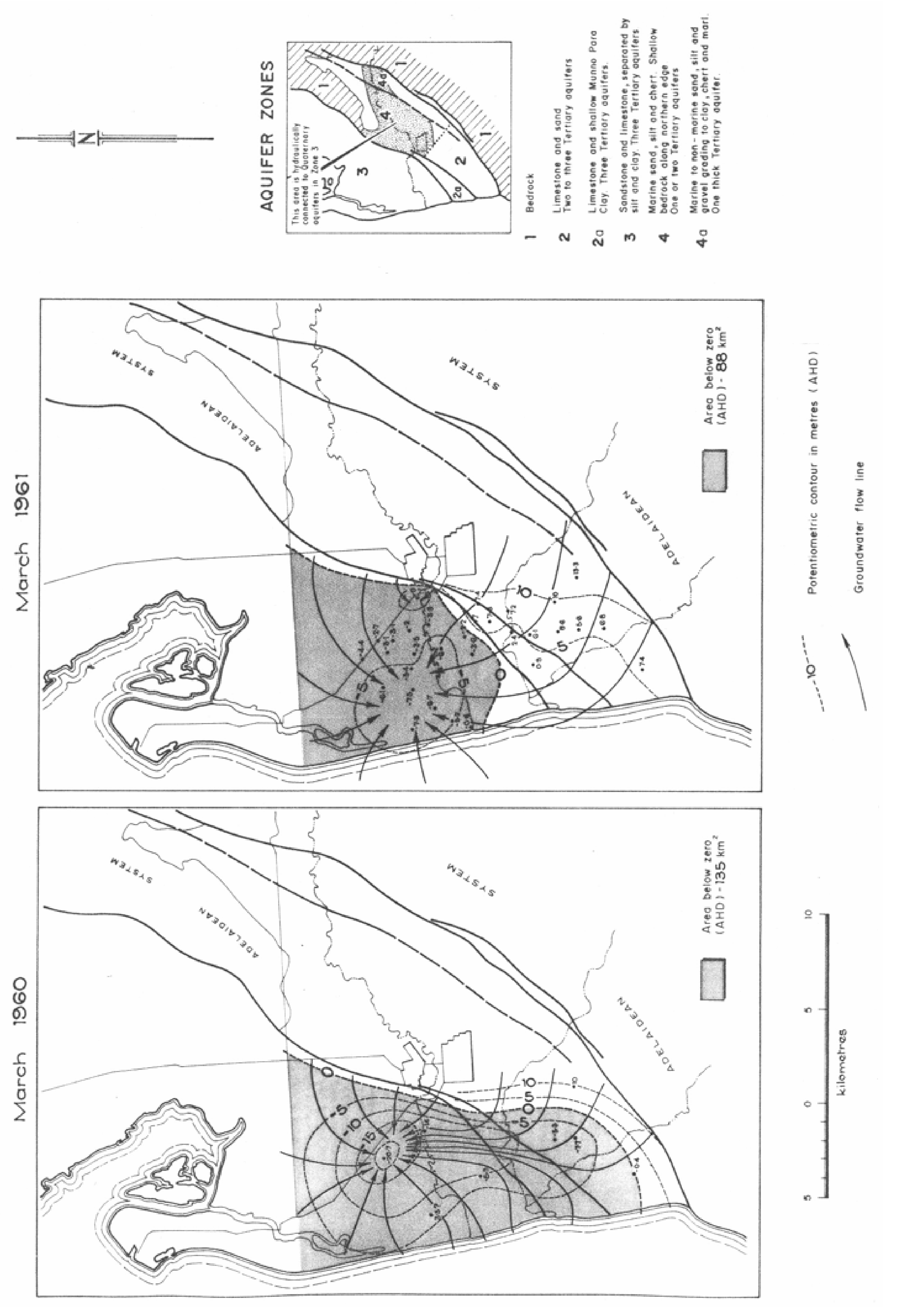

Figure 30 First Tertiary Aquifer, Potentiometric Surface March 1960 and 1961

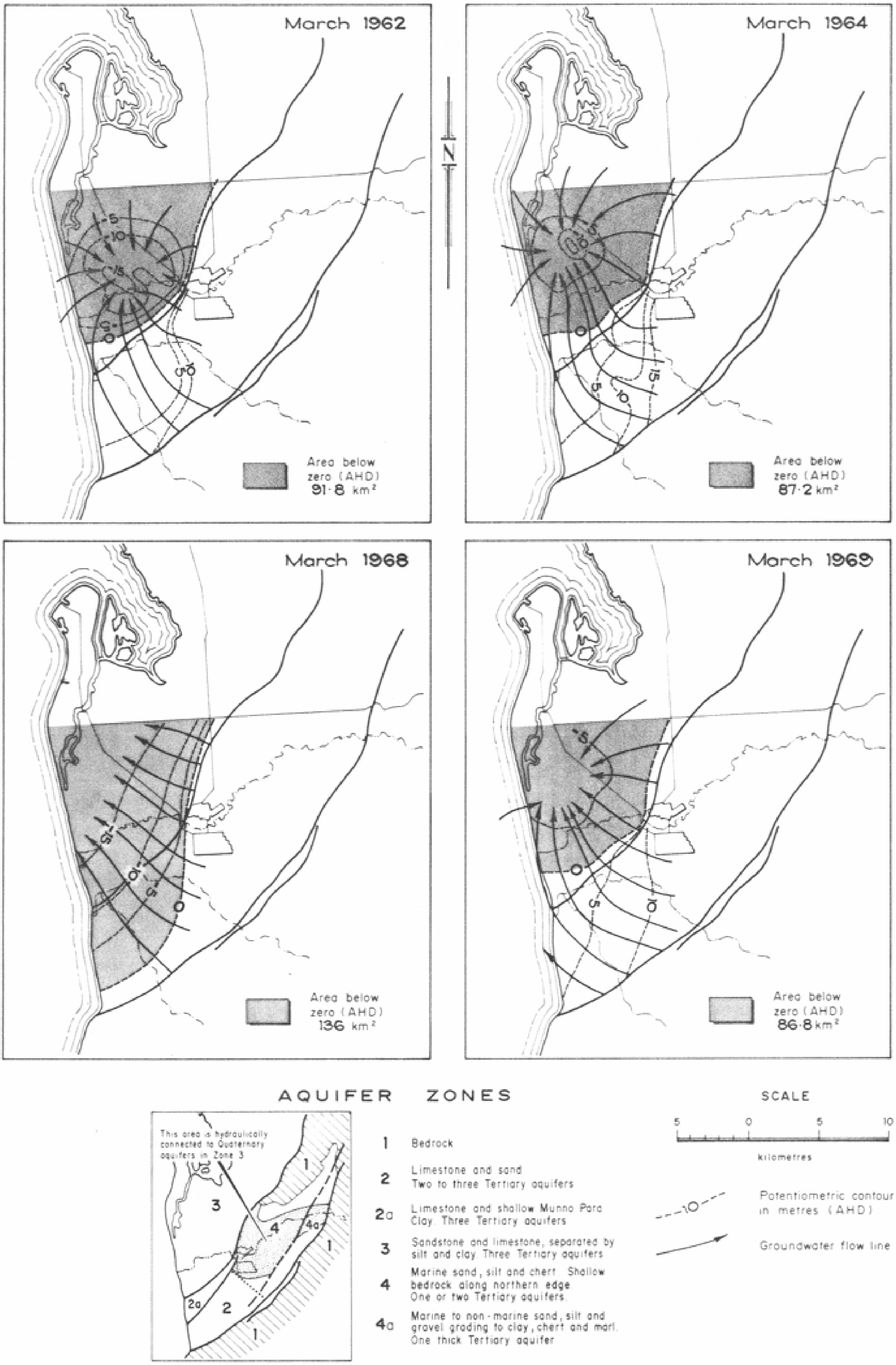

Figure 31 First Tertiary Aquifer, Potentiometric Surface March 1962, 1964, 1968 and 1969

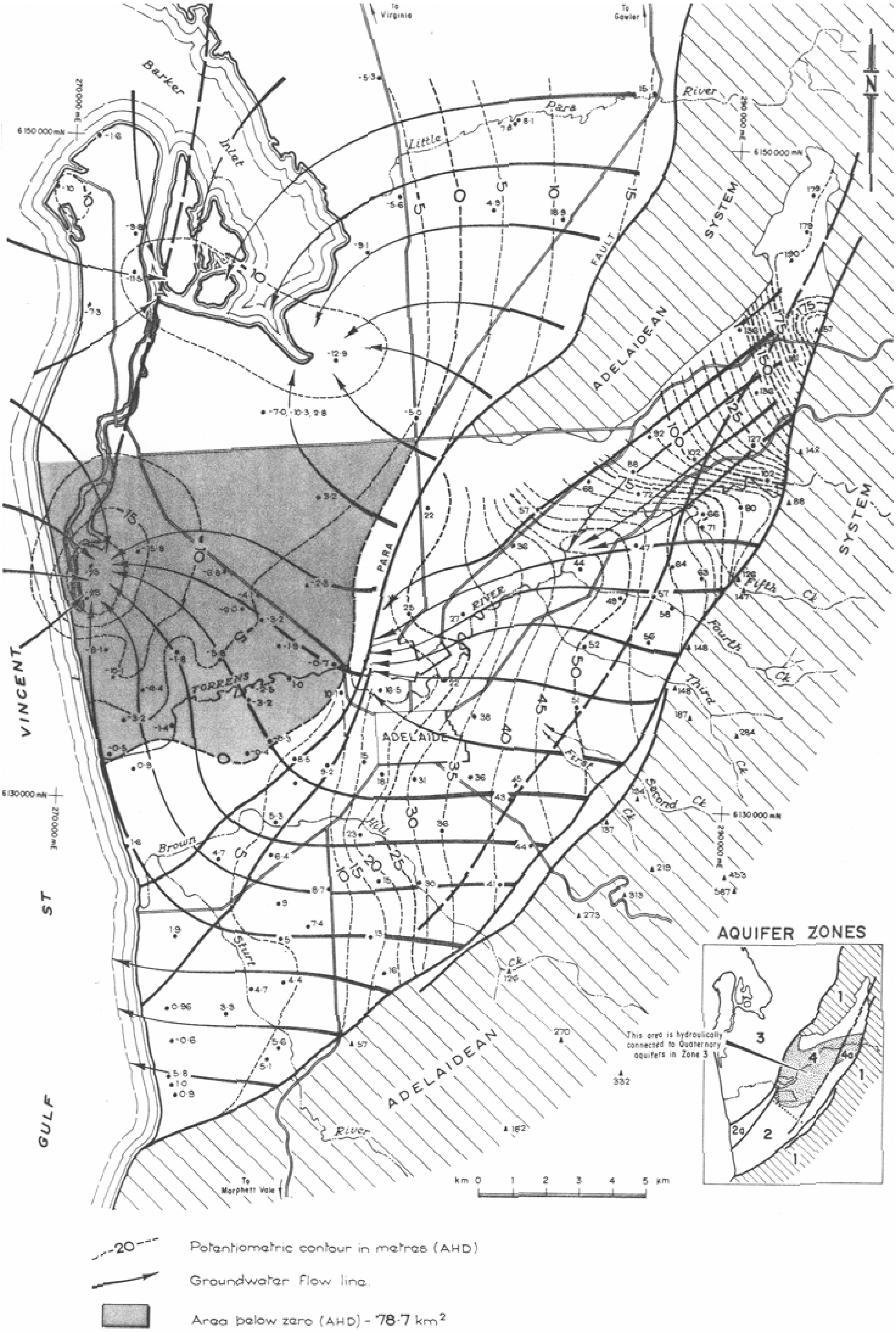

Figure 32 First Tertiary Aquifer, Potentiometric Surface March 'Last Decade'

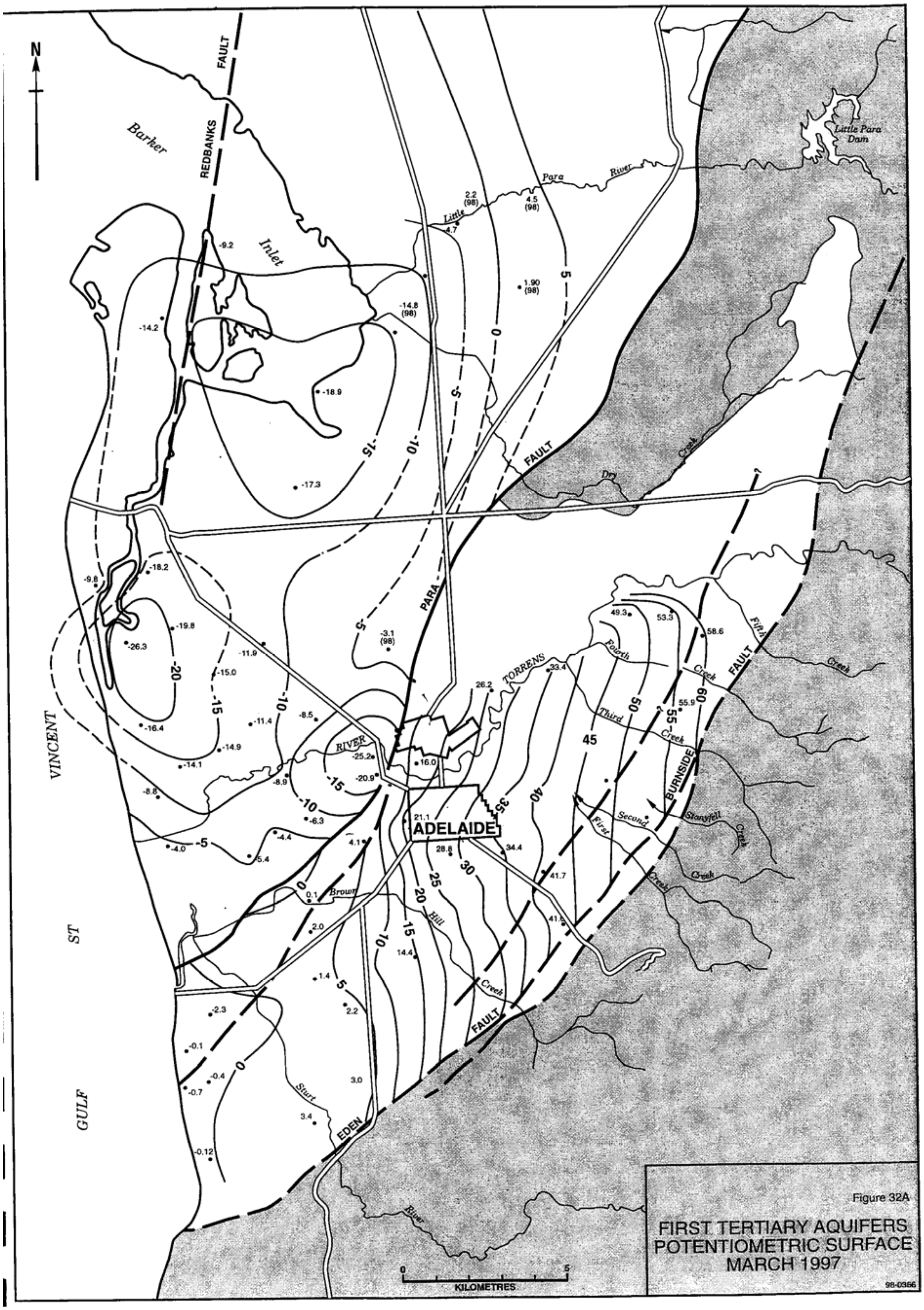

Figure 32a First Tertiary Aquifers Potentiometric Surface March 1997

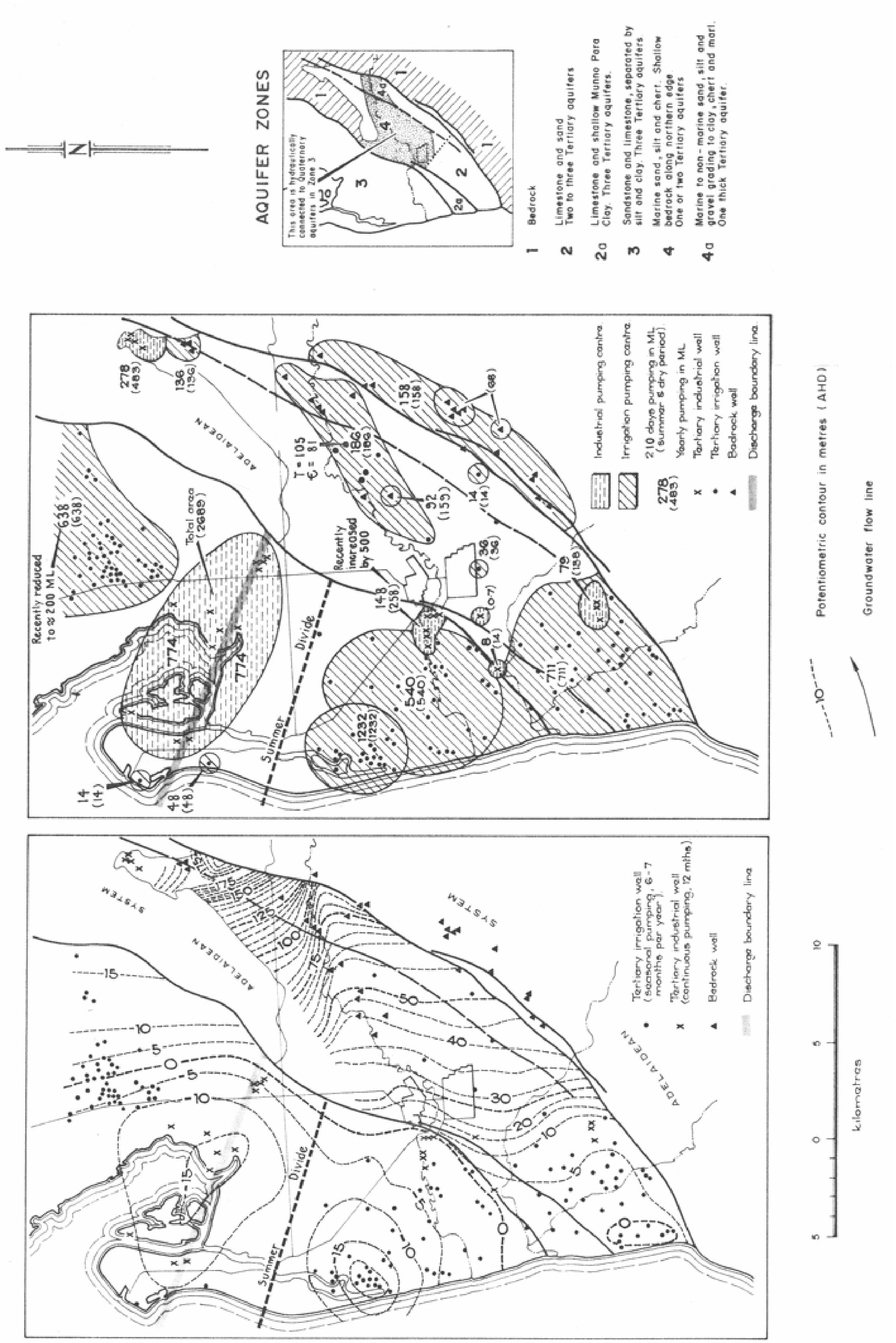

Figure 33 First Tertiary Aquifer, Potentiometric Contours, Industrial Centres and Extraction Volumes March 'Last Decade'

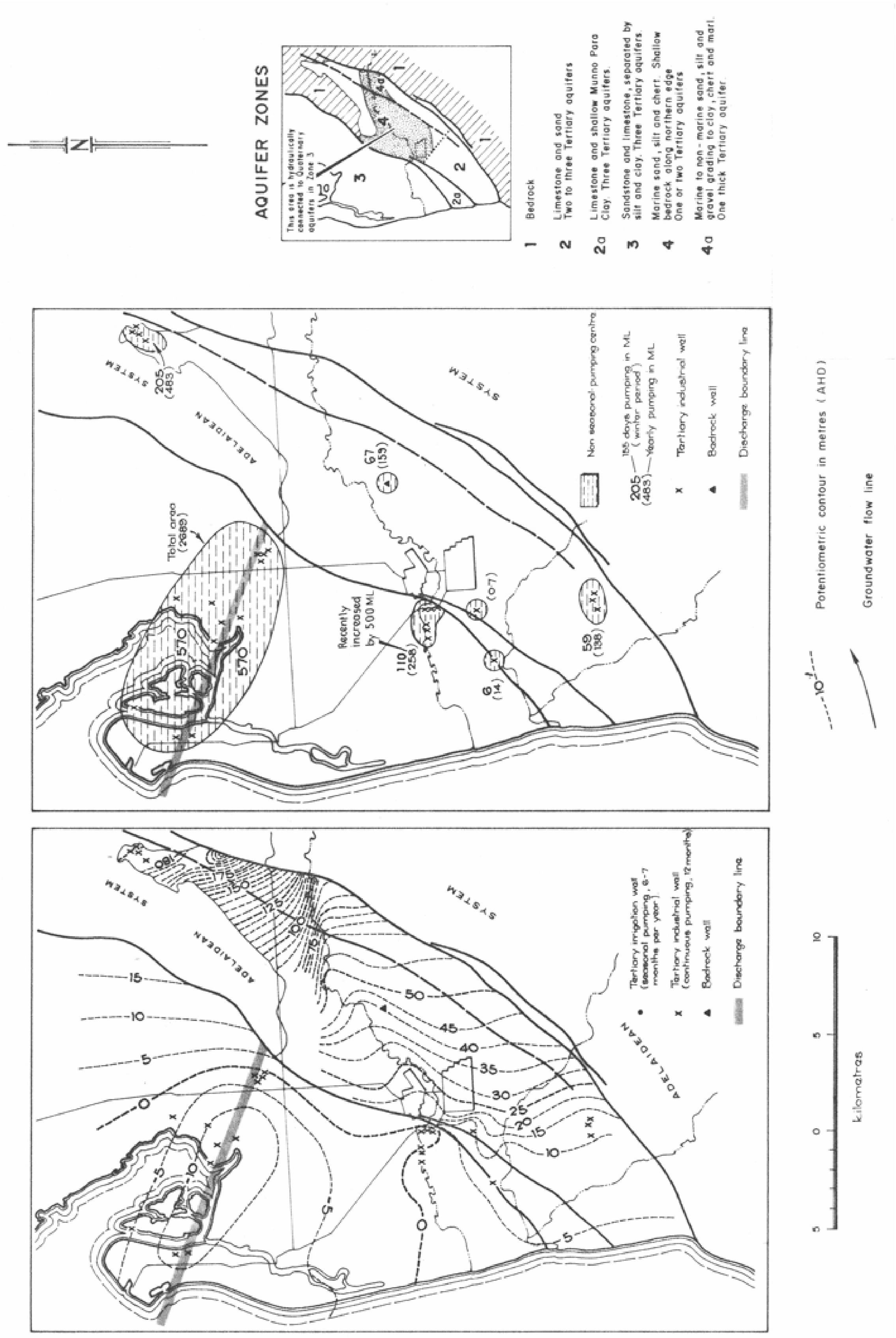

Figure 34 First Tertiary Aquifer, Potentiometric Contours, Industrial Centres and Extraction Volumes

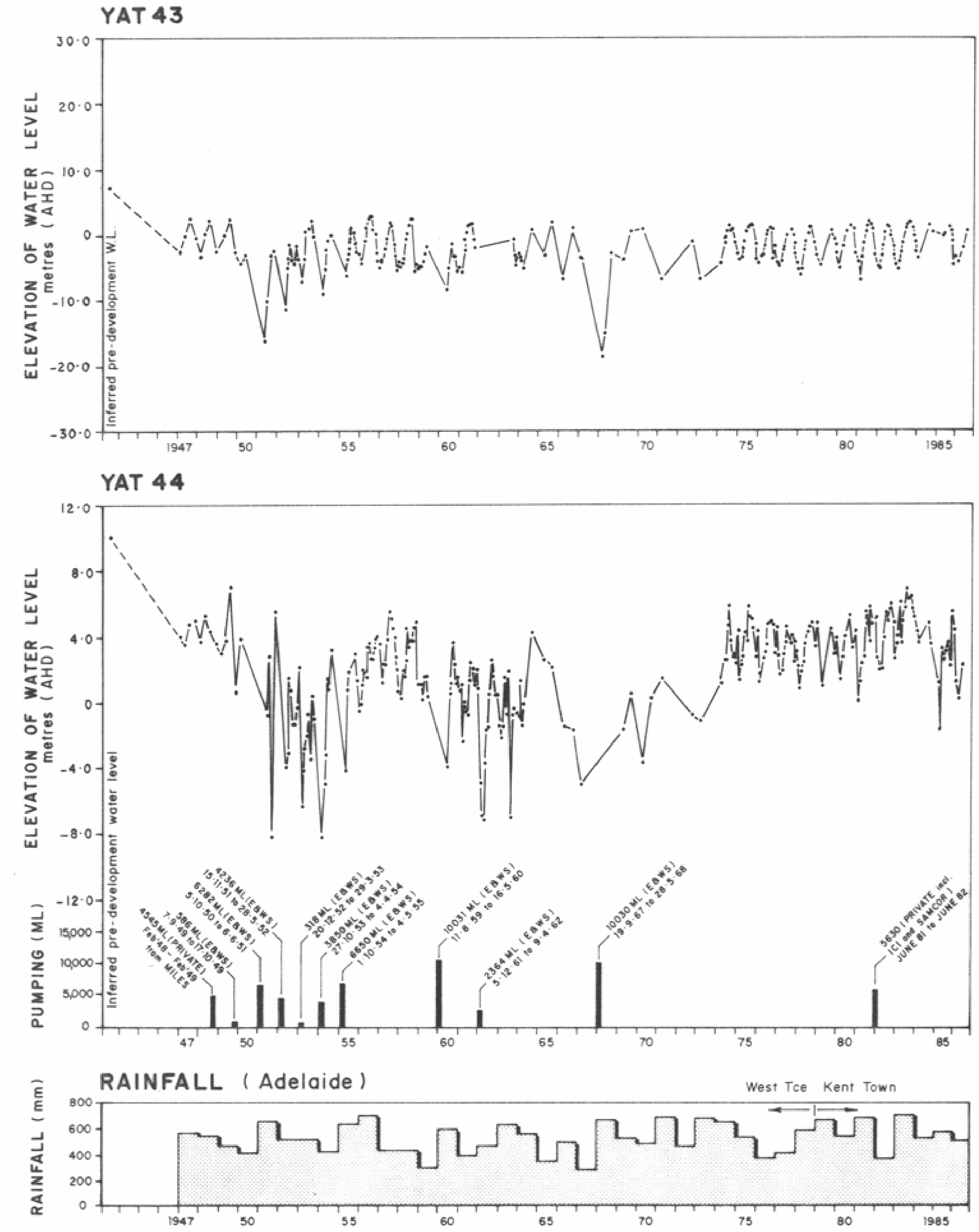

Figure 35 First Tertiary Aquifer Hydrographs, Observation Wells YAT 43 and 44

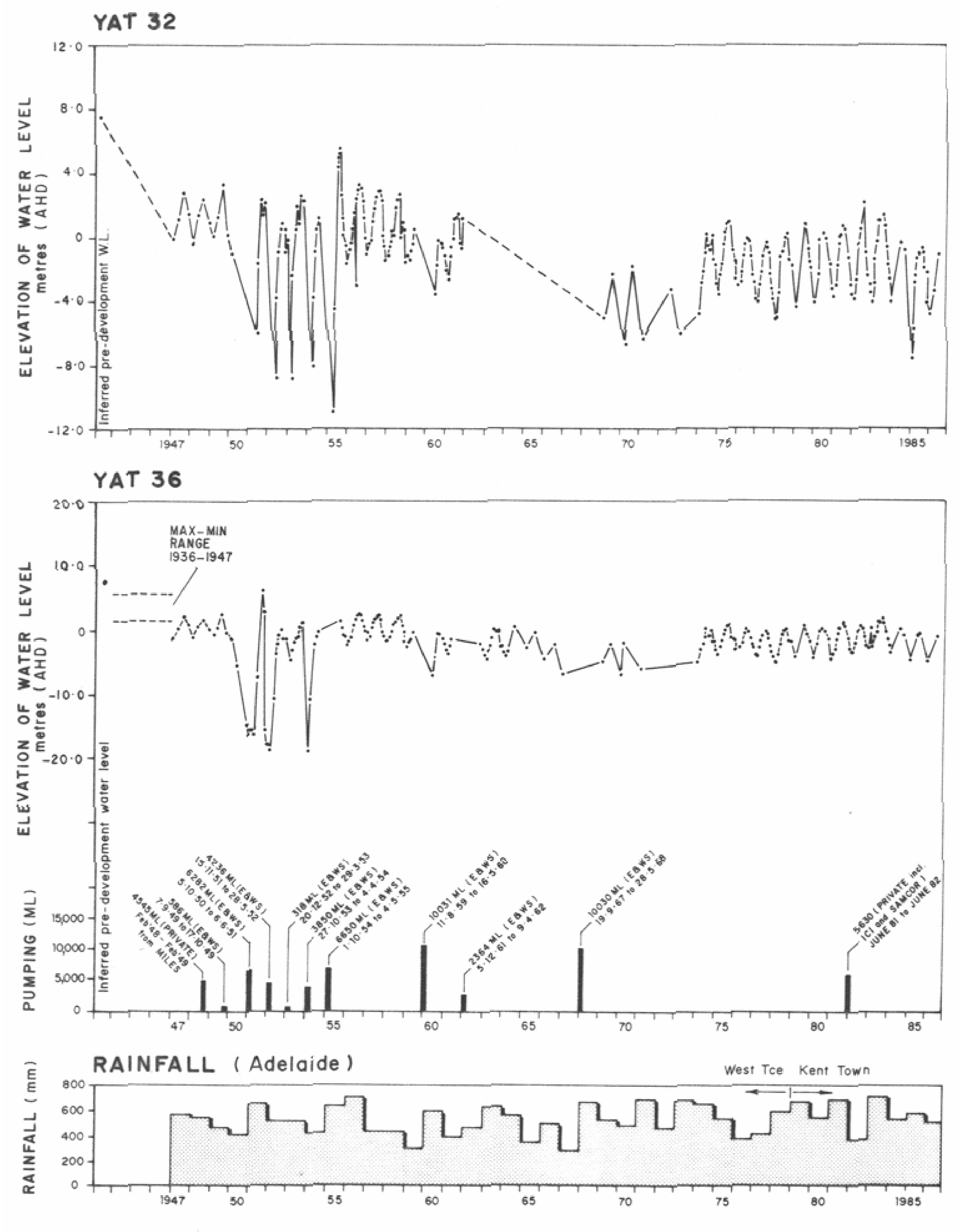

Figure 36 First Tertiary Aquifer Hydrographs, Observation Wells 32 and 36

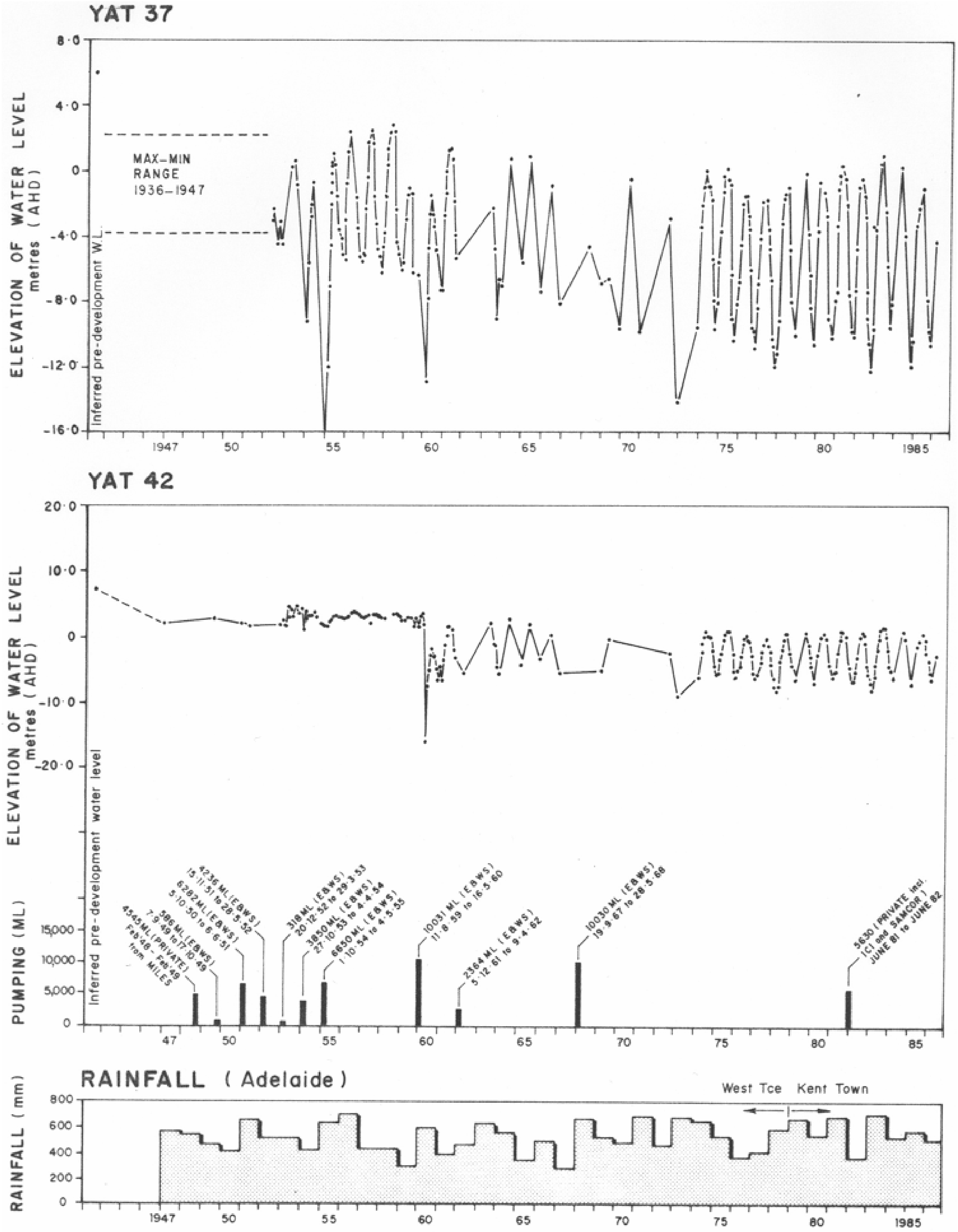

Figure 37 First Tertiary Aquifer Hydrographs, Observation Wells 37 and 42

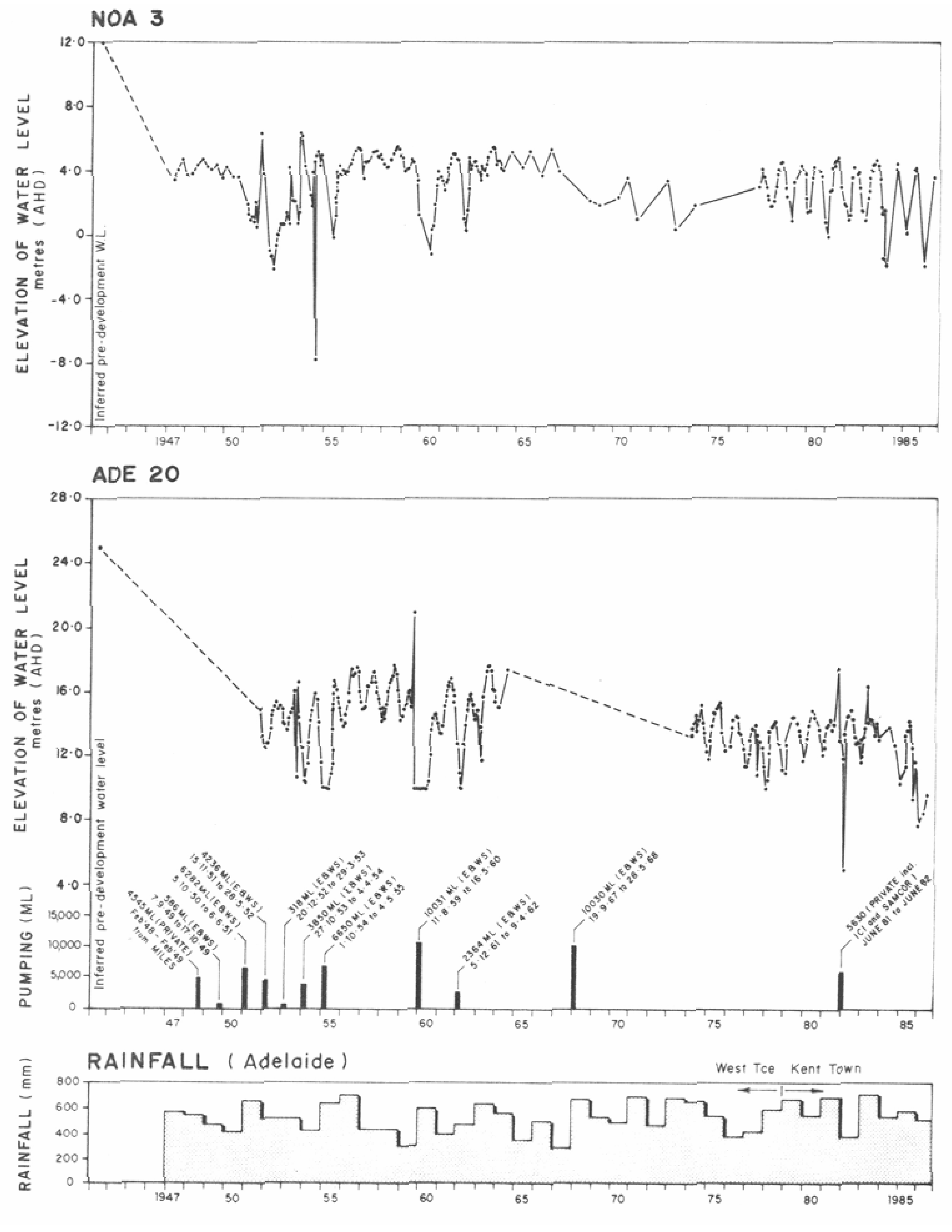

Figure 38 First Tertiary Aquifer Hydrographs, Observation Wells NOA 3, ADE 20

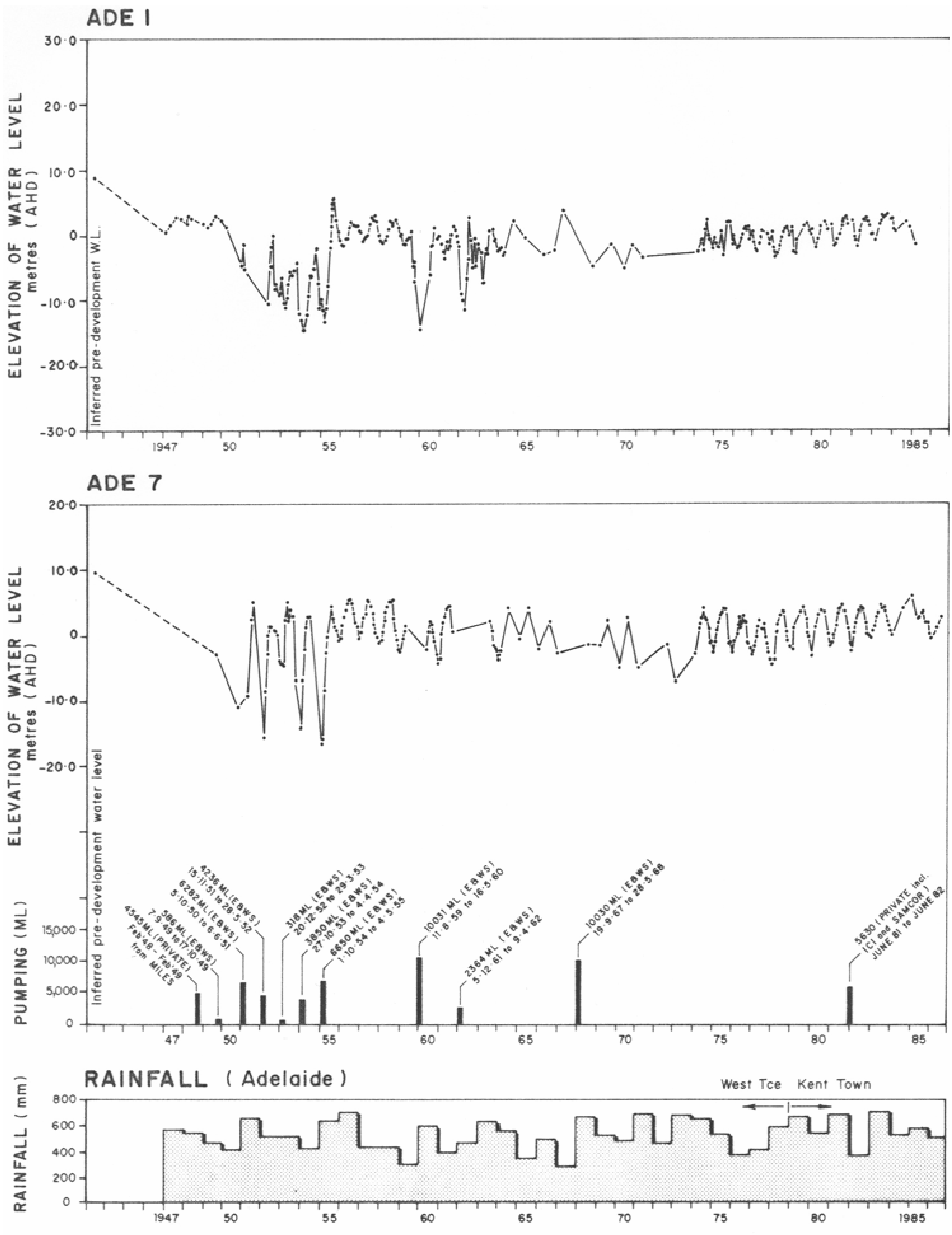

Figure 39 First Tertiary Aquifer Hydrographs, Observation Wells ADE 1 and ADE 7

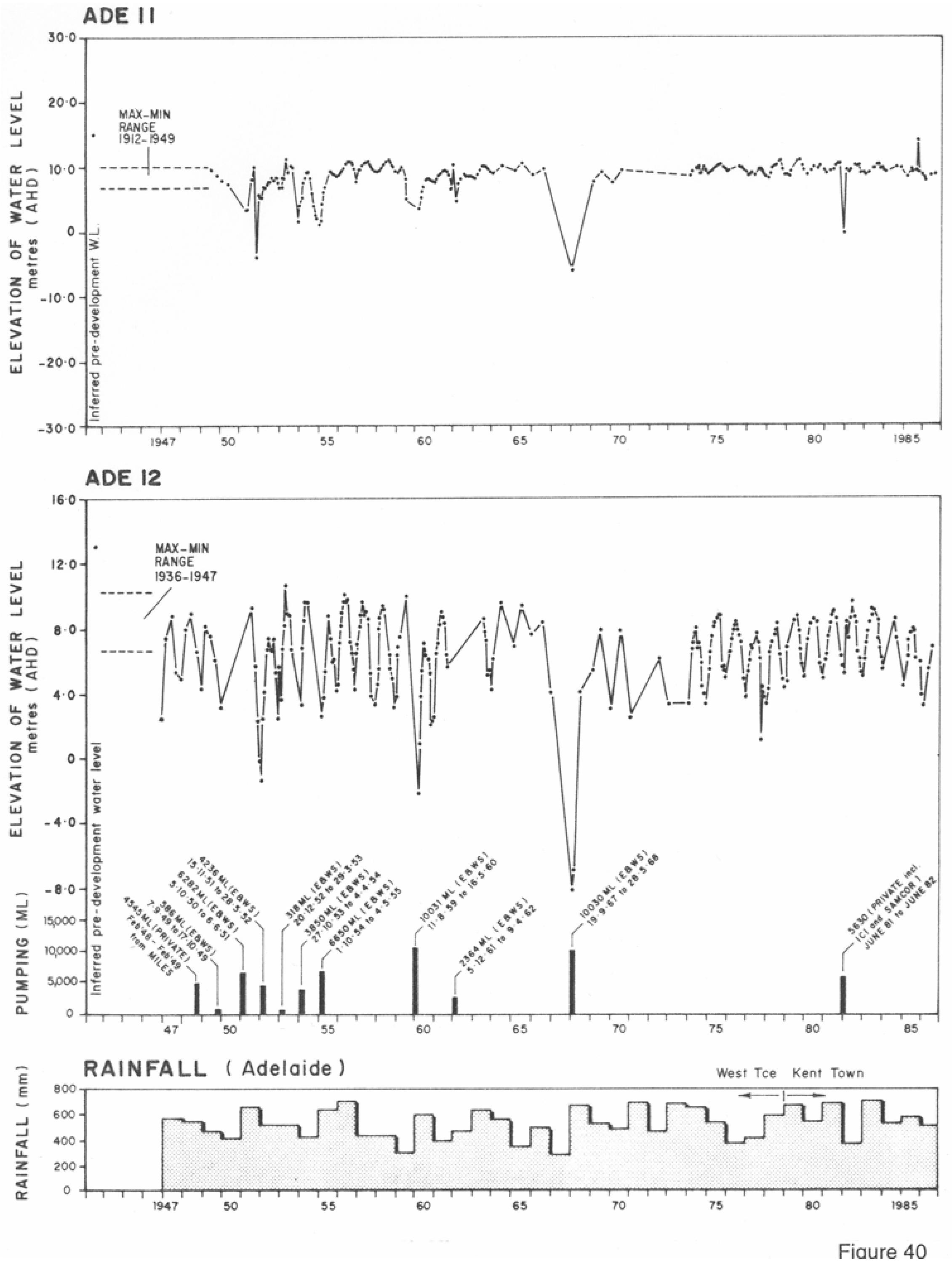

Figure 40 First Tertiary Aquifer Hydrographs, Observation Wells ADE 11 and ADE 12

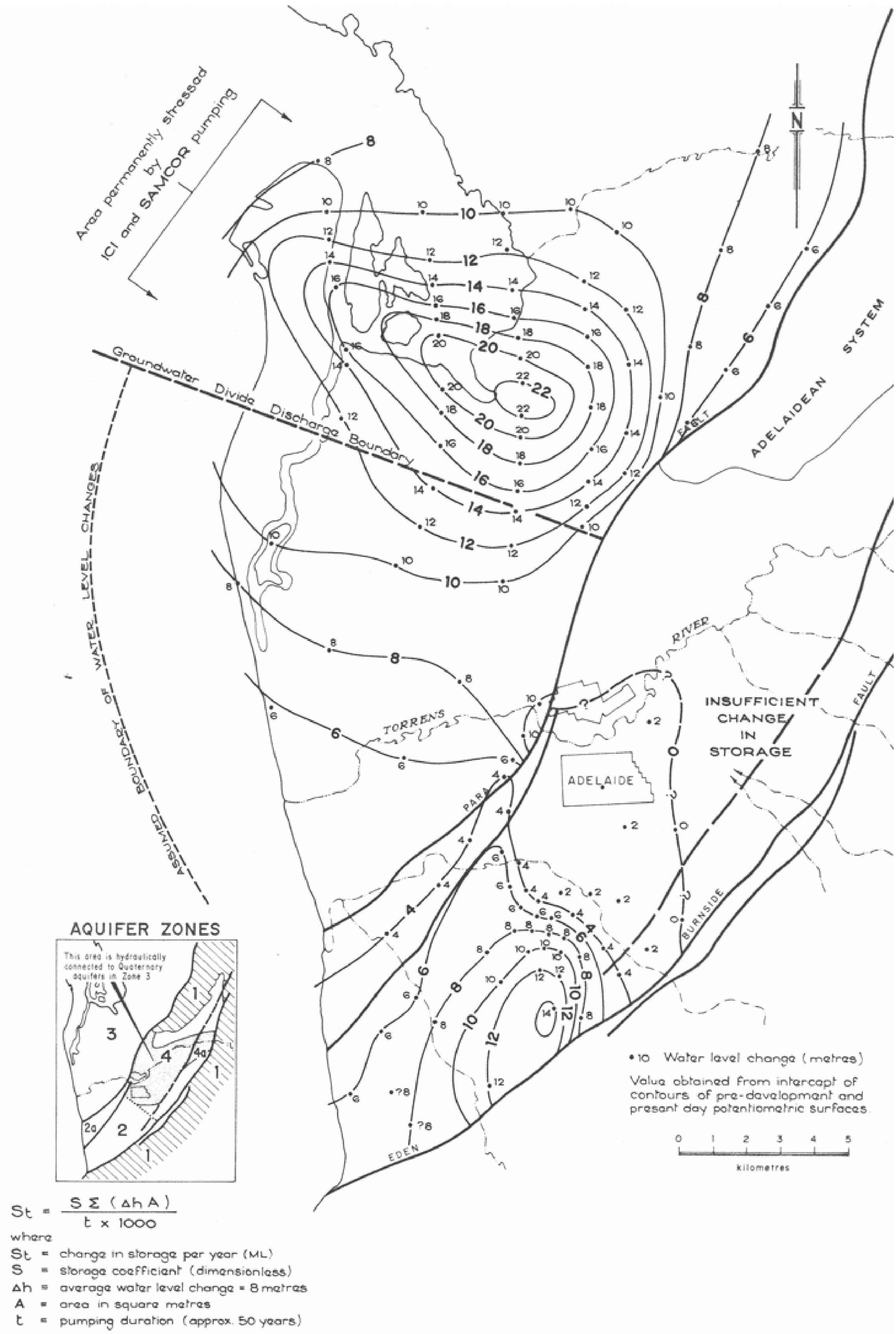

Figure 41 First Tertiary Aquifer, Changes in Water Level and Storage over the last 50 years

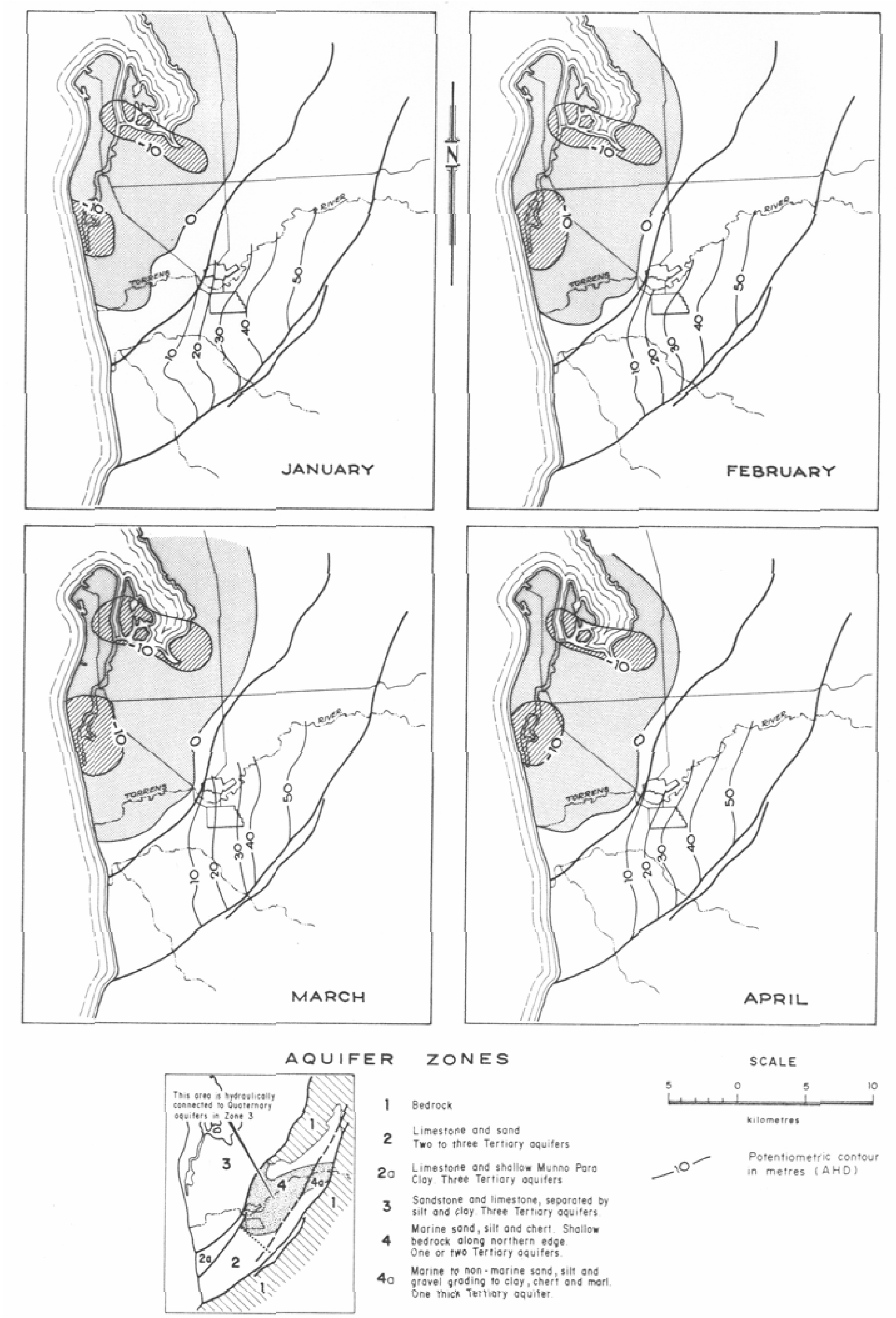

Figure 42 First Tertiary Aquifer, Potentiometric Surface January – April. (Last decade)

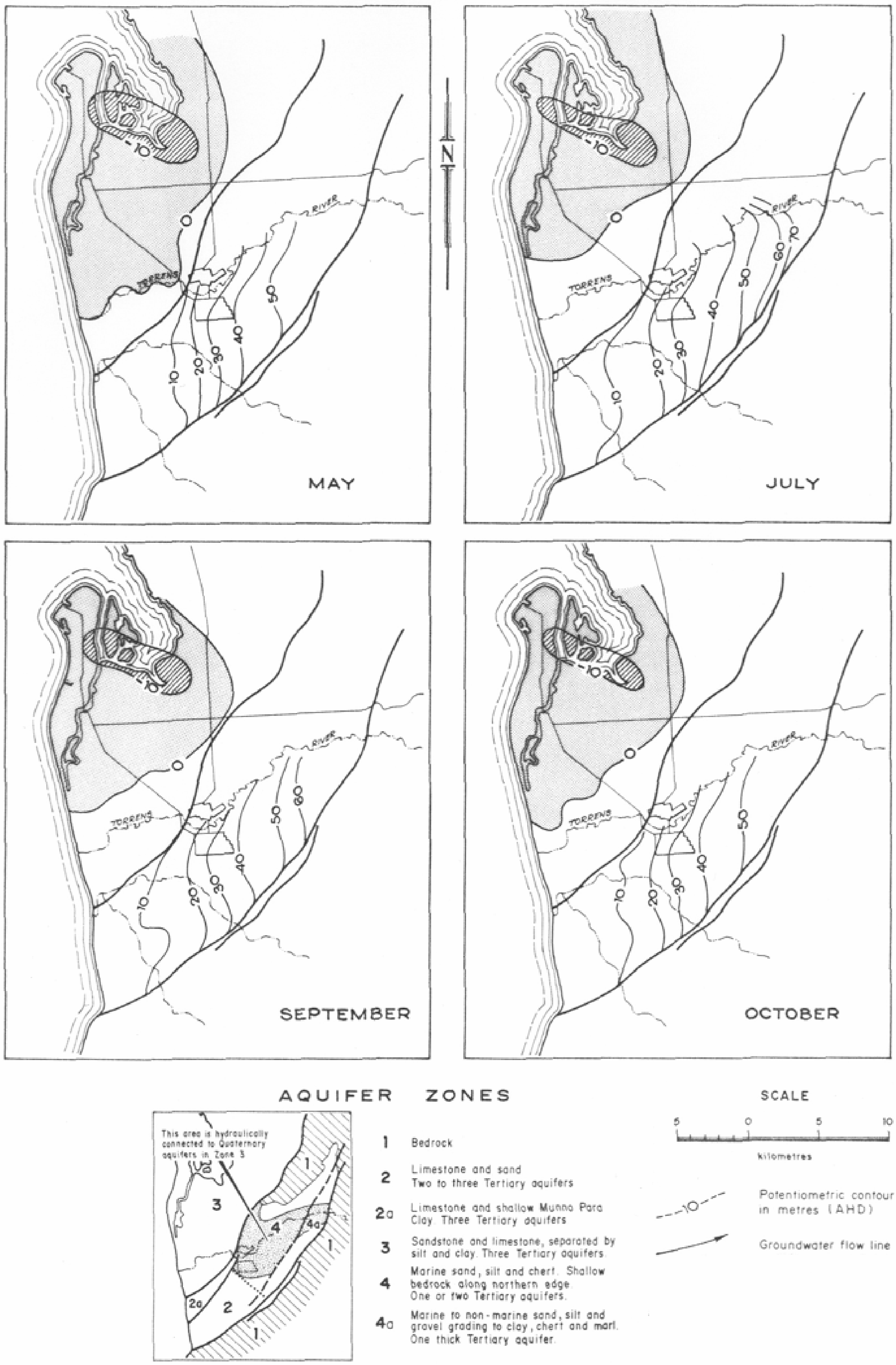

Figure 43 First Tertiary Aquifer, Potentiometric Surface May – October. (Last decade)

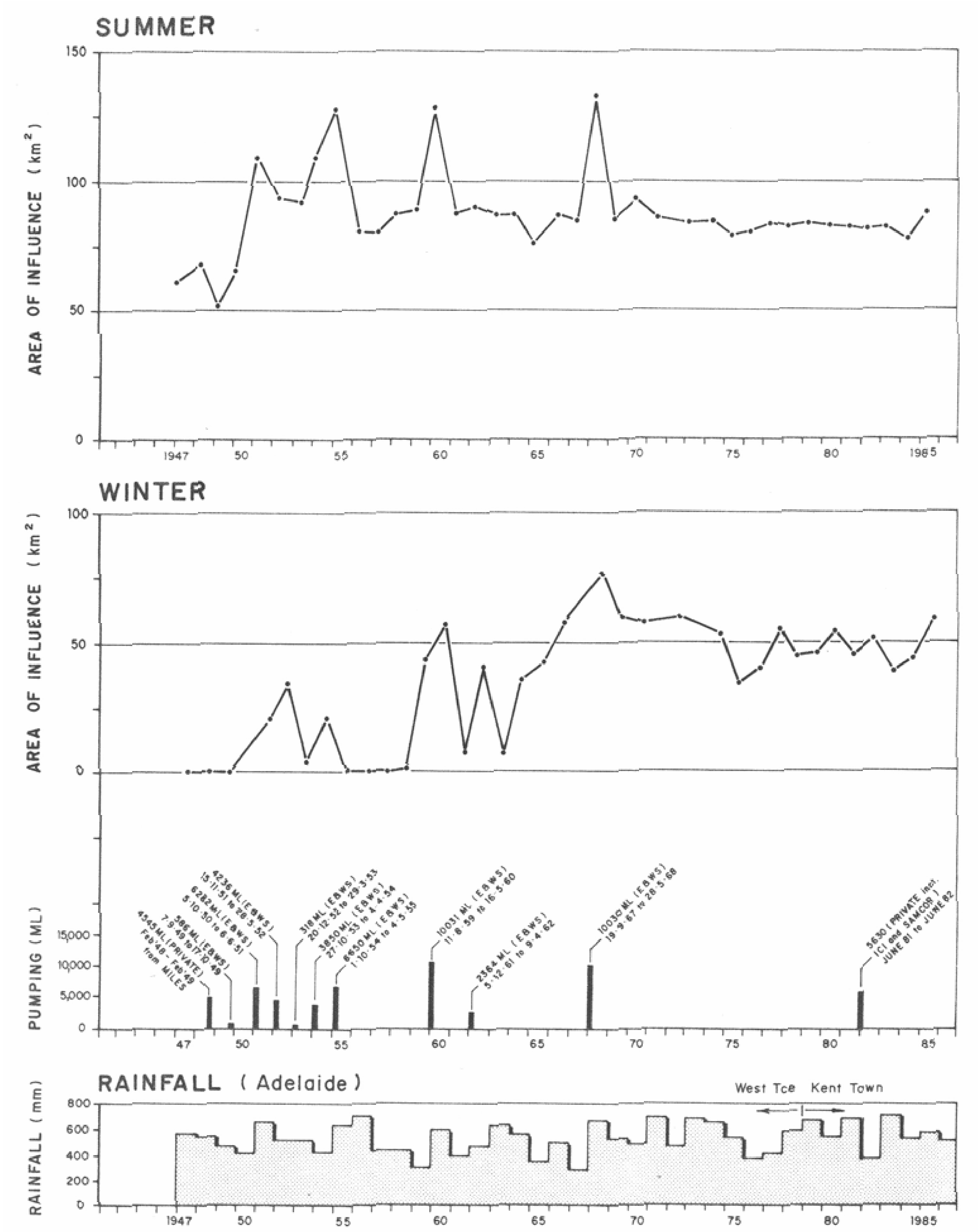

Figure 44 **Area of Influence (km^2) due to pumping of First Tertiary Aquifer (T1) mainly from Zone 3 and Sporadically Zone 2, 1947–85**

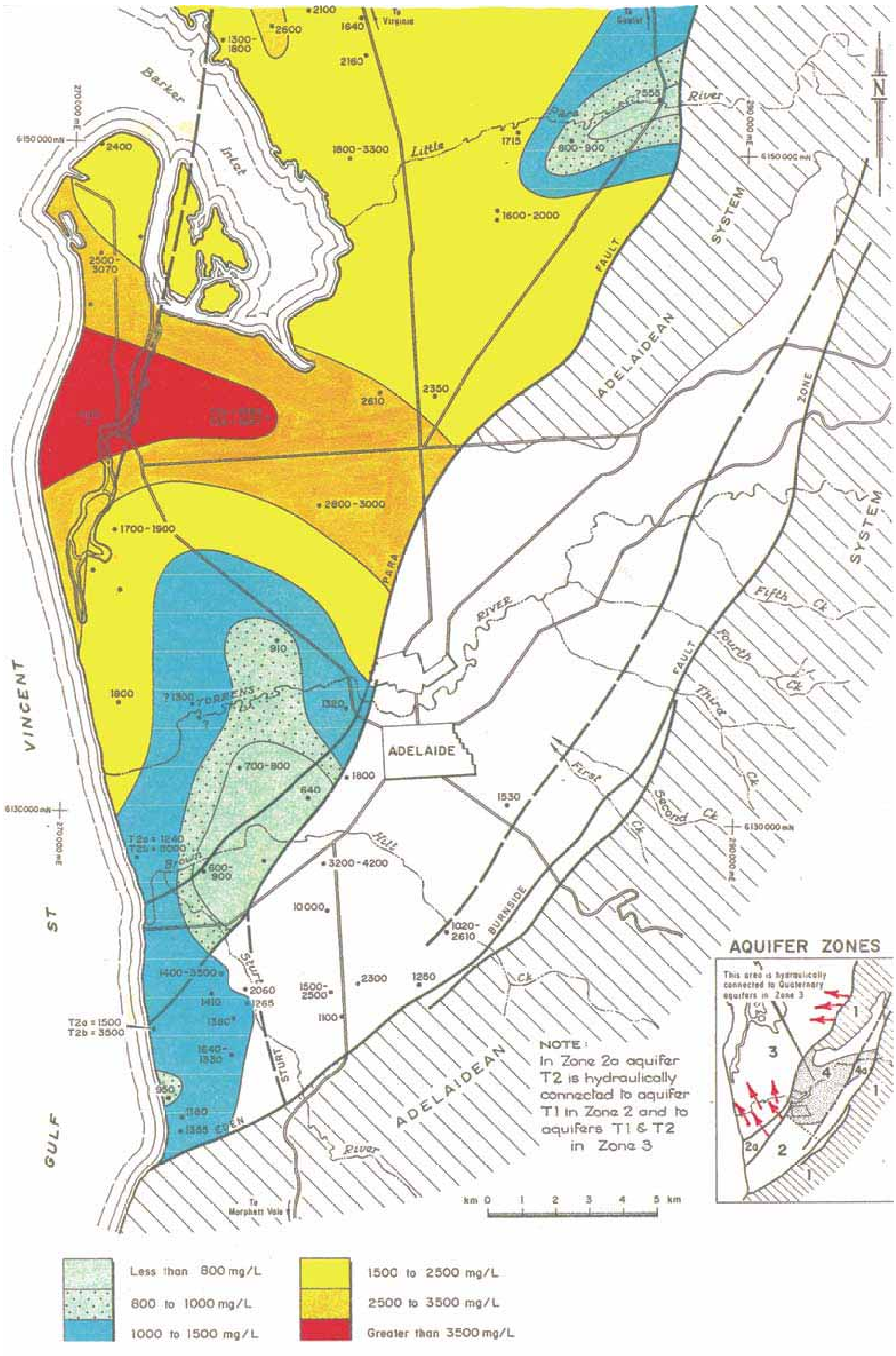

Figure 45 Second Tertiary Aquifer (mainly Port Willunga formation under Munno Para Clay) Salinity Plan

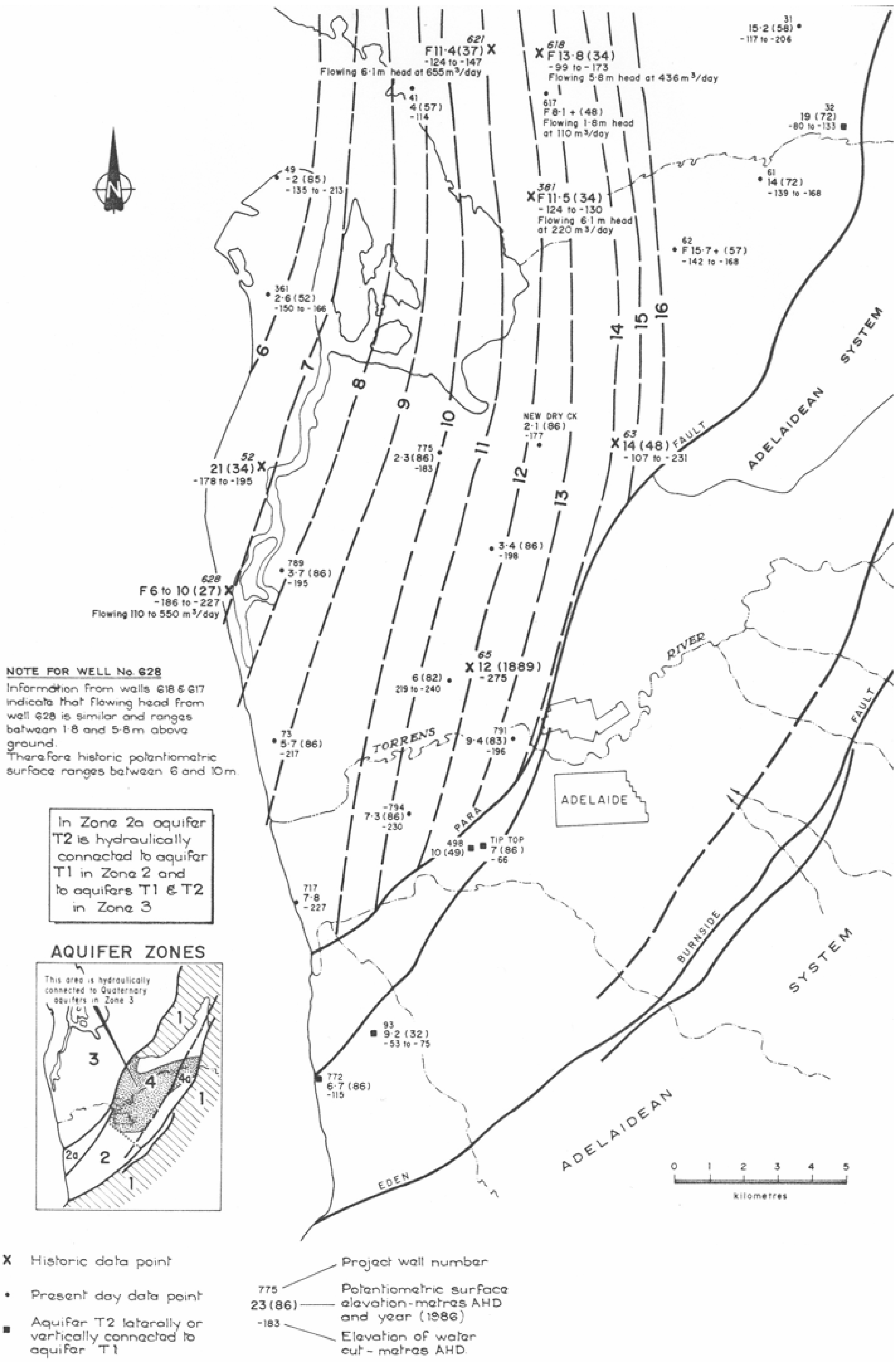

Figure 46 Second Tertiary Aquifer, Inferred Historic Potentiometric Surface early 1900s in zone 3

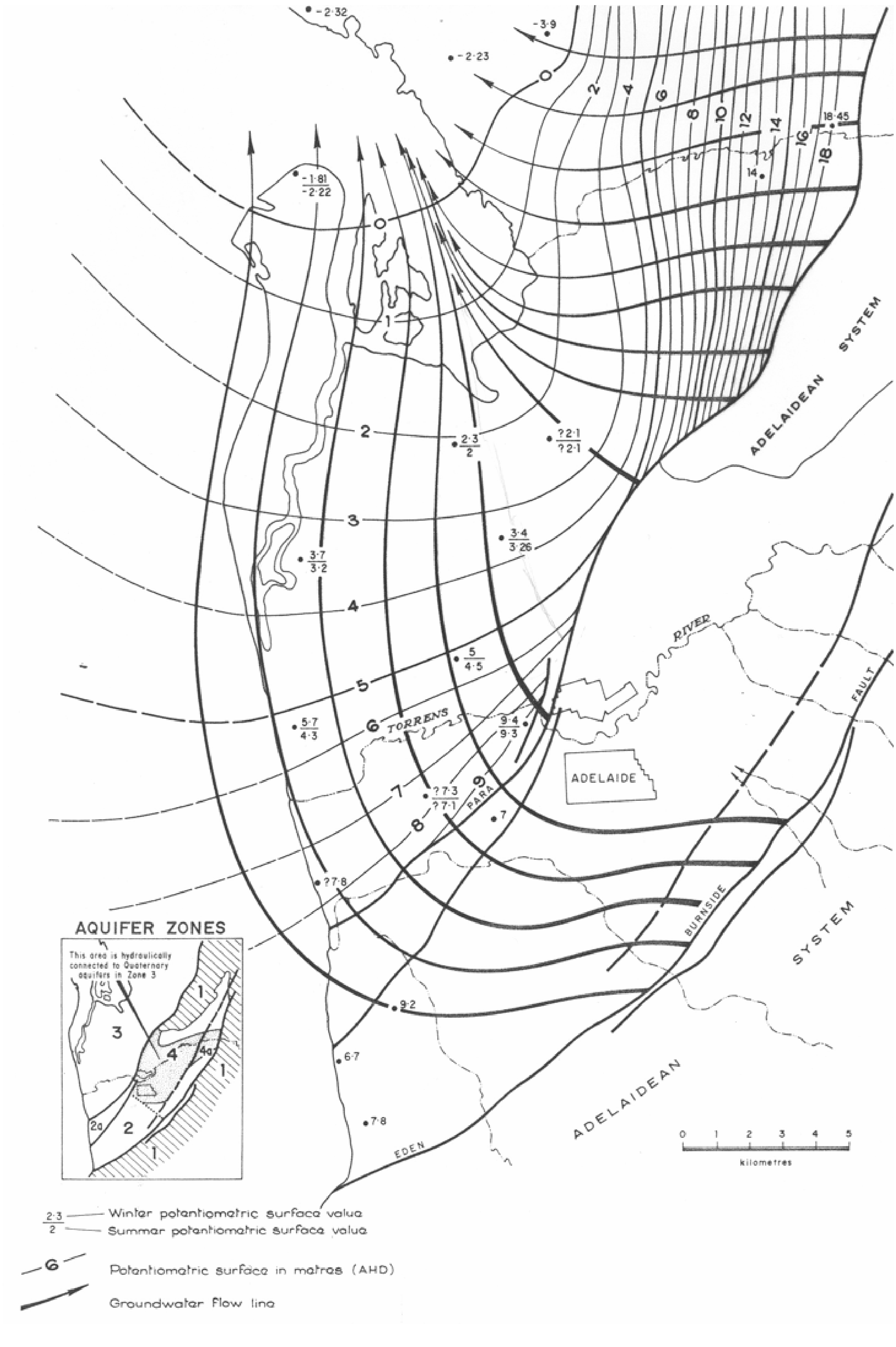

Figure 47 Second Tertiary Aquifer, Present Day Potentiometric Surface (September last decade)

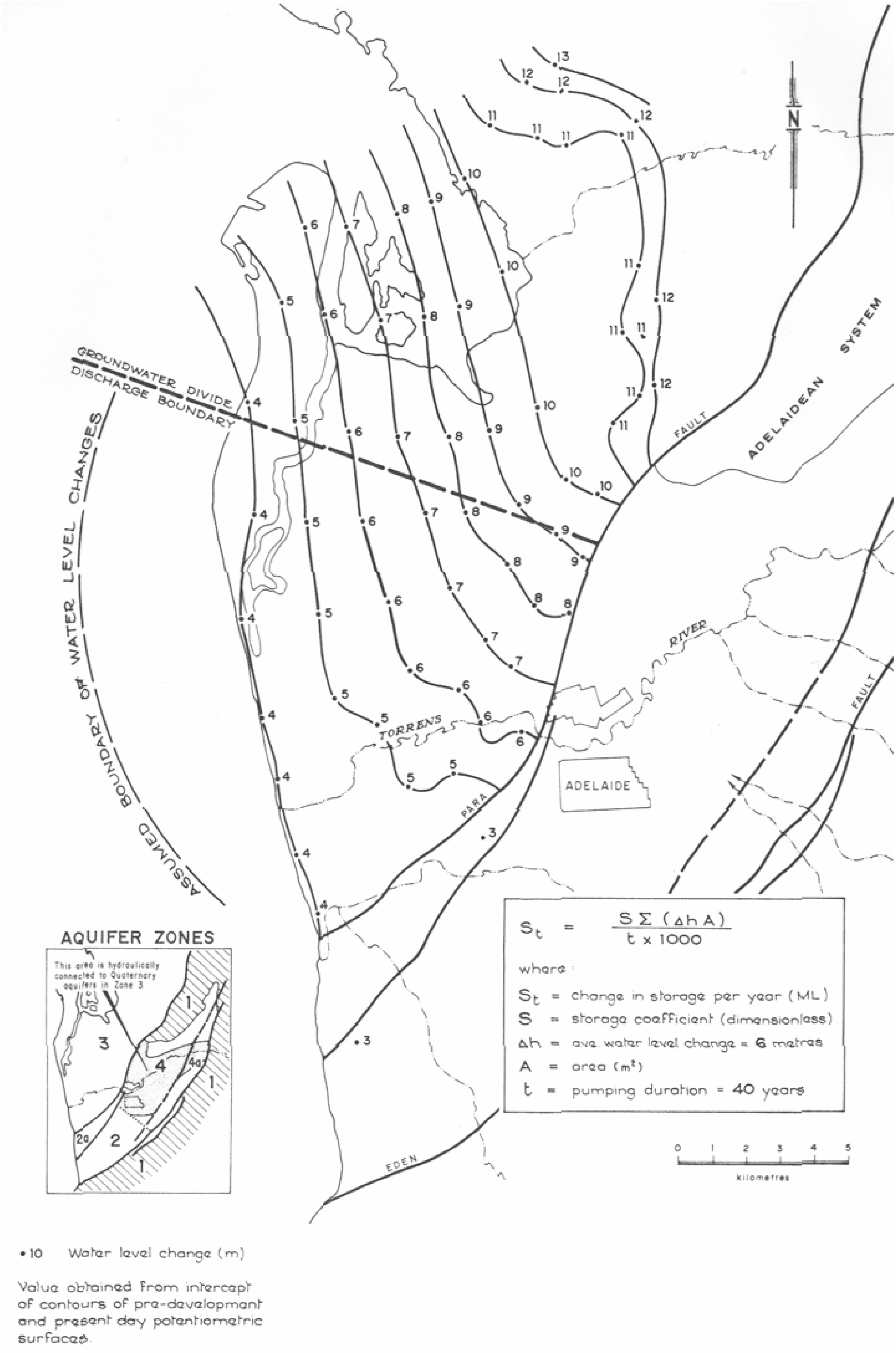

Figure 48 Second Tertiary Aquifer, Changes in Water Level and Storage in Zone 3 over the last 40 years

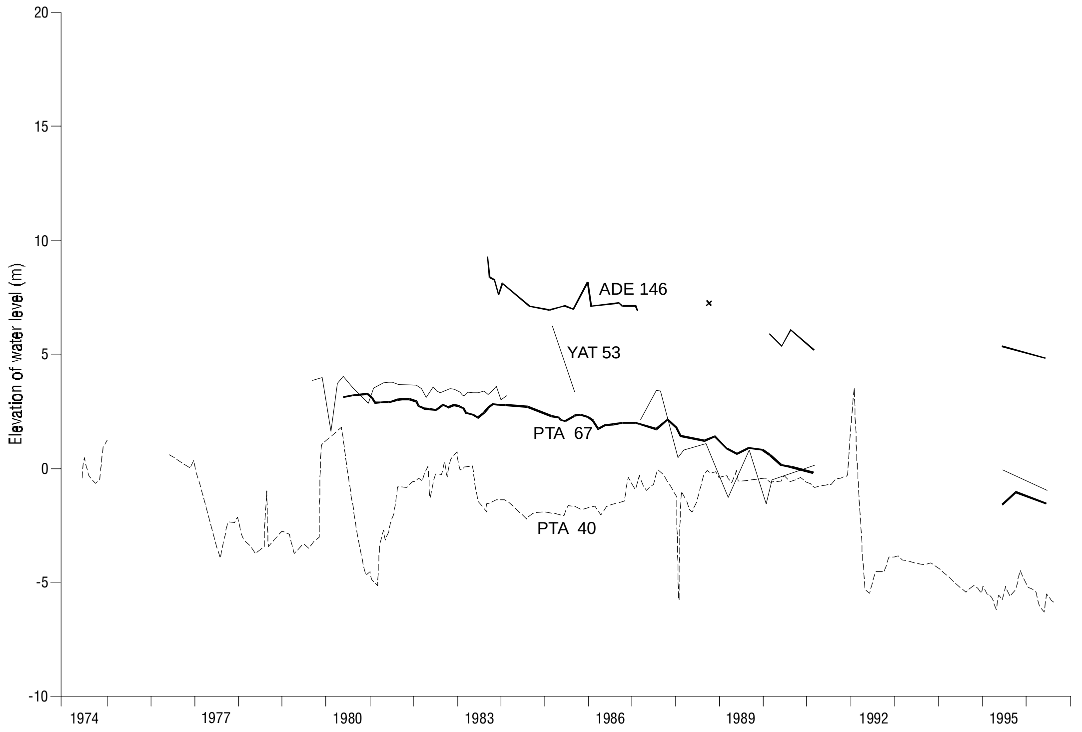

Figure 49

SECOND TERTIARY AQUIFER HYDROGRAPHS, ZONE 3, OBSERVATION WELLS ADE 146, PTA 40, PTA 67 AND YAT 53

Figure 49 Second Tertiary Aquifer Hydrographs, Zone 3, Observation Wells ADE 146, PTA 40, PTA 67 and YAT 53

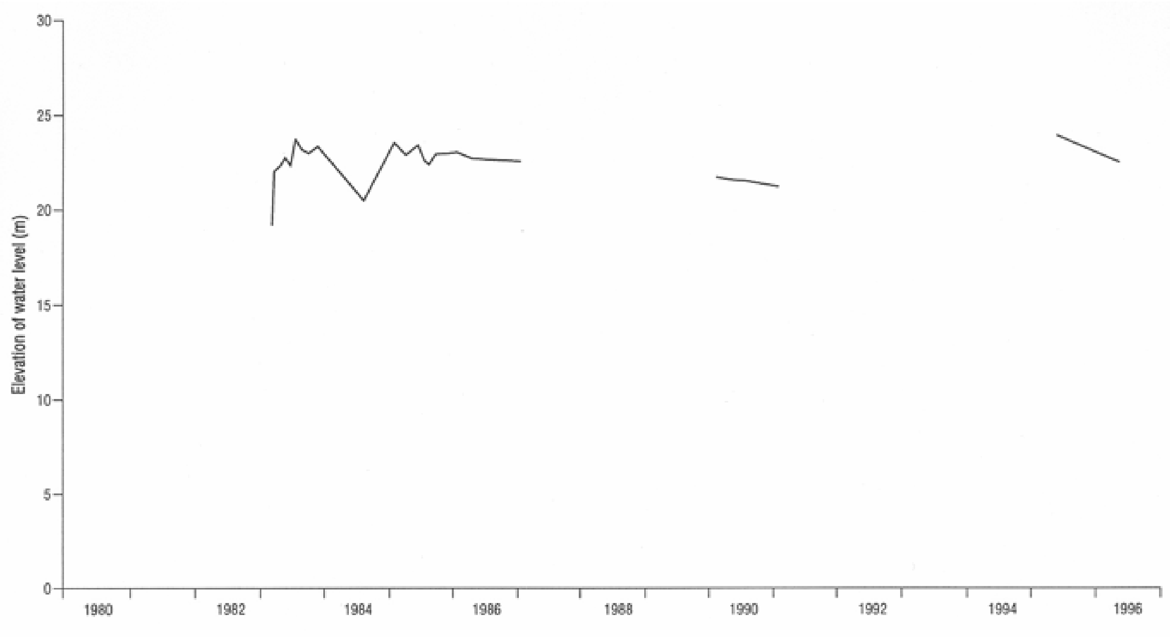

Figure 50 Third Tertiary Aquifer Hydrographs, Zone 2, Observation Well ADE 140

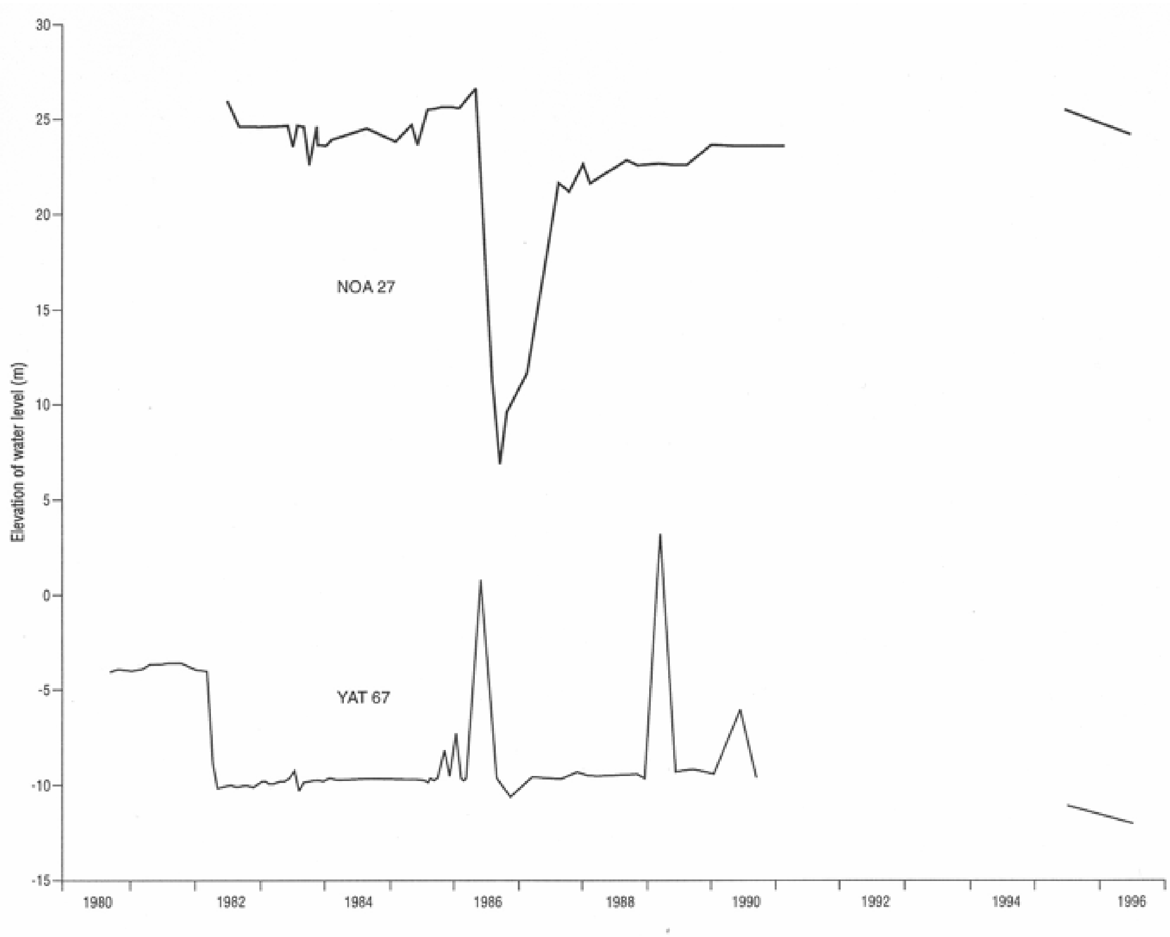

Figure 51 Fourth Tertiary Aquifer Hydrographs, Zone 3, Observation Wells YAT 67 and NOA 27

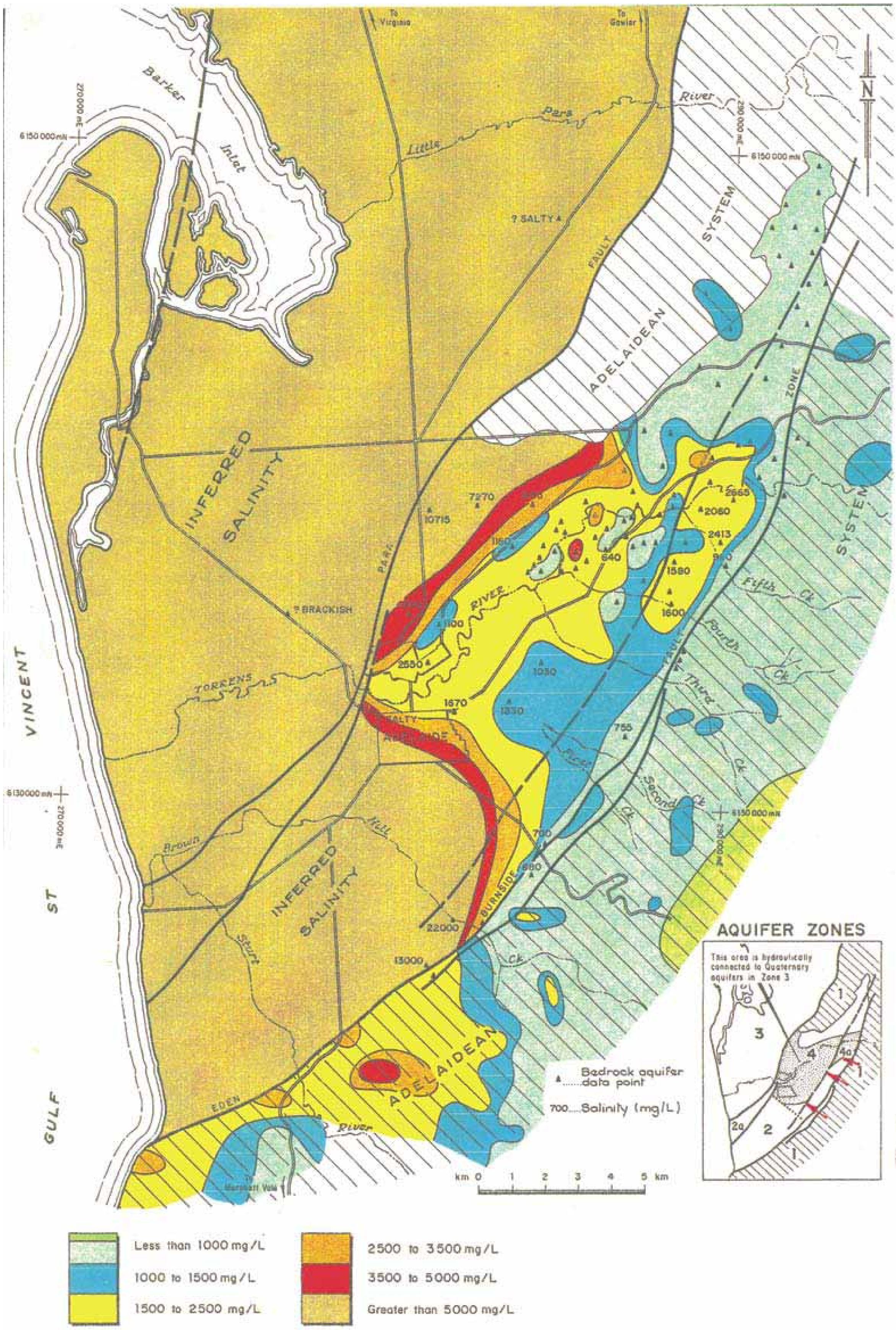

Figure 52 Fractured Bedrock Aquifer Salinity Plan

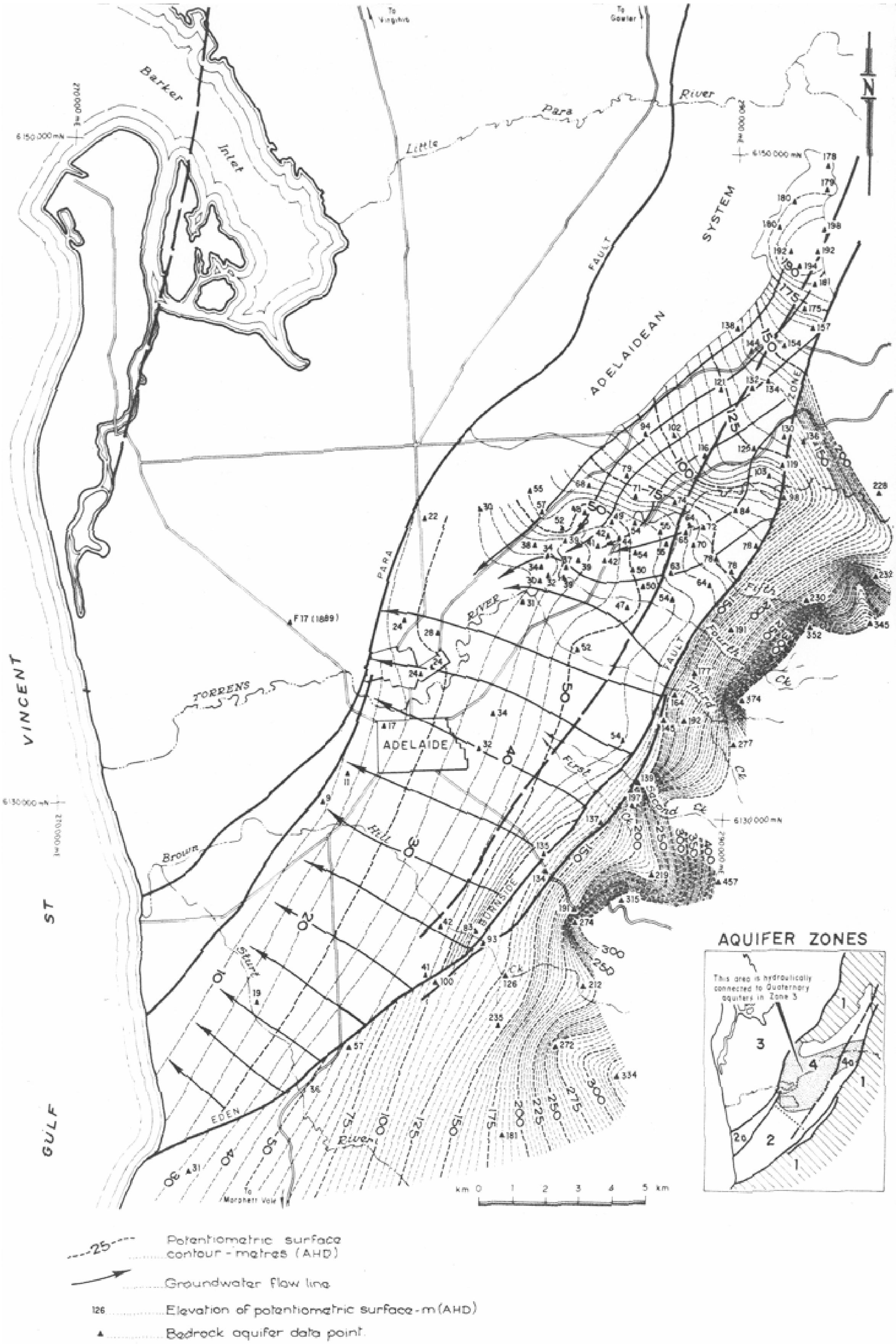

Figure 53 Fractured Bedrock Aquifer Potentiometric Surface

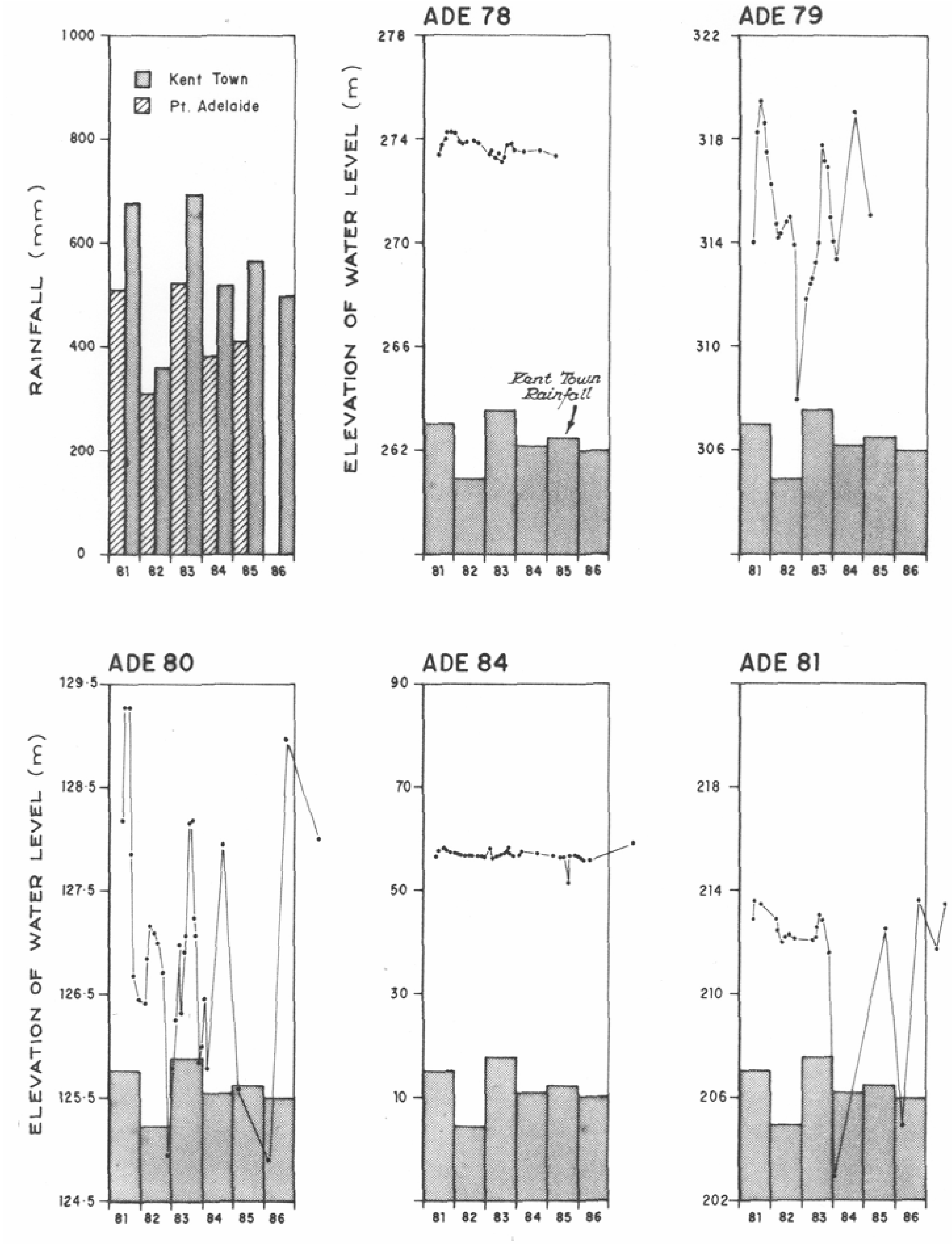

Figure 54 Fractured Bedrock Aquifer Hydrographs, Observation Wells ADE 78, ADE 79, ADE 80, ADE 84 and ADE 81

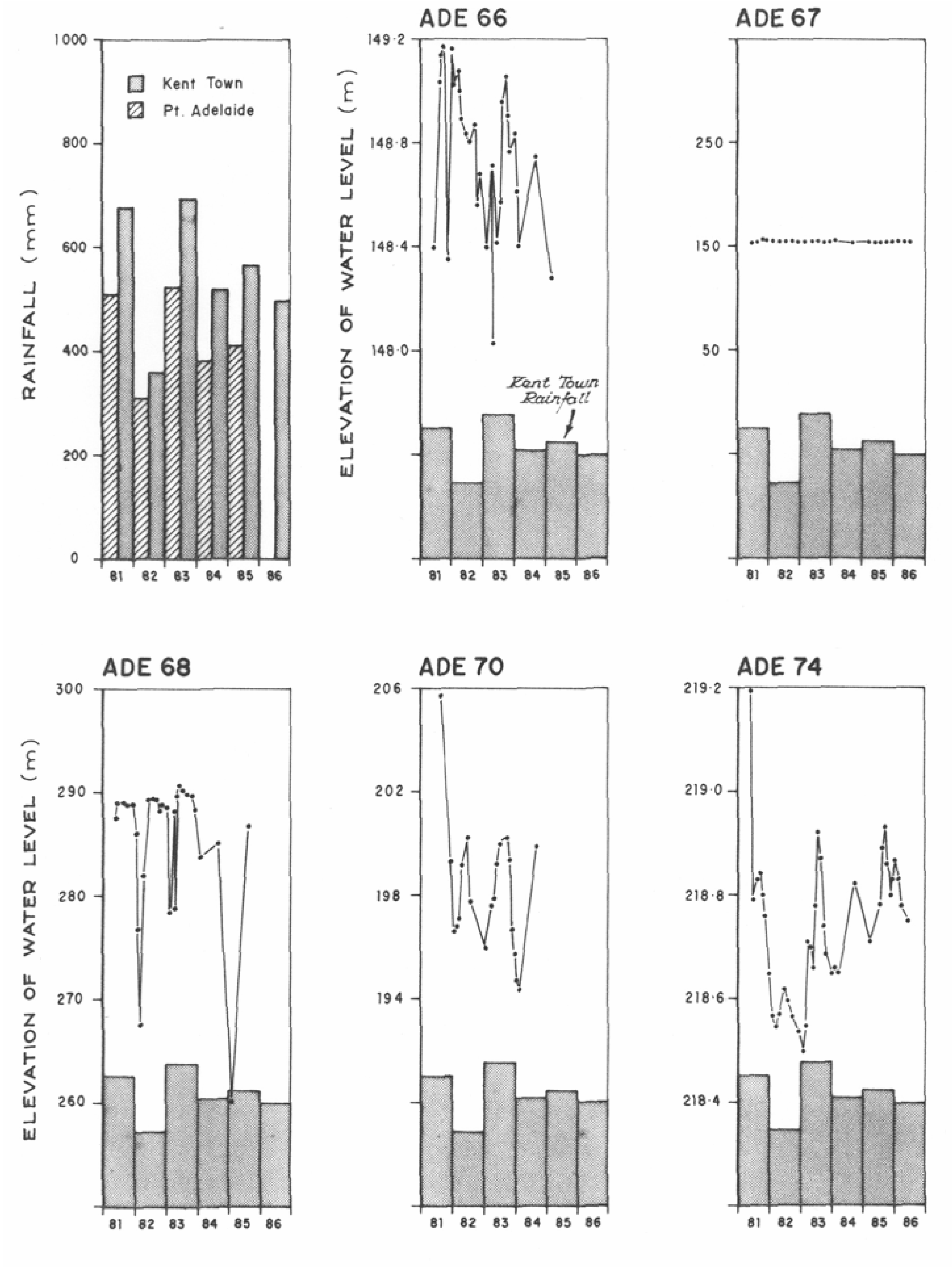

Figure 55 Fractured Bedrock Aquifer Hydrographs, Observation Wells ADE 66, ADE 67, ADE 68, ADE 70 and ADE 74

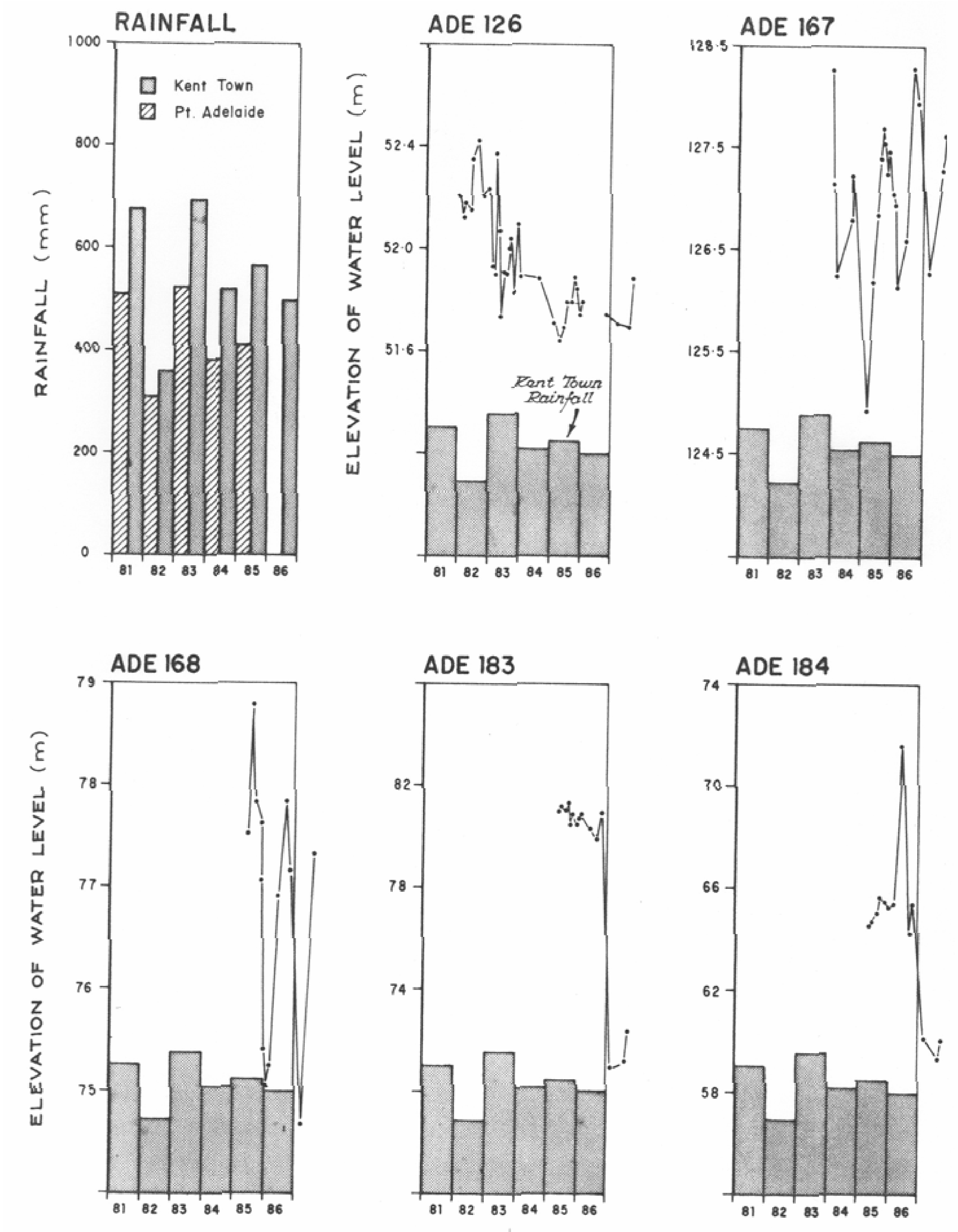

Figure 56 **Fractured Bedrock Aquifer Hydrographs, Observation Wells ADE 126, ADE 167, ADE 168, ADE 183m ADE 184**

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	356 or 366 days	time interval

δD	hydrogen isotope composition
$\delta^{18}O$	oxygen isotope composition
^{14}C	carbon-14 isotope (percent modern carbon)
CFC	chlorofluorocarbon (parts per trillion volume)
EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million
ppb	parts per billion
TDS	total dissolved solids (mg/L)

GLOSSARY

Act (the). In this document, refers to The *Natural Resources Management Act* (South Australia) 2004.

Adaptive management. A management approach, often used in natural resource management, where there is little information and/or a lot of complexity and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Algal bloom. A rapid accumulation of algal biomass (living organic matter) which can result in deterioration in water quality when the algae die and break down consuming the dissolved oxygen and releasing toxins.

Ambient. The background level of an environmental parameter (e.g. a background water quality like salinity).

Anabranch. A branch of a river that leaves the main stream.

Annual adjusted catchment yield. Annual catchment yield with the impact of dams removed.

Aquifer. An underground layer of rock or sediment which holds water and allows water to percolate through.

Aquifer, confined. Aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer.

Aquifer, storage and recovery (ASR). The process of recharging water into an aquifer for the purpose of storage and subsequent withdrawal.

Aquifer test. A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resource available for development from the well.

Aquifer, unconfined. Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

Aquitard. A layer in the geological profile that separates two aquifers and restricts the flow between them.

Arid lands. In South Australia arid lands are usually considered to be areas with an average rainfall of less than 250 mm and support pastoral activities instead of broad acre cropping.

Artesian. Under pressure such that when wells penetrate the aquifer water will rise to the ground surface without the need for pumping.

Artificial recharge. The process of artificially diverting water from the surface to an aquifer. Artificial recharge can reduce evaporation losses and increase aquifer yield. *(See recharge, natural recharge, aquifer.)*

Barrage. Specifically any of the five low weirs at the mouth of the River Murray constructed to exclude seawater from the Lower Lakes.

Baseflow. The water in a stream that results from groundwater discharge to the stream. (This discharge often maintains flows during seasonal dry periods and has important ecological functions.)

Basin. The area drained by a major river and its tributaries.

Benchmark condition. Points of reference from which change can be measured.

Biological diversity (biodiversity). The variety of life forms: the different life forms including plants, animals and micro-organisms, the genes they contain and the *ecosystems (see below)* they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity.

Biota. All of the organisms at a particular locality.

Bore. *See well.*

Buffer zone. A neutral area that separates and minimises interactions between zones whose management objectives are significantly different or in conflict (e.g. a vegetated riparian zone can act as a buffer to protect the water quality and streams from adjacent land uses).

Catchment. A catchment is that area of land determined by topographic features within which rainfall will contribute to runoff at a particular point.

Catchment water management board. A statutory body established under Part 6, Division 3, s. 53 of the Act whose prime function under Division 2, s. 61 is to implement a catchment water management plan for its area.

Catchment water management plan. The plan prepared by a CWMB and adopted by the Minister in accordance with Part 7, Division 2 of the Water Resources Act 1997.

Codes of practice. Standards of management developed by industry and government, promoting techniques or methods of environmental management by which environmental objectives may be achieved.

Cone of depression. An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction which exceeds the rate of recharge. Continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality.

Conjunctive use. The utilisation of more than one source of water to satisfy a single demand.

Council of Australian Governments (COAG). A council of the Prime Minister, State Premiers, Territory Chief Ministers and the President of the Australian Local Government Association which exists to set national policy directions for Australia.

CWMB. Catchment Water Management Board.

Dams, off-stream dam. A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted, or pumped, from a watercourse, a drainage path, an aquifer or from another source. Off-stream dams may capture a limited volume of surface water from the catchment above the dam.

Dams, on-stream dam. A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water.

Dams, turkey nest dam. An off-stream dam that does not capture any surface water from the catchment above the dam.

Diffuse source pollution. Pollution from sources such as an eroding paddock, urban or suburban lands and forests; spread out, and often not easily identified or managed.

District Plan. (District Soil Conservation Plan) An approved soil conservation plan under the repealed *Soil Conservation Act 1989*. These plans are taken to form part of the relevant regional NRM plans under the transitional provisions of the *Natural Resources Management Act 2004* (Schedule 4 – subclause 53[4] until regional NRM plans are prepared under Chapter 4, Part 2 of the Act.

Domestic purpose. The taking of water for ordinary household purposes and includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares.

Domestic wastewater. Water used in the disposal of human waste, for personal washing, washing clothes or dishes, and swimming pools.

DSS (decision support system). A system of logic or a set of rules derived from experts, to assist decision making. Typically they are constructed as computer programs.

DSS. Dissolved suspended solids.

DWLBC. Department of Water, Land and Biodiversity Conservation. Government of South Australia.

EC. Abbreviation for electrical conductivity. 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25 degrees Celsius. Commonly used to indicate the salinity of water.

Ecological processes. All biological, physical or chemical processes that maintain an ecosystem.

Ecological values. The habitats, the natural ecological processes and the biodiversity of ecosystems.

Ecologically sustainable development (ESD). Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.

Ecology. The study of the relationships between living organisms and their environment.

Ecosystem. Any system in which there is an interdependence upon and interaction between living organisms and their immediate physical, chemical and biological environment.

Ecosystem Services. All biological, physical or chemical processes that maintain ecosystems and biodiversity and provide inputs and waste treatment services that support human activities.

Effluent. Domestic wastewater and industrial wastewater.

EIP. Environment improvement program.

EMLR. Eastern Mount Lofty Ranges.

Entitlement flows. Minimum monthly River Murray flows to South Australia agreed in the Murray-Darling Basin Agreement 1992.

Environmental values. The uses of the environment that are recognised as of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Environmental water provisions. Those parts of environmental water requirements that can be met, at any given time. This is what can be provided at that time with consideration of existing users' rights, social and economic impacts.

Environmental water requirements. The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk.

EP. Eyre Peninsula.

EPA. Environment Protection Agency.

Ephemeral streams / wetlands. Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Erosion. Natural breakdown and movement of soil and rock by water, wind or ice. The process may be accelerated by human activities.

ESD. Ecologically sustainable development *(see above for definition)*.

Estuaries. Semi-enclosed waterbodies at the lower end of a freshwater stream that are subject to marine, freshwater and terrestrial influences and experience periodic fluctuations and gradients in salinity.

Eutrophication. Degradation of water quality due to enrichment by nutrients (primarily nitrogen and phosphorus), causing excessive plant growth and decay. *(See algal bloom).*

Evapotranspiration. The total loss of water as a result of transpiration from plants and evaporation from land, and surface waterbodies.

Fishway. A generic term describing all mechanisms that allow the passage of fish along a waterway. Specific structures include fish ladders (gentle sloping channels with baffles that reduce the velocity of water and provide resting places for fish as they 'climb' over a weir) and fishlifts (chambers, rather like lift-wells, that are flooded and emptied to enable fish to move across a barrier).

Floodplain. Of a watercourse means: (a) the floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under Part 7 of the Water Resources Act 1997; or (b) where paragraph (a) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the Development Act 1993, or (c) where neither paragraph (a) nor paragraph (b) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse.

Flow bands. Flows of different frequency, volume and duration.

GAB. Great Artesian Basin.

Gigalitre (GL). One thousand million litres (1 000 000 000).

GIS (geographic information system). Computer software allows for the linking of geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

GL. *See gigalitre.*

Greenhouse effect. The balance of incoming and outgoing solar radiation which regulates our climate. Changes to the composition of the atmosphere such as the addition of carbon dioxide through human activities, have the potential to alter the radiation balance and to effect changes to the climate. Scientists suggest that changes would include global warming, a rise in sea level and shifts in rainfall patterns.

Geological features. Include geological monuments, landscape amenity and the substrate of land systems and ecosystems.

Greywater. Household wastewater excluding sewage effluent. Wastewater from kitchen, laundry and bathroom.

Groundwater. *See underground water.*

Habitat. The natural place or type of site in which an animal or plant, or communities of plants and animals, lives.

Heavy metal. Any metal with a high atomic weight (usually, although not exclusively, greater than 100), for example mercury, lead and chromium. Heavy metals have a widespread industrial use, and many are released into the biosphere via air, water and solids pollution. Usually these metals are toxic at low concentrations to most plant and animal life.

Hydrogeology. The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers. *(See hydrology.)*

Hydrography. The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time.

Hydrology. The study of the characteristics, occurrence, movement and utilisation of water on and below the earth's surface and within its atmosphere. *(See hydrogeology.)*

Hyporheic zone. The wetted zone among sediments below and alongside rivers. It is a refuge for some aquatic fauna.

Indigenous species. A species that occurs naturally in a region.

Industrial wastewater. Water (not being domestic wastewater) that has been used in the course of carrying on a business (including water used in the watering of irrigation of plants) that has been allowed to run to waste or has been disposed of or has been collected for disposal.

Infrastructure. Artificial lakes; or dams or reservoirs; or embankments, walls, channels or other works; or buildings or structures; or pipes, machinery or other equipment.

Integrated catchment management. Natural resources management that considers in an integrated manner the total long-term effect of land and water management practices on a catchment basis, from production and environmental viewpoints.

Intensive farming. A method of keeping animals in the course of carrying on the business of primary production in which the animals are confined to a small space or area and are usually fed by hand or by mechanical means.

Irrigation. Watering land by any means for the purpose of growing plants.

Irrigation season. The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May.

Lake. A natural lake, pond, lagoon, wetland or spring (whether modified or not) and includes: part of a lake; and a body of water declared by regulation to be a lake; a reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

Land. Whether under water or not and includes an interest in land and any building or structure fixed to the land.

Land capability. The ability of the land to accept a type and intensity of use without sustaining long-term damage.

Leaching. Removal of material in solution such as minerals, nutrients and salts through soil.

Licence. A licence to take water in accordance with the Water Resources Act 1997. *(See water licence.)*

Licensee. A person who holds a water licence.

Local water management plan. A plan prepared by a council and adopted by the Minister in accordance with Part 7, Division 4 of the Act.

Macro-invertebrates. Animals without backbones that are typically of a size that is visible to the naked eye. They are a major component of aquatic ecosystem biodiversity and fundamental in food webs.

MDBC. Murray-Darling Basin Commission.

Megalitre (ML). One million litres (1 000 000).

ML. *See megalitre.*

MLR. Mount Lofty Ranges.

Model. A conceptual or mathematical means of understanding elements of the real world which allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change.

Mount Lofty Ranges Watershed. The area prescribed by Schedule 1 of the regulations.

Natural recharge. The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.) *(See recharge area, artificial recharge.)*

NHMRC. National Health and Medical Research Council.

NHT. Natural Heritage Trust.

Natural Resources. Soil; water resources; geological features and landscapes; native vegetation, native animals and other native organisms; ecosystems.

Natural Resources Management (NRM). All activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively.

Occupier of land. A person who has, or is entitled to, possession or control of the land.

Owner of land. In relation to land alienated from the Crown by grant in fee simple — the holder of the fee simple; in relation to dedicated land within the meaning of the *Crown Lands Act 1929* that has not been granted in fee simple but which is under the care, control and management of a Minister, body or other person — the Minister, body or other person; in relation to land held under Crown lease or licence — the lessee or licensee; in relation to land held under an agreement to purchase from the Crown — the person entitled to the benefit of the agreement; in relation to any other land — the Minister who is responsible for the care, control and management of the land or, if no Minister is responsible for the land, the Minister for Environment and Heritage.

Palaeochannels. Ancient buried river channels in arid areas of the state. Aquifers in palaeochannels can yield useful quantities of groundwater or be suitable for ASR.

Pasture. Grassland used for the production of grazing animals such as sheep and cattle.

Percentile. A way of describing sets of data by ranking the data set and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Permeability. A measure of the ease with which water flows through an aquifer or aquitard.

Personal property. All forms of property other than real property. For example, shares or a water licence.

Phreaphytic vegetation. Vegetation that exists in a climate more arid than its normal range by virtue of its access to groundwater.

Phytoplankton. The plant constituent of organisms inhabiting the surface layer of a lake; mainly single-cell algae.

PIRSA. (Department of) Primary Industries and Resources South Australia.

Pollution, diffuse source. Pollution from sources that are spread out and not easily identified or managed (e.g. an eroding paddock, urban or suburban lands and forests).

Pollution, point source. A localised source of pollution.

Potable water. Water suitable for human consumption.

Potentiometric head. The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer.

Precautionary principle. Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

Prescribed area, surface water. Part of the State declared to be a surface water prescribed area under the Water Resources Act 1997.

Prescribed lake. A lake declared to be a prescribed lake under the Water Resources Act 1997.

Prescribed water resource. A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed watercourse. A watercourse declared to be a prescribed watercourse under the Water Resources Act 1997.

Prescribed well. A well declared to be a prescribed well under the Water Resources Act 1997.

Property right. A right of ownership or some other right to property, whether real property or personal property.

Proponent. The person or persons (who may be a body corporate) seeking approval to take water from prescribed water.

PWA. Prescribed Wells Area.

PWCA. Prescribed Watercourse Area.

PWRA. Prescribed Water Resources Area.

Ramsar Convention. This is an international treaty on wetlands titled The Convention on Wetlands of International Importance Especially as Waterfowl Habitat. It is administered by the International Union for Conservation of Nature and Natural Resources. It was signed in the town of Ramsar, Iran in 1971, hence its common name. The Convention includes a list of wetlands of international importance and protocols regarding the management of these wetlands. Australia became a signatory in 1974.

Recharge area. The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. *(See artificial recharge, natural recharge.)*

Reclaimed water. Treated effluent of a quality suitable for the designated purpose.

Rehabilitation (of waterbodies). Actions that improve the ecological health of a waterbody by reinstating important elements of the environment that existed prior to European settlement.

Remediation (of waterbodies). Actions that improve the ecological condition of a waterbody without necessarily reinstating elements of the environment that existed prior to European settlement.

Restoration (of waterbodies). Actions that reinstate the pre-European condition of a waterbody.

Reticulated water. Water supplied through a piped distribution system.

Riffles. Shallow stream section with fast and turbulent flow.

Riparian landholder. A person whose property abuts a watercourse or through whose property a watercourse runs.

Riparian rights. These were old common law rights of access to, and use of water. These common law rights were abolished with the enactment of the Water Resources Act 1997, which now includes similar rights under s. 7. Riparian rights are therefore now statutory rights under the Act. Where the resource is not prescribed (Water Resources Act 1997, s. 8) or subject to restrictions (Water Resources Act 1997, s. 16), riparian landholders may take any amount of water from watercourses, lakes or wells without consideration to downstream landholders, if it is to be used for stock or domestic purposes. If the capture of water from watercourses and groundwater is to be used for any other purpose then the right of downstream landholders must be protected. Landholders may take any amount of surface water for any purpose without regard to other landholders, unless the surface water is prescribed or subject to restrictions.

Riparian zone. That part of the landscape adjacent to a water body, that influences and is influenced by watercourse processes. This can include landform, hydrological or vegetation definitions. It is commonly used to include the in-stream habitats, bed, banks and sometimes floodplains of watercourses.

Seasonal watercourses or wetlands. Those watercourses and wetlands that contain water on a seasonal basis, usually over the winter/spring period, although there may be some flow or standing water at other times.

State water plan. The plan prepared by the Minister under Part 7, Division 1, s. 90 of the Act.

Stock Use. The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act).

Stormwater. Runoff in an urban area.

Surface water. (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir.

Taxa. General term for a group identified by taxonomy — which is the science of describing, naming and classifying organisms.

To take water. From a water resource includes (a) to take water by pumping or syphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water in a watercourse from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir.

Total kjeldhal nitrogen (TKN). The sum of aqueous ammonia and organic nitrogen. Used as a measure of probable sewage pollution.

Transfer. A transfer of a licence (including its water allocation) to another person, or the whole or part of the water allocation of a licence to another licensee or the Minister under Part 5, Division 3, s. 38 of the Act. The transfer may be absolute or for a limited period.

Underground water (groundwater). Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

Volumetric allocation. An allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period of time, usually per water use year (as distinct from any other sort of allocation).

Wastewater. *See domestic wastewater, industrial wastewater.*

Water affecting activities. Activities referred to in Part 4, Division 1, s. 9 of the Act.

Water allocation. (a) in respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s. 11 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Water allocation, area based. An allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water use year.

Water allocation plan (WAP). A plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with Division 3 of Part 7 of the Act.

Water licence. A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area. This grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water. A water licence confers a property right on the holder of the licence and this right is separate from land title.

Water plans. The State Water Plan, catchment water management plans, water allocation plans and local water management plans prepared under Part 7 of the Act.

Water service provider. A person or corporate body that supplies water for domestic, industrial or irrigation purposes or manages wastewater.

Waterbody. Waterbodies include watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers.

Watercourse. A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; and a lake through which water flows; and a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse.

Water-dependent ecosystems. Those parts of the environment, the species composition and natural ecological processes, which are determined by the permanent or temporary presence of flowing or standing water, above or below ground. The in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems.

Water-use year. The period between 1 July in any given calendar year and 30 June the following calendar year. This is also called a licensing year.

Well. (a) an opening in the ground excavated for the purpose of obtaining access to underground water; (b) an opening in the ground excavated for some other purpose but that gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

Wetlands. Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic/intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides does not exceed six metres.

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