MOUNT LOFTY RANGES GROUNDWATER ASSESSMENT
Piccadilly Valley

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PRIMARY INDUSTRIES AND RESOURCES SA

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by

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MOUNT LOFTY RANGES GROUNDWATER ASSESSMENT - Piccadilly Valley

S.R. Barnett and D. Zulfic

A water balance study of the Piccadilly Valley has indicated that almost 20% of annual rainfall amounting to 2000 ML recharges the fractured rock aquifers. The current usage of about 1200 ML represents just under 60% of the annual recharge. Total pumping in the area has decreased by just over 50% since 1970, due to the reduction in the area of vegetable irrigation and the change in land use to vineyards. The water balance should be revised periodically to take into account such changes.

The Basket Range Sandstone is the most productive aquifer with yields of up to 20 litres/sec. All rock units have low salinities mostly below 500 mg/L and show a trend of increasing salinity with depth. Since monitoring began in 1979, groundwater levels have been strongly controlled by rainfall and show no evidence of overwithdrawal. Falling water levels in early 1995 were caused by one of the driest spells on record during 1993-94, not overpumping.

Salinity monitoring has not been consistent and consequently, no trends are evident. However, higher salinities are observed beneath irrigated areas. Extensive sampling by AGSO has shown general groundwater quality to be very good, with only very few bores not meeting drinking water guidelines.

Because of uncertainties over the effect of groundwater pumping on environmental baseflows, it is recommended that the sustainable yield be limited to a maximum of 75% of recharge, which in the Piccadilly Valley, amounts to 1500 ML. This represents an increase of approximately 300 ML over current use, which if developed, may have local impacts on groundwater levels.

The effect of groundwater pumping on baseflows which could have environmental significance, needs to be investigated with some urgency. Regular water level and salinity monitoring should continue and the metering of all irrigation and industrial supplies should be carried out to allow accurate estimates of water use. Efforts should be made to increase irrigation efficiencies, especially for vegetable irrigation.

INTRODUCTION

The Mount Lofty Ranges (MLR) contain a significant groundwater resource of low salinity. As this resource is coming under increasing pressure for development, it is imperative to gain an understanding of the extent of the resource and to develop appropriate management strategies in order to ensure that future development is sustainable.

The assessment of the groundwater resources has not been attempted until now for several reasons. Firstly, fractured rock aquifer systems are far more complex than those found in sedimentary basins. There are large variations in permeability and yield within each fractured rock borehole, not to mention the variation between holes in a similar lithology or even holes in different geological units in the same catchment. Adding to the difficulties is the fact that there are thousands of boreholes with information (of varying quality) on water levels, yields, salinities and lithology. Detailed analysis of this data would be extremely time-consuming.

The Piccadilly Valley was chosen as the first study area because of its good monitoring record but more importantly, concerns about alleged groundwater overpumping and the viability of the resource, especially after the two dry years 1993-94. Groundwater has been pumped for the irrigation of vegetables and orchards for over 30 years in the Piccadilly Valley, which lies 10 km southeast of Adelaide (Fig. 1). It enjoys the highest rainfall in the State (>1 000 mm), and ranges between 460 and 550 m in altitude.

Previous hydrogeological investigations found a close correlation between geology and well yields and also “an apparent overall increase of about 10% in groundwater salinity over recent years”

(Wake-Dyster, 1974). Edwards (1979) constructed a potentiometric surface map which showed groundwater movement in fractured rock aquifers from the elevated catchment boundaries toward the streams in the centre of the valley (Fig. 2).

This report does not present the results of a detailed hydrogeological investigation. It uses existing information to assess various techniques for estimation of the sustainable yield of groundwater resources in the Piccadilly Valley and makes recommendations for future work. The conclusions reached in this report should be reassessed if more detailed information becomes available in the future.

GEOLOGY

The rocks underlying the Piccadilly Valley are of two fundamentally different types and very different ages.

- the metamorphic crystalline basement of the Barossa Complex which is 1 600 million years old and forms the oldest core of the Mt Lofty Ranges
- younger sedimentary rocks of the Burra Group which overlie the basement and were deposited about 800 million years ago

Figure 3 shows the geology of the area and a diagrammatic geological cross-section.

BAROSSA COMPLEX

This unit is composed of quartz-feldspar gneiss and fine-grained schist. Originally, these were igneous and sedimentary rocks metamorphosed at high temperature and pressure deep in the Earth's crust. The Barossa Complex occurs on the east side of the Piccadilly Valley, where it has been thrust westwards over the Burra Group.

BASKET RANGE SANDSTONE

This the first of four formations of the Burra Group which cover the basement. It is a medium and coarse-grained, generally thickly bedded yellow-grey sandstone (with some sandy slate interbeds) which lies to the northwest of the Barossa Complex. These rocks were originally included in the Aldgate Sandstone, but are now interpreted as a younger unit (Preiss, in press). The boundary is a complex zone along the Crafers Fault in which the basement rocks have been thrust westward over the sandstone, which is itself folded and faulted. The rocks are mostly deeply weathered and kaolinised and are locally associated with remnant ironstone.

WOOLSHED FLAT SHALE

Consisting of dark grey to black siltstone, slate and phyllite with some dolomitic lenses, and sometimes pyritic, the Woolshed Flat Shale has faulted contacts with the overlying Basket Range Sandstone in the Piccadilly area. Due to the relatively ductile behaviour of these rocks under deformation, joint systems have developed mainly in zones of faulting.

STONYFELL QUARTZITE

This unit overlies the Woolshed Flat Shale as a gently dipping capping on the ridge of Mountt Lofty and Mount Bonython at the western boundary of the valley and consists of feldspathic quartzite, sandstone and minor siltstone (Fig. 3). The upward-coarsening transition between the two formations can be seen on the western slopes of Mount Bonython. Quartzite, being more resistant to erosion than most rocks, outcrops along ridges while the softer shales and sandstones underlie areas of lower relief.

AQUIFER CHARACTERISTICS

Groundwater in the Piccadilly Valley occurs in heterogenous fractured rock aquifers. The topographic catchment boundary is also considered to be the boundary of the groundwater catchment on the basis of the watertable contours presented in Figure 2 and water levels in adjacent catchments. The aquifers are unconfined, based on geological and chemical evidence.

The **Barossa Complex** is generally considered to be a poor aquifer from which irrigation supplies can not be obtained. The fine grain-size and rapid decomposition of some of the schistose and granitic rocks to clay, considerably reduce permeability in the weathered zone and may lead to an increase in the salinity of the groundwater.

The **Basket Range Sandstone** aquifer has a primary permeability in addition to the secondary joint system, which would significantly enhance its storage capabilities. Good supplies of good quality water are obtainable from these rocks. This aquifer is considered to be the best in the area and is extensively used for irrigation purposes.

The storage capacity of the **Woolshed Flat Shale** is mainly a function of fracture and joint development as the general permeability of the rocks is rather low. The fine grain-size and ready decomposition of these rocks may lead to some deterioration in the quality of the water, as does the presence of pyrite which may elevate iron levels.

Beneath Mount Lofty, the **Stonyfell Quartzite** contains a perched aquifer on top of the Woolshed Flat Shale with a limited areal extent and quite low salinities. Its natural spring discharge has been developed by a spring water company. Elsewhere, domestic supplies are obtained from this unit around the southern margin of the catchment.

Analysis of borehole data from the updated SA_GEODATA provided information on the yield and salinity characteristics of the above fractured rock aquifers.

AQUIFER SALINITIES

Figure 4 shows the salinity distribution for each of the fractured rock aquifers. The results show generally low salinities below 600 mg/L in response to the high rainfall and recharge, with rock type not having a major influence. The low permeability Barossa Complex has a higher median salinity, whilst the higher level perched Stonyfell Quartzite shows the lowest salinities.

Figure 5 shows the salinity profiles for each aquifer with the depth measured from below the static water level, ***not*** ground level. Each aquifer shows an increasing trend with depth. As fractures and joints also decrease in frequency and permeability with depth, the resultant longer groundwater residence times could lead to an increase in dissolution of the rock matrix.

The fresher groundwater at shallow depths may also reflect the effects of increased recharge since land clearing.

The samples were collected by airlifting and consequently, would have been mixed with shallower water cuts of lower salinity leading to a reduction in measured values.

AQUIFER YIELDS

Rock type plays a major role in determining yield characteristics (Fig. 6). The Basket Range Sandstone provides the highest median yield, perhaps aided by its primary porosity. Not surprisingly, the gneisses of the Barossa Complex are the lowest yielding. The Stonyfell Quartzite perched aquifer is generally thin and cannot sustain high yields for any length of time.

The yields displayed are only those measured during drilling and must be considered approximate. Yield estimates obtained during field surveys were ignored because they usually only represent the capacity of the pump installed at the time and not the well itself.

The yield *vs* depth profiles (Fig. 7) are measured below ground level and show the cumulative yield as the well is drilled. Each individual bar shows the upper and lower limits of each water cut and the approximate total yield The profiles show the depth at which the maximum yield is obtained. This represents the optimum depth to which a hole should be drilled, below which the chances of finding an increase in supply are low, due to the increasing tightness of the decreasing number of joints and fractures.

As an approximate rule of thumb, the optimum depth for most rock types appears to be about 100 m (with the exception of the Stonyfell Quartzite). Obviously, sites on top of hills will need to be up to 50 m deeper.

ADOPTED APPROACH

The keys to a successful methodology for groundwater assessment lie in choosing the appropriate scale for assessment and also choosing the appropriate database and information technology to assist in the interpretation of the large quantities of information available.

Because of the generally close relationship between groundwater divides and surface water divides in a fractured rock environment, and also because of legislative requirement for water management on a catchment basis, it was decided to also assess groundwater resources on a catchment basis. At this relatively large scale, it was thought that the

water balance method was the best way to estimate the sustainable yield of a catchment in a short time frame, and would also highlight data deficiencies.
The integration of data from SA_GEODATA (drillhole database) with Geographic Information Systems (GIS) enables interpretation of groundwater information and its relationship with areal coverages such as geology and land use. The upgrading of SA_GEODATA with more complete information from microfiche records has also allowed better interpretation for developing recommendations for future development.

WATER BALANCE COMPONENTS

One of the best ways to determine the health of a business is to examine its balance sheet - the same applies for a catchment. If spending (water outflow) is greater than income (water inflow), problems can be expected. Determining the water balance of a catchment is a fundamental step in establishing the sustainable groundwater yield for development. Each of the following components of the water balance for the Piccadilly Valley can be measured or estimated to a reasonable degree of accuracy.

RAINFALL

This is the main driving force of the hydrologic cycle and is the major water input to catchment. Rainfall is winter dominant, with the monthly averages for Uraidla, in mm, shown below. The annual average is 1 070 mm/year.

J	F	M	A	M	J	J	A	S	O	N	D
34	32	42	84	129	159	160	145	114	88	56	47

Because most of the summer rainfall is lost by evaporation before it has a chance to percolate down to the plant root zone or the watertable, only winter rainfall (April - October) is considered to be effective in contributing to the water balance. By combining an rainfall isohyet map with the areal coverage of a catchment, the total annual average volume of rainfall falling on the catchment can be calculated.
Because of the relatively small area of the Piccadilly Valley, the annual average of the long term rainfall from Bridgewater and Uraidla (at the southern and northern ends of the valley respectively) was used and taken to be 1070 mm/year, with an effective rainfall of 880 mm/year.

EVAPOTRANSPIRATION

After rain has fallen, water is absorbed by plants and trees through their roots. It is also evaporated from the topsoil and even from wet leaves in the tree canopy. Following recent research, reasonable estimates of plant water use by transpiration for various crops can be made. Surprisingly, this is often the largest water use component in the catchment.

A GIS coverage of land use in the MLR was constructed in 1993 using current aerial photographs and ground truthing. This coverage can provide areas of native vegetation, pasture, vineyards etc in any catchment and hence, the volume of water transpired (from non-irrigated areas) can be calculated. It has been assumed that under native vegetation, almost all of the effective rainfall is transpired, leaving 50 mm available for recharge.

A map of the 1993 land use in the Piccadilly Valley is shown in Figure 8, however the details of water use presented in Table 1 have been updated using 1997 aerial photography.

STREAMFLOW

There is a network of about 70 continuous recording gauging stations throughout the MLR. Most of the data is stored at the Department of Environment, Heritage and Aboriginal Affairs (DEHAA) on HYDSIS. Runoff and baseflow components can be separated from these records. Baseflow is the contribution to streamflow provided by groundwater discharge from the fractured rock aquifers.

A stream gauging station is located on Cox Creek which is located virtually in the centre of the catchment (Fig. 3), and therefore does not measure streamflow from all of the catchment. The total was estimated by extrapolating the streamflow per unit area of the smaller gauged catchment to the total area of the Piccadilly catchment.

SURFACE STORAGES

A recent study by DEHAA has calculated the volume of all farm dams in the MLR using infra-red aerial photography and a carefully derived formula. It is assumed that the dams are full at the end of winter/spring, and receive no more inflows during summer. In the Piccadilly Valley, the estimated dam volume was 58 ML.

GROUNDWATER PUMPING

Figure 3 shows the locations of all water wells in the Piccadilly Valley area. Unfortunately, very few of these bores have meters installed to measure their discharge. The main component of groundwater pumping is irrigation. The 1993 land use survey coverage on GIS (Fig. 4) updated by 1997 aerial photography, can provide a reasonably accurate estimate of the area and crop type irrigated.

Estimates of the various crop water application requirements for irrigation during summer can then allow an approximate calculation of the total volume extracted (Table 1). This irrigation component is the difference between the total plant water requirement and the amount available by evapotranspiration from rainfall and soil moisture.

In normal years, about half of the vineyards are not irrigated at all (B Croser, pers comm.) with about 13 mm applied in very dry years. To account for variations in irrigation practice, a generous 6.5 mm application has been assumed for an average year on these vineyards. The remaining 50% of the vineyards in the valley are assumed to have an average of 45 mm applied (allowing for both new and established vines), based on advice from a viticultural consultant. The total use for vineyards in Table 1 includes 6 ML consumption for processing at the Petaluma winery.

The Mount Lofty Botanic Garden irrigates 70 ha of cool temperate exotic species using three bores and a large dam which captures both rainfall runoff and excess irrigation water. Metered groundwater withdrawals average 175 ML in normal years.

Irrigation efficiencies vary greatly throughout the MLR, with some crops being 'under-irrigated' as well as 'over-irrigated'. Recirculation of excess irrigation water to the watertable may occur in areas where its depth is less than 10 -15 m.

It must be stressed that these estimates are accurate only to +/- 10 to 15 % and consequently, the withdrawal estimates in Table 1 can at best, only have a similar accuracy. Metering of irrigation and industrial users is strongly recommended to obtain accurate estimates of groundwater use.

The estimates for pumping from private wells for domestic use is based on the number of domestic wells on SA-GEODATA and the average domestic consumption from SA Water reticulation in the area. It is probably an overestimate. There may be combined borehole/dam water supplies and some field verification of actual use may be required.

GROUNDWATER RECHARGE

This is perhaps the most important component and is the most difficult to estimate. It can generally only be measured indirectly, and is variable over any given catchment because of its dependence on other variable factors such as soil type and vegetation cover. There are several methods available to estimate recharge.

a) water balance

Essentially this means calculating all other components of the balance with the outstanding quantity being attributed to recharge. A summary of these components can be seen in Figure 9. Examination of hydrographs has shown very little change in storage in average rainfall years and consequently, recharge can be calculated by :-

Recharge =
Rainfall - (ET + runoff + dam storage)

Another possible method of calculation is to look at only the groundwater component of the water balance :-

Recharge =
Groundwater pumping + baseflow

For the Piccadilly Valley using the data estimates from Table 1,

Recharge =
Rainfall - (ET & runoff + dam storage)
= 9346 - (5967 + 1985 + 58)
= **1336 ML** or **125 mm/yr (12% annual rainfall)**

By using the groundwater balance only,

Recharge =
Groundwater extraction + baseflow
= 1185 + 1760
= **2945 ML** or **277 mm/yr (26% annual rainfall)**

TABLE 1

CATCHMENT WATER BALANCE **PICCADILLY**

IRRIGATION / EXTRACTION

Crop Type/Use	*Area (ha)*	*Water Need (mm)*	*Water Use (ML)*
Vegetables	**179.2**	**400**	**717**
Orchards	**34.1**	**400**	**136**
Vineyards	**141.2**	**26 average**	**43**
Berry fruits	**5.4**	**400**	**22**
Botanic Gardens	**70**		**175**
Spring water			**50**
Domestic use			**40**
		TOTAL	***1183***

EVAPOTRANSPIRATION

Land Use	*Area (ha)*	*Water Use (mm)*	*Water Loss (ML)*
Native vegetn	**262.1**	**830**	**2175**
Pasture	**381.7**	**420**	**1603**
Winter veges	**179.2**	**600**	**1075**
Vineyards	**141.2**	**475**	**670**
Botanic Gardens	**70**	**445**	**311**
Orchards	**34.1**	**400**	**133**
		TOTAL	***5967***

STREAMFLOW

Runoff (ML)	***1985***
Baseflow (ML)	**1760**
TOTAL	***3745***

RECHARGE

Method	*Comments*	*Estimate (ML)*
Deduction	**Rainfall -(ET + runoff + damvol)**	*1336*
Deduction	**Groundwater extractn + baseflow**	**2943**
Chloride	**Comparison rainfall & groundwater**	**1190 - 1438**
Watertable rise	**Recharge volumes for various specific yields**	**2200 - 4000**
	ADOPTED VALUE	**2000**

DAM STORAGE

TOTAL ***58*** ⇒ ***TOTAL OUTFLOW*** ***9346 ML***

RAINFALL (EFFECTIVE) ***880*** mm **X** AREA ***10.62*** km^2 ⇒ ***9346 ML*** ***INFLOW*** *b) chloride balance*

The chloride ion can be used to estimate recharge provided that it is not dissolved from rocks and minerals. After rain falls, evapotranspiration processes remove water from the soil. The conservative chloride ion remains and is consequently concentrated in the reduced amount of water that eventually percolates down to recharge the groundwater. By taking into account the chloride removed by runoff, recharge can be calculated by:-

$$\text{Recharge} = (\text{annual rainfall - runoff}) \times \frac{Cl_{rf}}{Cl_{gw}}$$

where Cl_{rf} = chloride in rainfall (mg/L)
and Cl_{gw} = chloride in groundwater (mg/L)

Care must be taken when using this method for several reasons. Intensive irrigation may result in recirculation of the groundwater with further evaporative concentration of the chloride ion. Additional chloride may also be added by the application of fertilizers.

The chloride content of rainfall decreases with distance from the coast and several equations have been derived to quantify this relationship.

Hutton, 1976

$$CL = \frac{0.99}{\sqrt[4]{d}} - 0.23$$

where d = distance from coast in km
Cl = milliequivalents/litre

Kayaalp, 1998

$$Cl = 1.1 + 2.98\, e^{-d/111} \quad \text{WET}$$

where d = distance from coast in km
Cl = milligrams/litre

$$Cl = 60 + 1\,043\, e^{-d/2.7} \quad \text{DRY}$$

where d = distance from coast in km
Cl = kg/km^2/month

The chloride content of groundwater can be obtained from the Water Chemistry module of SA_GEODATA.

A total of 71 chloride values have been obtained from groundwater analyses in the Piccadilly Valley. Rainfall chloride values have been derived by using the two equations mentioned earlier, as well as actual measurements over a seven year period at Aldgate which averaged 9.0 mg/L. The resultant recharge values calculated are presented in Table 2 for each of the geological units together with the percentage of the annual rainfall.

The chloride content of groundwater in Basket Range Sandstone is almost bimodal with values averaging 100 mg/L in the northern portion of Piccadilly Valley where vegetable irrigation is still occurring, and values averaging 50 mg/L to the south where it is not (Fig. 4). The higher values have been ignored in Table 2. The recharge values show a good correlation with rock type with the highest rates associated with permeable rocks and the lowest rates with granitic gneisses of the Barossa Complex.

The values calculated by the chloride method appear to be low when compared to the other methods of calculating recharge. This probably indicates that a new chloride equilibrium has not been reached since land clearing and that the values obtained could reflect pre-clearing recharge rates.

Table 2 also shows the volume of recharge calculated using the area of each geological unit and the recharge rate. The volumes shown are derived from the measured rainfall chloride which closely approximates the Hutton values and are more consistent with recharge estimates calculated by other methods. A range of 1190 - 1438 ML is selected, which equates to 112–135 mm/year or 10–13% of rainfall.

Table 2 Chloride Recharge Estimates

GEOLOGICAL UNIT		RECHARGE mm/yr (% rainfall)			RECHARGE ML
		Kayaalp (Clrf = 4.5)	Hutton (Clrf = 8.2)	Measured (Clrf = 9.0)	Measured (Clrf = 9.0)
Basket Range Sandstone	Cl_{gw}= 56 mg/L	71 (7%)	130 (12%)	142 (13%)	745
Woolshed Flat Shale	Cl_{gw}= 54	73 (8%)	134 (13%)	147 (14%)	435
Stonyfell Quartzite	Cl_{gw}= 41.5	96 (9%)	174 (16%)	191 (18%)	180
Barossa Complex	Cl_{gw}= 152	26 (2%)	48 (4%)	52 (5%)	78 Total 1438
Whole catchment average	Cl_{gw}= 71	56 (5%)	102 (10%)	112 (10%)	1190

c) Watertable rise

This technique measures the direct effect of recharge during the winter season which leads to an increase in water stored in the aquifer. This is a reasonably straightforward method, however uncertainties are introduced because the measured watertable rise must be multiplied by the specific yield to obtain the volume of recharge which has entered the aquifer. Specific yield values are difficult to measure and are highly variable, even within the same aquifer. Calculations were made using a range of values from recognised texts, namely from a conservative 0.02 to a generous 0.10 Discharge to streams as well as groundwater withdrawals are normally recommended to be taken into account when calculating recharge using this method.
Recharge =
(Change in storage x specific yield) + discharge

Within the PIRSA observation well database OBSWELL, a facility exists which forms a grid over the network. The boundaries of the catchment can be defined, and the watertable level changes measured at each observation well are assigned to the appropriate locations on the grid. The matrix is then relaxed to average and smooth the watertable level changes over the whole catchment. Smoothing is justified because of the heterogeneous nature of fractured rock aquifers.

The observation well network in the Piccadilly Valley has provided estimates of average watertable rise at the individual well sites. Several private wells were also monitored at strategic locations around the valley catchment boundary or divide, where the rise would expected to be greatest because it is furthest from the discharge zones along the streams. Conversely, it has been assumed that along these streams, the watertable rise will be zero. Table 3 shows the outline of the catchment, the measured watertable rises in bold, the location of streams as zero values and the extrapolated watertable rises around the boundary of the catchment.

Table 3 Measured And Extrapolated Watertable Rises

---- ---- ---- 8.00 ---- ---- ---- ---- ---- ---- **8.36** 7.00 7.00 6.00 **5.00**
---- ---- ---- 8.00 8.00 8.00 **8.00** 8.00 8.00 8.00 **** **** **** **** ****
---- ---- 9.00 **** **** **4.50** **** **** **** **** **** **** **** 5.00 ----
---- ---- 9.00 **** **** **** **** **** **** **** **** **** **** **** ----
---- ---- 9.00 **** **** **** **** **** **** 0.00 **** **** **** **** ----
---- ---- 10.0 **** 0.00 **** **** **** **** 0.00 **** **1.87** **** 5.00 ----
---- ---- 10.0 **** **** 0.00 0.00 **** **** 0.00 0.00 **** **** ---- ----
---- ---- 11.0 **** **** **** **** 0.00 **** 0.00 **** **** **** ---- ----
---- ---- 11.0 **** **** **** **** **** 0.00 0.00 **** **** 5.00 ---- ----
---- ---- 11.0 **10.1** **** **** **** **** **0.33** 0.00 5.00 ---- ---- ---- ----
---- ---- 11.0 **** **** **** **** **** 0.00 0.00 **** ---- ---- ---- ----
---- 11.0 **** **** **** **** **** 0.00 **** 0.00 **** ---- ---- ---- ----
---- 11.0 **** **** **** **** 0.00 **** **** 0.00 5.00 ---- ---- ---- ----
---- 10.0 **** **** 0.00 0.00 **** **** **** 0.00 ---- ---- ---- ---- ----
---- 10.0 **** **** **** 0.00 **** **** **** 0.00 ---- ---- ---- ---- ----
---- 10.0 **** **** **5.23** 0.00 5.00 **** **** 0.00 ---- ---- ---- ---- ----
---- 9.00 **** **** **** **** ---- ---- 5.00 0.00 ---- ---- ---- ---- ----
---- 9.00 **** **** **** 7.00 ---- ---- ---- ---- ---- ---- ---- ---- ----
---- ---- 8.00 **** 7.50 ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
---- ---- ---- 8.00 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----

Table 4 Smoothed Watertable Rises

8.72	8.66	8.43	8.00	8.00	8.00	8.00	8.01	8.03	8.10	8.36	7.00	7.00	6.00	5.00
8.79	8.73	8.54	8.00	8.00	8.00	8.00	8.00	8.00	8.00	7.01	6.31	6.01	5.58	5.29
8.96	8.95	9.00	7.61	6.36	4.50	5.62	5.86	5.78	5.59	5.36	5.22	5.17	5.00	5.01
9.14	9.11	9.00	7.07	5.32	4.21	4.13	4.02	3.69	3.23	3.63	4.05	4.44	4.69	4.76
9.40	9.33	9.00	6.36	3.64	2.88	2.66	2.40	1.73	0.00	1.87	2.91	3.86	4.55	4.65
9.81	9.82	10.0	5.73	0.00	1.03	1.22	1.20	0.81	0.00	0.93	1.87	3.53	5.00	4.75
10.2	10.2	10.0	6.56	2.80	0.00	0.00	0.38	0.32	0.00	0.00	1.97	3.38	4.22	4.36
10.6	10.6	11.0	7.71	4.64	2.28	1.03	0.00	0.08	0.00	1.27	2.65	3.80	4.16	4.23
10.8	10.8	11.0	8.65	5.78	3.44	1.83	0.70	0.00	0.00	2.45	3.54	5.00	4.38	4.26
10.9	10.9	11.0	10.1	6.38	3.88	2.14	0.97	0.33	0.00	5.00	4.05	4.21	4.09	4.04
10.9	11.0	11.0	8.49	5.76	3.55	1.89	0.71	0.00	0.00	2.81	3.46	3.70	3.74	3.73
10.9	11.0	9.39	7.08	4.62	2.68	1.14	0.00	0.06	0.00	2.77	3.29	3.40	3.42	3.42
10.8	11.0	8.49	5.82	2.96	1.41	0.00	0.26	0.22	0.00	5.00	3.52	3.19	3.12	3.11
10.2	10.0	7.76	4.75	0.00	0.00	0.68	0.84	0.57	0.00	2.23	2.61	2.71	2.76	2.77
10.0	10.0	7.81	5.41	2.66	0.00	1.88	1.84	1.20	0.00	1.31	1.97	2.28	2.43	2.47
9.80	10.0	8.06	6.41	5.23	0.00	5.00	3.44	2.41	0.00	1.03	1.68	2.03	2.20	2.25
9.19	9.00	8.03	6.94	5.89	4.44	4.87	4.50	5.00	0.00	1.15	1.68	1.95	2.09	2.13
8.95	9.00	8.12	7.44	6.96	7.00	5.55	4.67	3.92	2.16	1.90	1.94	2.01	2.07	2.09
8.62	8.51	8.00	7.73	7.50	6.69	5.66	4.73	3.83	2.83	2.34	2.15	2.10	2.09	2.09
8.51	8.41	8.10	8.00	7.40	6.62	5.67	4.74	3.85	3.00	2.48	2.23	2.13	2.10	2.10

Change in storage = 4402 ML, 436 mm rainfall equiv. Sy=0.1000 Area= 1010 ha.

Table 5 Watertable Rise Recharge Estimates

SPECIFIC YIELD	VOLUME (ML)	MM/YR	% RAINFALL
Recharge + Discharge			
0.10	7340	691	64
0.05	5138	484	45
0.02	3818	360	34
Recharge			
0.10	4402	436	41
0.05	2200	207	20
0.02	880	83	8

Table 4 shows the smoothed watertable rises and the calculated change in storage and recharge for a given value of specific yield.

As stated previously, estimates of discharge (groundwater pumping + baseflow), should normally be added to the calculated recharge and therefore, for a specific yield of 0.05,

Recharge = 2200 + 2945
= 5145 ML (45% rainfall)

This value is quite large and therefore, Table 5 shows the calculated recharge for the range of specific yield values with, and also without the discharge added, because the highly seasonal nature of winter recharge and summer discharge could mean that the observed watertable rise is in fact, truly indicative of the recharge.

It is interesting to note that recharge rates similar to the water balance method are associated with values of specific yield normally attributed to fractured rock aquifers ie 0.02 (including discharge) and 0.05 (ignoring discharge). It is therefore proposed to accept a range of 2200 - 4000 ML (207–377 mm/yr) for recharge using this method.

(d) Discussion

The three different methods of estimating recharge obtained different ranges of values, although most were of the same order of magnitude.

Table 6 Ranges of calculated recharge

METHOD	MM/YEAR	ML
Water balance	125 - 277	1336 - 2945
Chloride	112 - 135	1190 - 1438
Watertable rise	207 - 377	2200 - 4000

An earlier water balance study in the Lenswood Creek catchment (Leonard, Argue and Waterhouse, 1981) deduced a recharge rate of 335 mm/yr which was calculated using less accurate information than is available today and lies at the upper end of the scale for Piccadilly Valley.

The water balance estimate of 1336 ML is considered conservative because of the assumptions made in the calculation, namely :

- the November-March rainfall does not contribute to the water balance
- the area attributed to vegetables is fully utilised in both summer and winter.

The chloride estimate is also considered conservative because of the possibility that a new chloride equilibrium has not been reached since land clearing and that the values obtained could reflect pre-clearing recharge rates.

It is therefore proposed to accept a value of 2000 ML for the annual recharge (190 mm/year), which is just below the average of all the estimates. This represents almost 20% of the annual rainfall which is not unreasonable for a high rainfall area lying 500 m above sea level.

SUMMARY

An annual recharge of 2000 ML has been determined for the Piccadilly Valley which constitutes almost 20% of annual rainfall. Current usage represents just under 60% of the estimated annual recharge.

SUSTAINABLE YIELD

Normally, the concept of the sustainable yield of an aquifer is to ensure that the long term rate of withdrawal should be equal to, or not exceed, the average annual recharge. This would result in no net change in the volume of groundwater stored in the aquifer and consequently, no net change in groundwater levels.

In the fractured rock aquifers of the MLR, groundwater levels fluctuate seasonally. During summer, the watertable falls due to pumping, evapotranspiration and discharge to streams. In winter, recharge from rainfall occurs, with the watertable rising as the aquifer storage fills up. The excess groundwater 'overflows' and discharges to the streams as baseflow.

During years of drought or below-average rainfall, the reduced rate of recharge may not keep pace with the increased pumping and the discharge to streams. Watertables may then fall several metres as groundwater is used from the huge amount of storage within the aquifer which contains groundwater in fractures down to depths of at least 100 m. A return to normal rainfall will rapidly fill the empty storage volume and return the watertable to its normal level.

A complicating factor in the sustainable yield concept outlined above, is the increasing awareness of the requirement for maintaining flows in streams for environmental purposes. Even though groundwater withdrawals may be well below the sustainable yield, any increase may reduce baseflow with a consequent reduction in streamflow. A recent study (Hatton and Evans, 1998), found a low level of understanding of these processes and concluded that the relationships between groundwater pumping, baseflow and the minimum streamflow required for environmental purposes are important questions to be resolved.

In the Piccadilly Valley, there has not been a noticeable increase in baseflow due to the 50% decrease in pumping since 1970.

For the purposes of this study, it is proposed that the sustainable yield not exceed 75% of the estimated recharge. Therefore, volumes are presented at 50% (a minimum estimate) and 75% of recharge (a maximum) in Table 7.

Table 7 Estimates Of Sustainable Yield (ML)

CURRENT USE	50% RECHARGE	75% RECHARGE
1185	1000	1500

Assuming an estimated recharge of 2000 ML, the recommended sustainable yield in the Piccadilly Valley is therefore 1500 ML. This recommended sustainable yield represents an increase of approximately 300 ML over current use, which if developed, may have local impacts on groundwater levels on neighbouring properties.

In addition to the sustainable yield based on annual recharge, there are large volumes of groundwater stored in joints and fractures down to at least 100 m below ground level. Using conservative values of 75 m for the thickness of the fractured rock aquifer, and 0.02 for the specific yield, the total volume in storage is approximately 20 000 ML, which is about ten times the annual recharge.

GROUNDWATER USE

It is important to examine the current groundwater status in any catchment in the context of its previous history. This means examining where possible, the historical groundwater development and use. Table 1 details the irrigated crop types and areas as well as other groundwater users based on recent land use surveys. Inspection of aerial photographs has allowed an estimate of historical land and water use as shown in Table 8.

Table 8 Historical Land And Water Use

Crop	Area (ha)			
	1970	1987	1993	1997
Vegetables	400	275	209	179
Orchards	48	40	42	34
Vineyards	-	22	84	141
Use (ML)	1790	1260	1118	893

The table shows an interesting trend of a change in land use from vegetables to vineyards with a corresponding decrease in groundwater extraction by just over 50% since 1970. This decrease reflects the lower water requirement of vines and the more efficient methods used to irrigate them. The areas no longer used for vegetable irrigation are underlain by the Woolshed Flat Shale and is probably a response to supply and/or water quality problems in addition to economic considerations.

Obviously, the water balance needs to be revised at regular intervals to take into account such changes in land use and irrigation practices. In the early 1970s, it appeared that pumping exceeded the current estimate of sustainable yield of 1500 ML. In the absence of any monitoring at the time, there was no evidence of aquifer depletion.

Recent concerns about the sustainability of the resource have centred on the spring water industry which has expanded over recent years in response to market demand. It is instructive to examine the quantities used by the various industries in the Piccadilly Valley, and the economic return generated by them (Table 9).

Table 9 Economic Benefits Of Water Use

INDUSTRY	QUANTITY PUMPED (ML)	ECONOMIC RETURN ($million)	SIDE EFFECTS
Vegetable	717	10-15	Nutrient loss
Spring water	50	10-15	Heavy trucks
Vineyards	43	3	Low impact

GROUNDWATER LEVEL TRENDS

A network of some eleven observation wells have been monitored since 1979. Figure 10 shows the water levels averaged over the whole network. Also plotted is the cumulative deviation of the mean annual rainfall. This graph measures the difference between the actual measured rainfall and the average rainfall on an annual basis. An upward trend in this line indicates above average rainfall, and conversely, a downward trend indicates below average rainfall.

The important trend evident from Figure 10 is that the groundwater level closely follows the rainfall deviation which confirms the strong relationship between groundwater levels and rainfall. There is no evidence of declining water levels due to overpumping of the resource in a regional context.

Concerns were expressed about falling water levels at the end of the summer of 1995. This was not caused by overpumping, but by the fact that both 1994 and 1995 had well below average rainfall as shown in Figure 11 which depicts the rainfall cumulative deviation since 1880 for the Bridgewater rainfall station. Sharp declines in the graph indicate dry years which are labelled with how much the actual rainfall fell short of the average. The occurrence of dry years has increased in frequency since 1958 to every ten years or so. In comparison to previous years, the 1994-95 event was the most severe.

Little can be done to safeguard against such dry spells, except to deepen pumps, ensure that water is used efficiently, and in extreme cases, to deepen wells. When average rainfall resumes, water levels would be expected to recover to normal levels.

GROUNDWATER QUALITY TRENDS

A salinity monitoring network was also established in 1979 but readings were discontinued after several years. Occasional samples taken in recent years have shown no rising trend for those particular bores. Edwards (1979) sampled some 50 wells in both urban and irrigation areas for nitrate and found ten above 20 mg/L and only two above 45 mg/L.

A summary of the intensive groundwater sampling program carried out by AGSO in 1994 (Ivkovic *et al,* 1998) is presented in Appendix A1. Forty two bores were sampled for major ions, heavy metals, isotopes, pesticides and bacteria in a major baseline study. This program showed the overall groundwater quality to be quite good, with only very few bores exceeding drinking water guidelines. Lack of previous extensive sampling precluded any examination of trends, with the exception of nitrate which showed minor increases from human sources (fertilisers, septic tanks) since the 1979 survey. Some of the bores sampled by AGSO could form the basis of a groundwater quality monitoring network throughout the Onkaparinga Catchment.

Examination of historical salinities from SA-GEODATA found only few bores with multiple records over a significant period. Most were sampled over a 5 - 10 year period and showed both increases and decreases within natural variations. These variations of up to 100 mg/L appear more significant than usual when the normal salinity is below 500 mg/L. Apart from the normal salinity monitoring network, additional wells were sampled in early 1998 to verify or otherwise, a possible rising trend. Only one (ONK 5), has shown a consistent rising trend since 1969, and that is of only 2 mg/L per year.

Figure 8 shows that, even though almost all salinities are below 500 mg/L, the higher range of 250 - 500 mg/L occurs mostly beneath those areas currently irrigated for vegetables as well as those areas previously irrigated. This could indicate a small degree of recirculation of the groundwater causing evaporative concentration of the chloride ion. Additional chloride may also be added by the application of fertilizers.

There also appears to be a trend for higher salinities beneath the urban area of Piccadilly.

CONCLUSIONS AND RECOMMENDATIONS

A water balance study of the Piccadilly Valley has indicated that almost 20% of annual rainfall amounting to 2000 ML recharges the fractured rock aquifers. The current usage of about 1200 ML represents just under 60% of the annual recharge recharges the fractured rock aquifers.
Concerns about the effects of the spring water industry on the water resource are unfounded as it extracts only about 7% of the quantity pumped for the irrigation of vegetables, yet generates a similar economic return. Total pumping in the area has decreased by just over 50% since 1970, due to the reduction in the area of vegetable irrigation and the change in land use to vineyards.

The water balance needs to be revised at regular intervals to take into account such changes in land use and irrigation practices.

The Basket Range Sandstone is the most productive aquifer with yields of up to 20 litres/sec. All rock units have low salinities mostly below 500 mg/L and show a trend of increasing salinity with depth. Since monitoring began in 1979, groundwater levels have been strongly controlled by rainfall and show no evidence of overwithdrawal. Falling water levels in early 1995 were caused by one of the driest spells on record during 1993-94, not overpumping.

Salinity monitoring has not been consistent and consequently, no trends are evident. However, higher salinities are observed beneath irrigated areas. Extensive sampling by AGSO has shown general groundwater quality to be very good, with only very few bores not meeting drinking water guidelines. Some of the bores sampled by AGSO could form the basis of a groundwater quality monitoring network throughout the Onkaparinga Catchment.

Because of uncertainties over the effect of groundwater pumping on environmental baseflows, it is recommended that the sustainable yield be limited to a maximum of 75% of recharge, which in the Piccadilly Valley, amounts to 1500 ML. This represents an increase of approximately 300 ML over current use, which if developed, may have only local impacts on groundwater levels.

The effect of groundwater pumping on baseflows which could have environmental significance, needs to be investigated with some urgency. Regular water level and salinity monitoring should continue and the metering of all irrigation and industrial supplies should be carried out to allow accurate estimates of water use. Efforts should be made to increase irrigation efficiencies, especially for vegetable irrigation.

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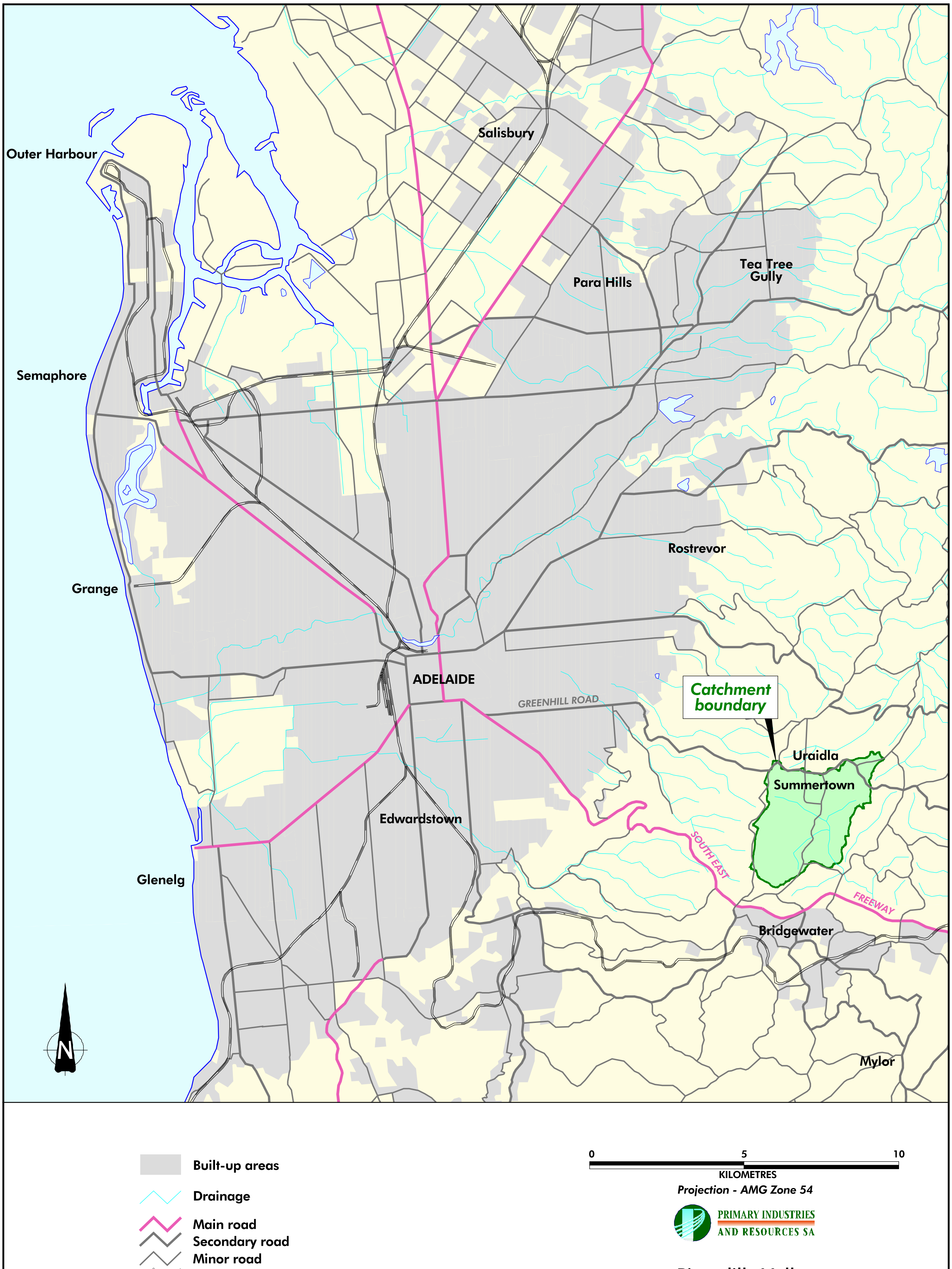


Projection - AMG Zone 54

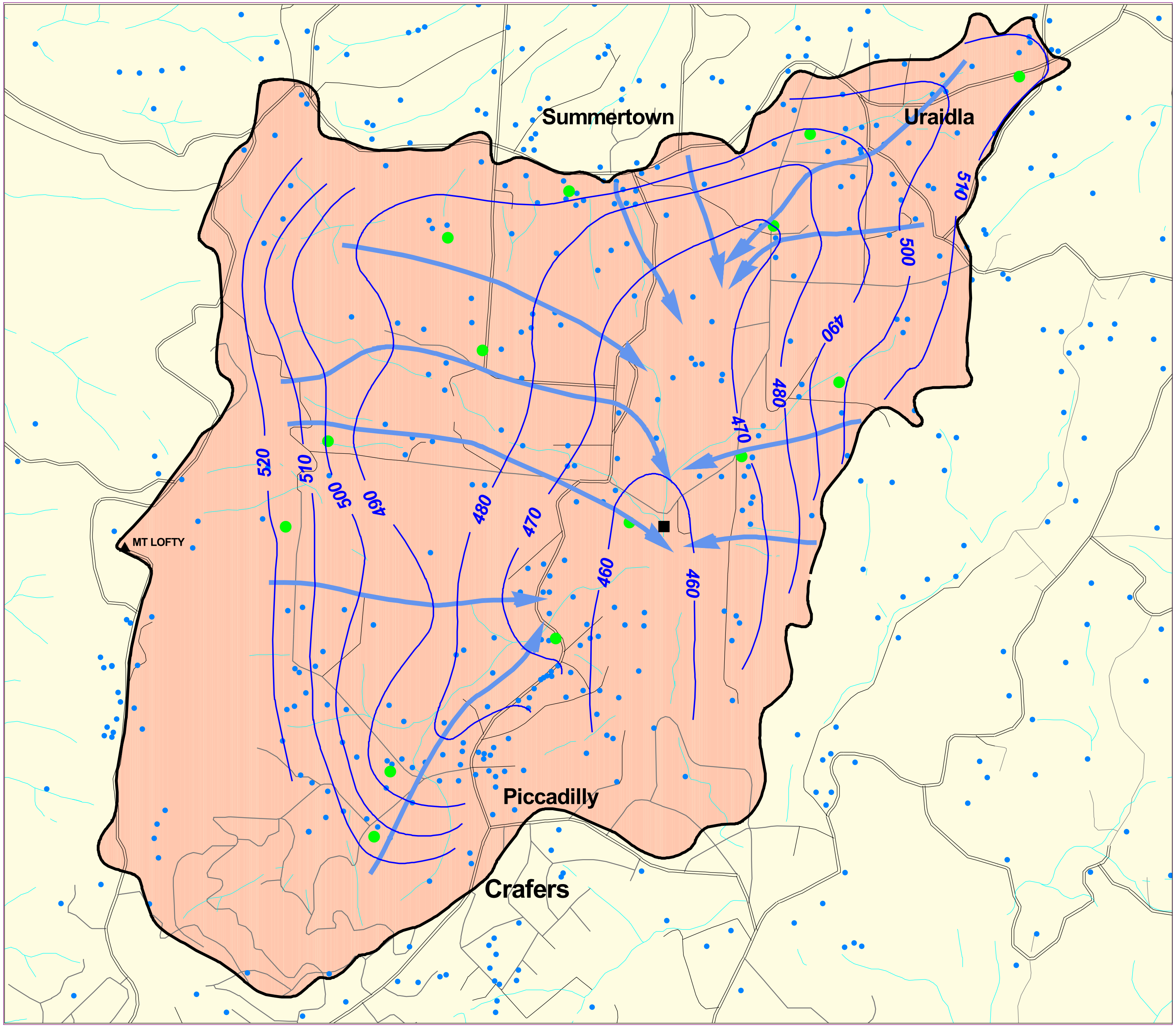
PRIMARY INDUSTRIES AND RESOURCES SA

Piccadilly Valley

LOCALITY PLAN

AV3:101071SB.APR:98-1038

Figure 1



LOCALITY PLAN

N

Catchment area

Watertable contours (m-AHD)

Direction of groundwater flow

Observation well location

Water well location

Stream gauging station

Main road

PRIMARY INDUSTRIES AND RESOURCES SA

0 200 400 600 800 Meters

Projection - AMG Zone 54

Piccadilly Valley

WATER WELL LOCATIONS and approximate WATER TABLE CONTOURS

AV3 : 101071A.APR : 98-0128

Figure 2

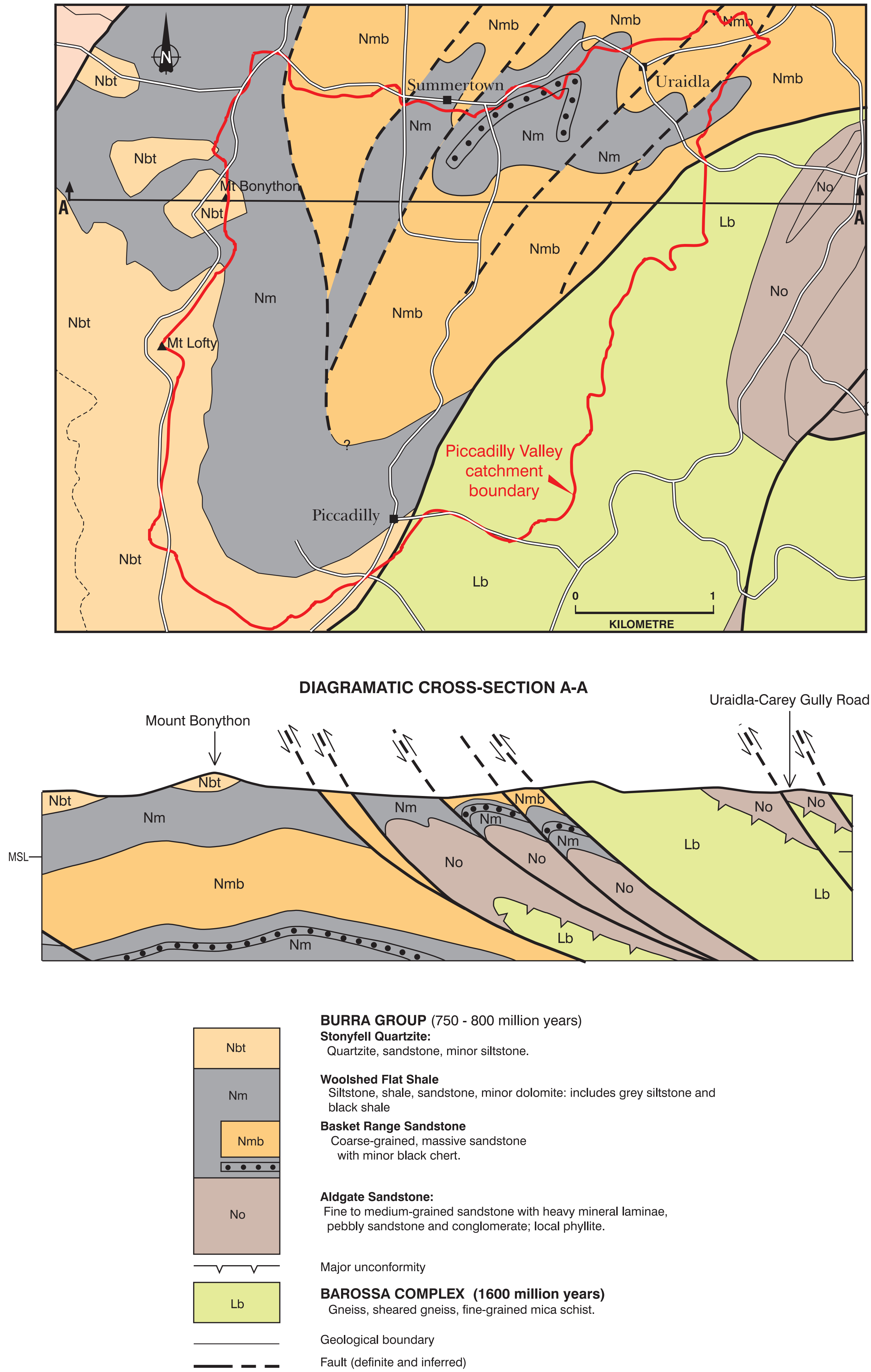


Figure 2

98-0127

PICCADILLY VALLEY
Aquifer Salinities

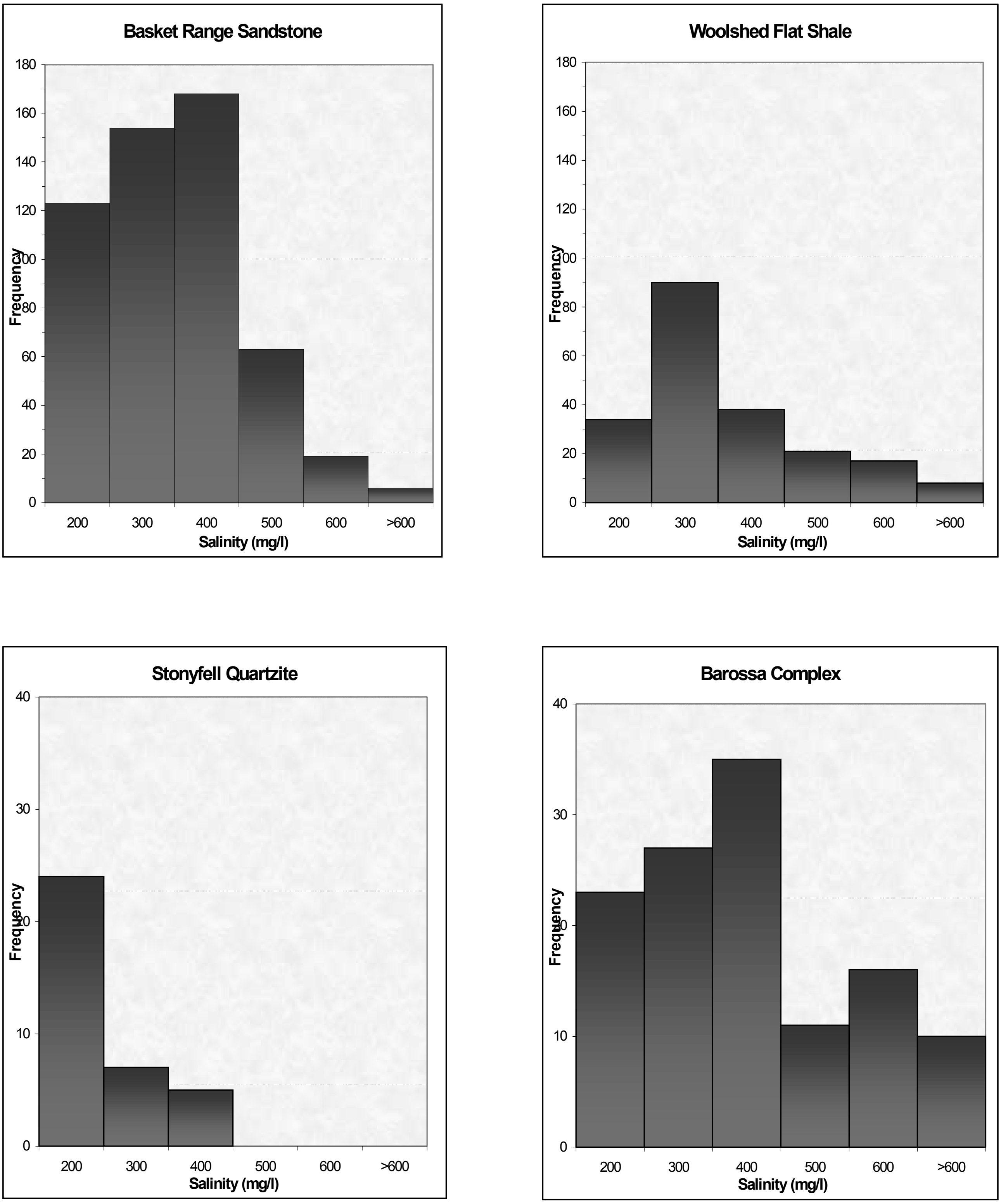


Figure 4 *Aquifer salinities*

PICCADILLY VALLEY
Aquifer Salinity vs Depth Profiles

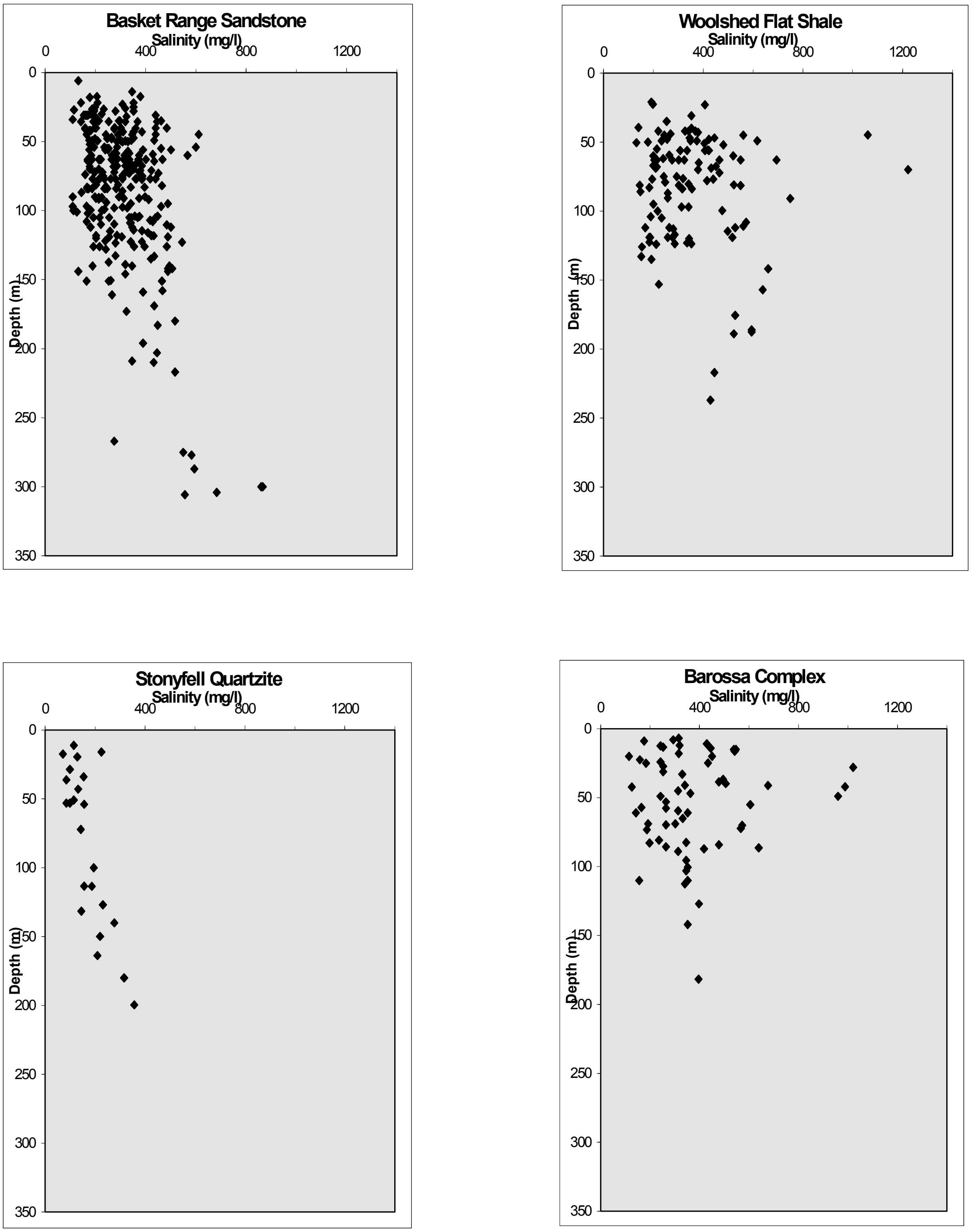


Figure 5 *Aquifer salinity vs depth profiles*

PICCADILLY VALLEY
Aquifer Yields

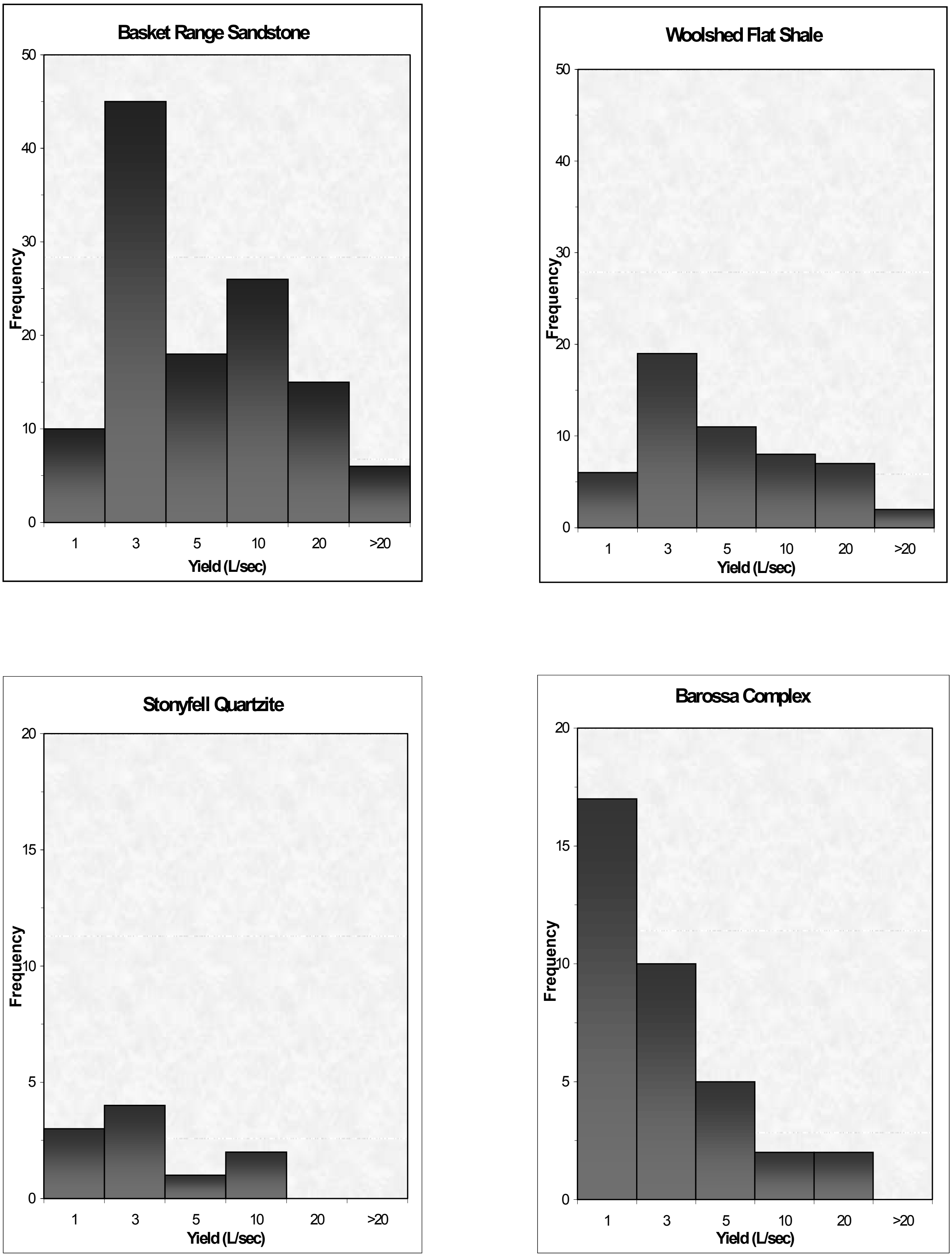


Figure 6 *Aquifer yields*

PICCADILLY VALLEY

Aquifer Yield vs Depth Profile

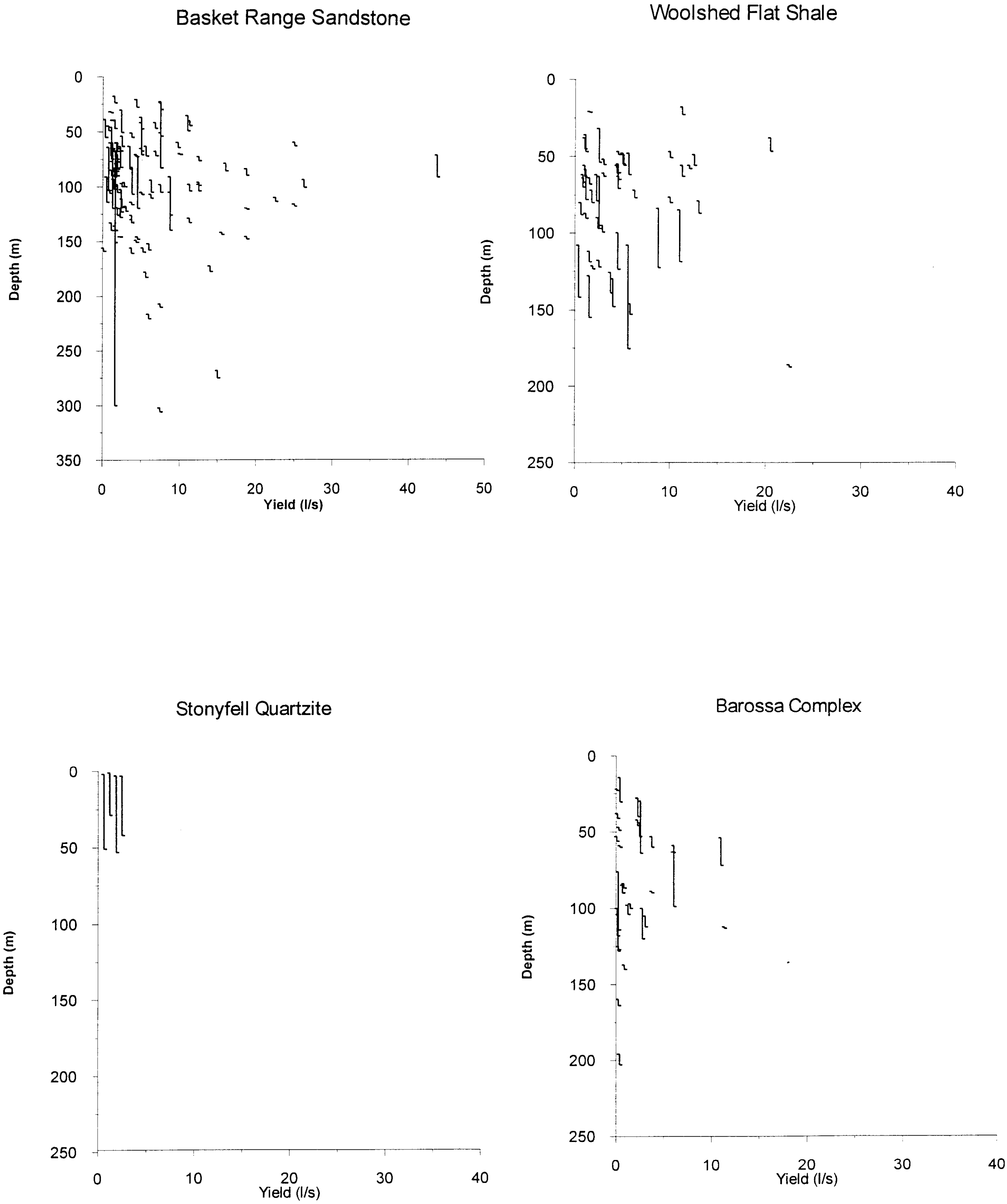
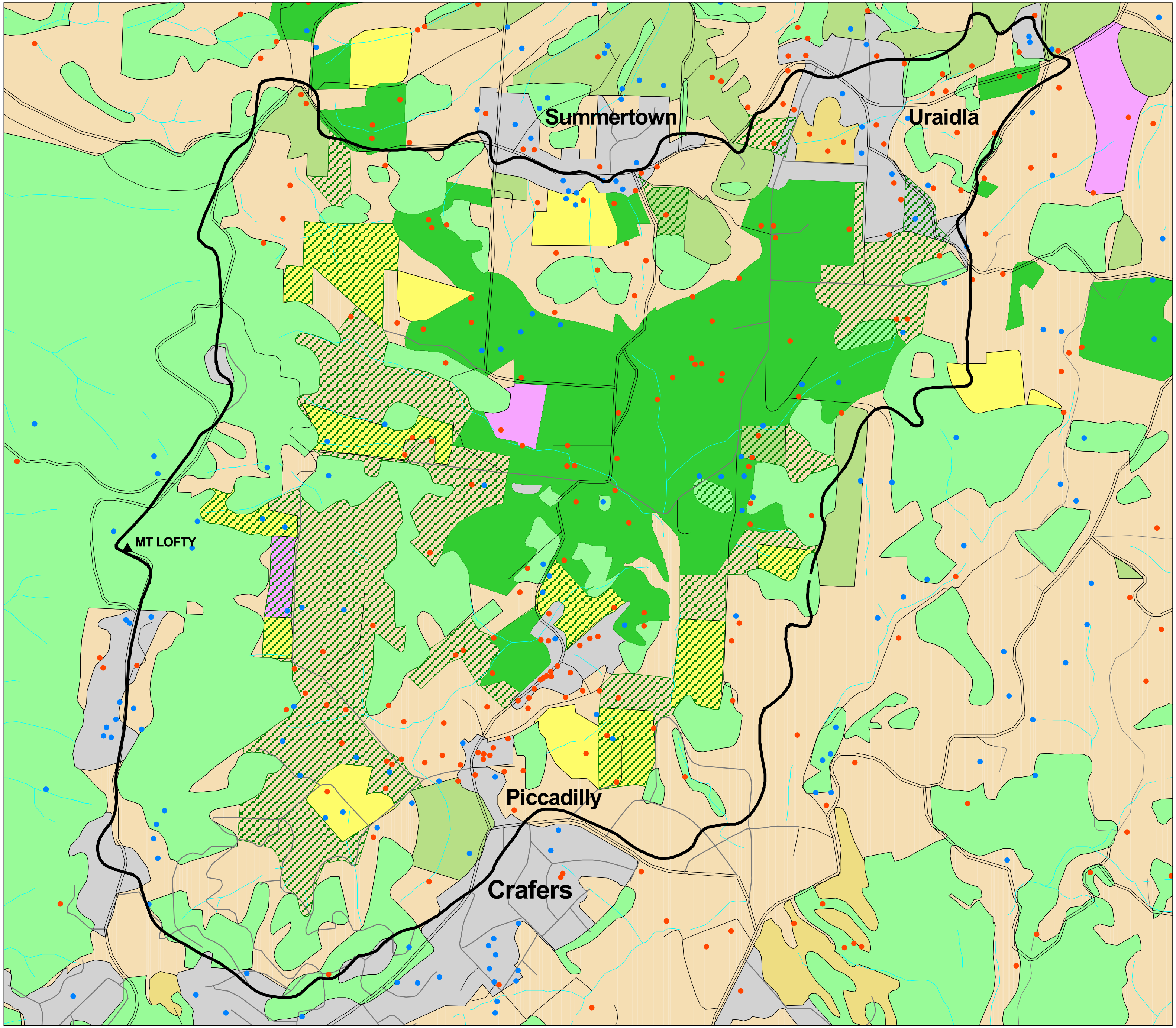


Figure 7 Aquifer yield vs depth profiles



LOCALITY PLAN

Catchment boundary

LAND USE CATEGORIES
- Berry
- Grazing
- Intensive vegetables
- Orchard
- Urban
- Vegetation
- Vineyard
- Other
- 1970 intense vegetables

SALINITY (mg/L)
- Less than 250
- Greater than 250

Main road

PRIMARY INDUSTRIES AND RESOURCES SA

0 200 400 600 800 Meters

Projection - AMG Zone 54

Piccadilly Valley

1993 LAND USE and GROUNDWATER SALINTIY

AV3 : 101071A.APR : 98-0129

Figure 8

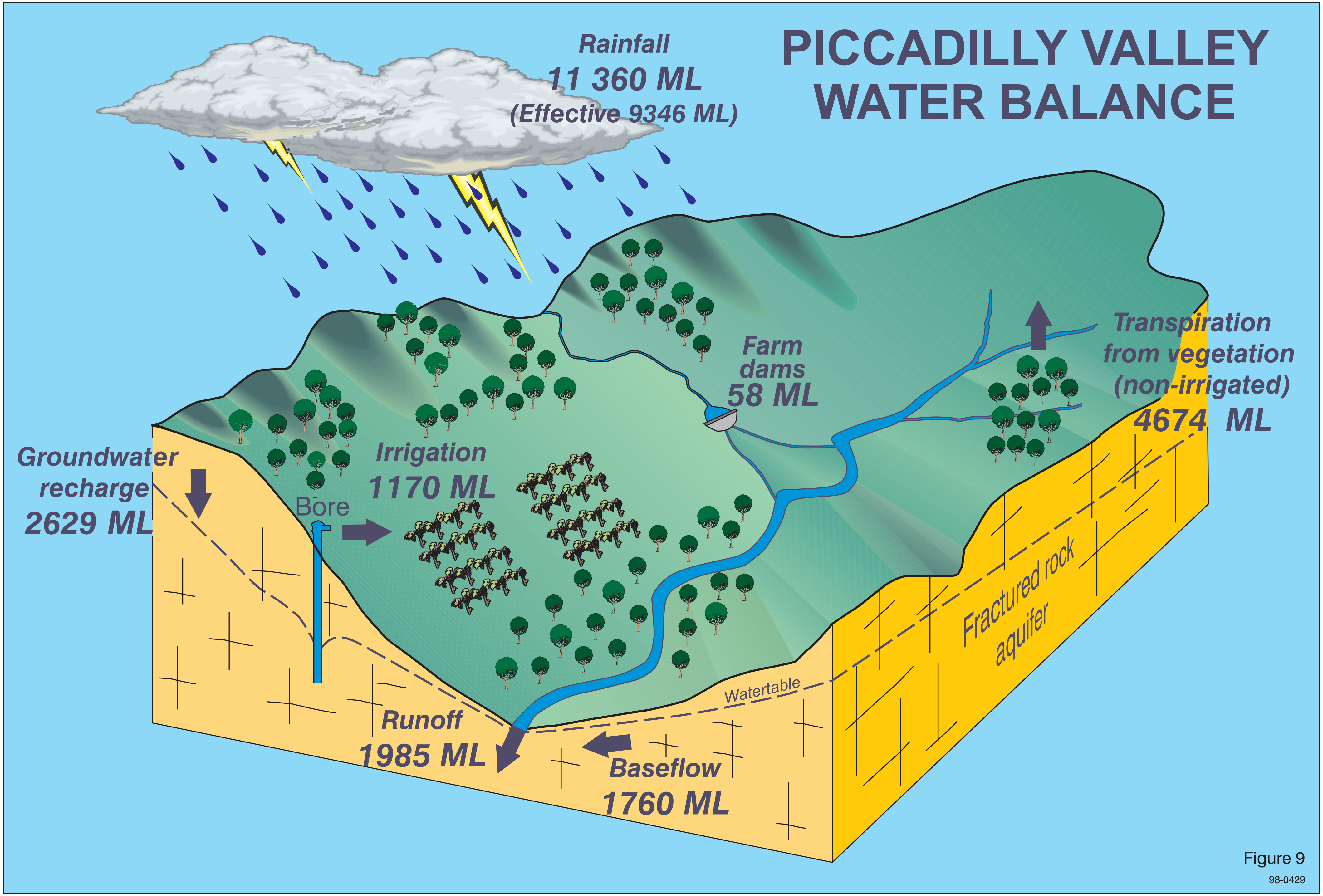


Figure 9

98-0429

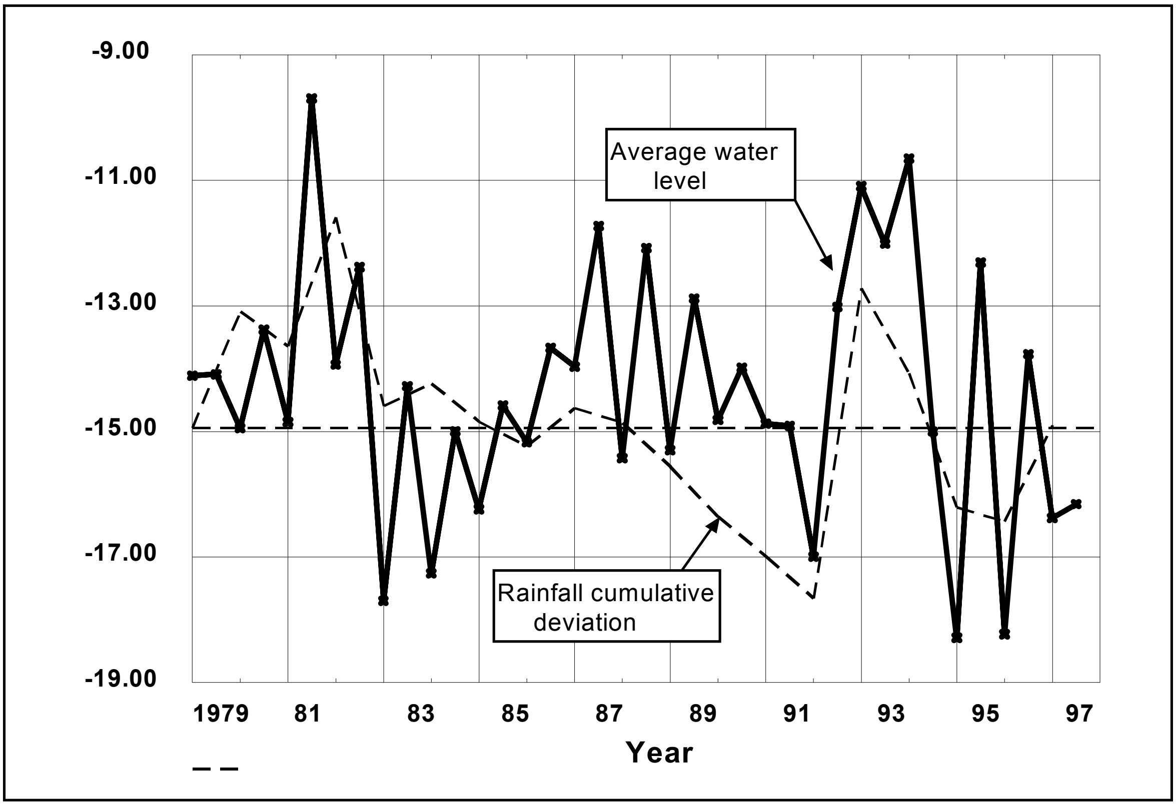


Figure 10 *Averaged Water Levels And Rainfall Deviation*

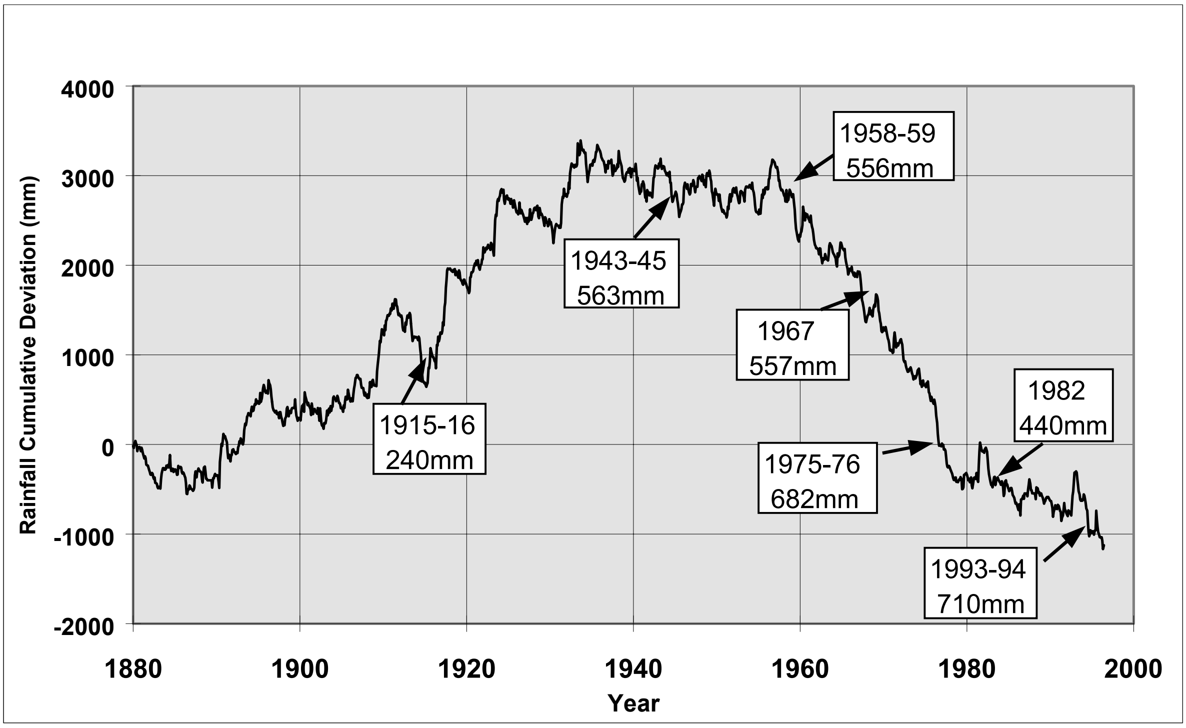


Figure 11 *Bridgewater rainfall station - cumulative deviation*

APPENDIX A1

SUMMARY OF AGSO GROUNDWATER SAMPLING - 1994

INTRODUCTION

The Australian Geological Survey sampled 42 bores in the Piccadilly Valley in April-May 1994. The groundwater samples were analysed for physical characteristics, major and minor inorganic chemical constituents, some stable and radioactive isotopes, nutrients, pesticides and indigenous and contaminant micro - organisms.

INORGANIC CHEMISTRY

The following table contains the minimum and median values found in the bore samples for some of the inorganic chemical constituents and physical characteristics analysed, as well as an indication of how many bores exceed the Draft 1995 NH&MRC/ARMCANZ Australian Drinking Water Guidelines.

Constituent	Guideline Value	# of Bores Exceeding	Minimum	Maximum	Median
TDS (mg/L)	500*	6	86	718	359
pH	6.5-8.5*	15	4.74	7.77	6.77
Aluminium(mg/L)	**0.2**	**1**	**<0.005**	**0.236**	**<0.005**
Arsenic (μg/L)	7	0	<0.02	4.2	0.2
Boron (mg/L)	0.3	0	0.018	0.141	0.037
Cadmium (μg/L)	2	0	<0.5	<0.5	<0.5
Calcium (mg/L)	n/a	0	0.62	1.034	0.047
Chloride (mg/L)	250*	0	37.3	246	59.35
Copper (mg/L)	1	0	<0.005	0.116	<0.005
Fluoride (mg/L)	1.5	0	<0.05	0.94	0.37
Iodide (mg/L)	**0.1**	**1**	**<0.05**	**0.16**	**0.03**
Iron(mg/L)	0.3*	25	0.01	14.46	0.509
Lead (μg/L)	10	0	<1	6	0.5
Magnesium (mg/L)	n/a	0	2.7	52.9	18.6
Manganese (mg/)	**0.5**	**3**	**<0.005**	**1.34**	**0.047**
Mercury (μg/L)	1	0	<0.1	<0.1	<0.1
Nickel (μg/L)	**20**	**1**	**<0.1**	**23**	**<0.1**
Nitrate-N (mg/L)	**11.3**	**1**	**<0.001**	**15.0**	**0.665**
Selenium (μg/L)	10	0	<0.1	4.2	0.5
Sodium (mg/L)	180*	0	24.2	153	45.65
Sulphate (mg/L)	500	0	4.57	194	13.4
Uranium (μg/L)	20	0	<0.1	1.4	0.1
Zinc (mg/L)	3*	0	<0.005	0.924	0.043

* *Aesthetic rather than health guideline* n/a *Not applicable*

The following elements exceeded the Draft 1995 NH&MRC/ARMCANZ drinking water guideline values:

Aluminium: Aluminium is not essential to humans and has been associated with Alzheimer's disease (ANZECC,1992). For this reason the Draft 1995 NH&MRC/ARMCANZ drinking water guideline value has been set at 0.2 mg/L.

Nickel: Nickel is now recognised as an essential trace element for man. Its oral toxicity is very low as it does not accumulate in tissues and is rapidly eliminated from the body. Long term exposure to nickel may result in toxic effects to the kidney and may be carcinogenic.

Manganese: The health-based guideline value of 0.5 mg/L for manganese in drinking water has been derived assuming that 10 mg/day is the amount of manganese that can be safely consumed from all sources. In one case involving human consumption of well water with a manganese concentration of about 14 mg/L, symptoms included lethargy, muscle tremors and mental disturbances; however, as concentrations of other metals were also high, the reported effects may not be due solely to manganese.

Iodide: Prisoners drinking water containing up to 1 mg/L iodine for five years showed no signs of iodism or hypothyroidism, but some changes in uptake of iodine by the thyroid gland were observed (Draft 1994 NH&MRC/ARMCANZ guidelines).

Nitrate: Nitrate is perhaps the most widespread contaminant within groundwater and is formed through the oxidation of nitrite. Elevated nitrate concentrations may occur naturally or arise as a result of livestock wastes, septic tanks and the application of nitrogenous fertilisers. The toxicity of nitrate to humans is mainly due to its reduction to nitrite (which may contribute to methaemoglobin formation). Nitrate may be also be converted to nitrosamines, suspected carcinogens, in the human digestive tract. Adults and children over 3 months of age can drink water with up to 100 mg/L nitrate (22.6 mg/L nitrate-N) (Draft 1995 NH&MRC / ARMCANZ).

PESTICIDES

All groundwater samples were analysed by GC-MS and HPLC for 115 compounds. Of the 42 bores, 26 were also analysed by GC-MS for an extra ten compounds.

Two bores were found to be contaminated with pesticides. One was found to contain the triazine herbicide atrazine (0.02 µg/L) and one of its degradation products desethylatrazine (0.03 µg/L). The other positive sample contained the fungicide vinclozolin, at 0.02 µg/L.

The draft 1997 NH&MRC Australian Drinking Water Guidelines state that pesticides should not be detected in drinking water. The level of atrazine found is well below that at which atrazine is considered to be of a health concern (20 µg/L). There are no specific health guideline values for the fungicide vinclozolin.

FAECAL INDICATOR BACTERIA

Faecal indicator bacteria were detected in eight of the 42 bores sampled (ie ca 20%).

Four samples contained Faecal Coliforms [FC] (range 1-196 CFU/100 ml). Of these four samples, three also contained Faecal Enterococci [FE] (range 1-120 CFU/100 ml) .

Three samples contained FE but no FC. While the Draft 1994 NH&MRC Australian Drinking Water Guidelines refer to FC to determine microbiological water quality (FC should be undetectable in 100 ml of sample), the presence of FE is also evidence of faecal contamination.

One sample which contained both FC and FE, also contained *Clostridium perfringens* spores, consistent with the possibility that faecal contamination might have been occurring for some time.