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THE HYDROGEOLOGY OF THE ANGAS-BREMER IRRIGATION AREA

ABSTRACT

Underground water resources in the Angas-Bremer irrigation area have been used to irrigate lucerne pasture since the late 1950's. Falling water levels and rising salinities in the main aquifer, a Tertiary limestone, prompted local farmers to form an irrigation association, and they approached the Department of Mines for advice in 1961. Investigations of the hydrogeology of the area have been carried out since 1967.

The aquifer from which supplies are obtained is confined over most of the area, and is recharged by the ephemeral, and often brackish, Bremer and Angas Rivers. Groundwater quality in the irrigation area is rarely better than 1 500 mg/l and rises to more than 6 000 mg/l within a few kilometres of the rivers.

Water balance studies have shown that an overlying unconfined aquifer contributes by downward leakage 52% of the estimated 25 000 megalitres/year extracted from the confined aquifer. This is made possible by the lack of effective confining beds between the two aquifers in the southern part of the area. The remaining withdrawals from the confined aquifer are balanced by natural recharge from the rivers in the north and north-west (22%), lateral flow of saline groundwater (14%), and induced recharge from the aquifer beneath Lake Alexandrina (12%). Changes in storage are not occurring from year to year in the confined aquifer except in response to changes in irrigation demand caused by variations in annual rainfall. There is no transport of salt out of the groundwater system, because of the permanent cones of depression in both aquifers.

The main problem facing water users is an inevitable salinity increase, caused by leakage of relatively saline water from the unconfined aquifer, and lateral inflow of saline groundwater from adjacent areas.

Using a model which assumes perfect mixing, the confined aquifer salinity is estimated to be increasing at an approximate annual rate of 40 mg/l. Much greater rates of salinity increase have been observed in practice, but problems of well construction make most sampling unreliable for quantitative assessment of aquifer salinity changes.

Remedial action to overcome salinity increases is needed, but may itself cause the problem of a rising water table.

There are several strategies which could be adopted for management of the groundwater resources. To maintain the present irrigated area reticulation of supplementary surface water would be necessary, either from Lake Alexandrina or the Murray Bridge-Onkaparinga pipeline. This water could supply an artificial recharge scheme or be used for direct irrigation. Alternatively the area under irrigation could be reduced so that withdrawals did not exceed river recharge. In any case artificial drainage may be required to prevent a rise in water table.

Future work will be carried out in conjunction with the Water Resources Branch of the Engineering and Water Supply Department to help formulate management strategies for the water resources.

INTRODUCTION

A study of the hydrogeology of the Angas-Bremer irrigation area (Figure 1) began in 1967, in response to requests from local landholders who were concerned about falling water levels and rising water salinities. Continuing local interest and support have been a feature of the investigations.

Groundwater is the main source of irrigation supplies used mainly for about 2 400 hectares (Plate 1) of locally grown lucerne and pasture grasses; it is also used in dry years to supplement river flood irrigation for the vineyards near Langhorne Creek.

A summary report (Waterhouse, 1977) has already been prepared, omitting technical details but presenting the results discussed here.

This report marks the end of the phase of general Department of Mines investigations and the beginning of co-ordinated studies by several departments which will hopefully lead to a management policy, and give local landowners a clear indication of their futures as irrigators.

DESCRIPTION OF AREA

The irrigation area occupies about 200 km² of a southerly sloping plain, with a few northwesterly trending sand dunes, usually less than 5 metres high. It is bounded to the north by the Mount Lofty Ranges, and by Lake Alexandrina to the south (Figure 1). To the east and west the groundwater is saline and agriculture is limited to dry farming, except where water from the lake is used for pasture irrigation.

Two rivers, the Angas and Bremer, traverse the area and discharge into Lake Alexandrina. Both flow in most winter months, and occasionally in the summer, in response to rainfall in their catchments in the Mount Lofty Ranges. Prior to settlement the River Angas discharged into swampy floodplain areas, but later a channel was dug to allow it to flow directly into Lake Alexandrina. The Bremer River has a larger flow than the Angas and has a natural channel to the lake.

There are two small towns in the area, Langhorne Creek and Milang, each with a population of about 150.

The area has been cleared of most natural vegetation, except for some dune areas, occasional swamps, and fine stands of river red gums especially near the Bremer River at Langhorne Creek.

GEOLOGY

General

The Angas-Bremer irrigation area occupies part of the western extremity of the Murray Basin (Figure 2), which has been described in numerous publications (e.g. Lawrence, 1975; Ludbrook, 1961; O'Driscoll, 1960). Most of the basin is shallow (less than 300 metres) with Tertiary sediments resting on Cambrian or pre-Cambrian basement (Thornton, 1974), and this is the case in the study area.

Several investigation holes have been drilled through the full sedimentary sequence to basement, which occurs at depths of 100-125 metres through most of the area, shallowing only near the northwest margin (Figure 3). The first stratigraphic well was examined micropalaeontologically (Lindsay and Kim, 1971) and work on the subsequent wells will follow in due course.

The area has been mapped at a scale of 1:63 360 and 1:250 000 (McGarry, 1958; Horwitz and Thomson, 1960; Thomson and Horwitz, 1962).

A vacation student, Peter Hansen, mapped the northern margin area in detail (Hansen, 1972); his work forms the basis of the geological map (Figure 4). Importantly it shows that the Tertiary outcrops north of the irrigation area are isolated, and are not potential recharge zones.

Stratigraphy is summarized in Table 1 (overleaf), and a more detailed description of the geology and geological history of the area in Appendix 1 (see also Plate 7).

Geological sections, and contour, isopach and facies maps may be found on Figures 5 to 12.

Geological logs of wells used to prepare sections, together with a locality plan, may be found in Volume III.

TABLE 1
STRATIGRAPHIC AND HYDROGEOLOGICAL SUMMARY

	<u>Formation</u>	<u>Aquifer Characteristics</u>
QUATERNARY SEQUENCE	Variable fluvial and lacustrine clays, silts and sands with occasional gravels. Equivalent in part to Blanchetown Clay and Chowilla Sand. Modern aeolian sands and floodplain silts with dated wood fragments overlies the sequence. 10-35m thick, typically red-brown and mottled.	Forms unconfined (sometimes slightly confined) aquifer in most of area. Generally low, but variable transmissivities and extremely variable salinities (1,000-30,000+ mg/l) characteristic. Good hydraulic separation from underlying aquifer system only in northern part of area. Little development has occurred because of generally high salinities and low well yields.
	Sands and clays of Parilla Sand, with occasional interfingering of shelly Norwest Bend Formation occur in most of area. 0-5 m thick, pale yellow brown.	Form aquifer which may be connected with either overlying unconfined or underlying confined aquifers, or both. Reputed to be more saline than underlying aquifer.
TERTIARY SEQUENCE	Sequence dominated by richly fossiliferous limestones with sandy and marly interbeds of variable thickness. Mannum and Ettrick Formations distinguishable on palaeontological grounds only. Carbonaceous clays and greensands towards base help identify Buccleuch beds.	Confined aquifer from which virtually all groundwater used locally is extracted. Salinities range from 1500 mg/l near recharge zone to more than 10,000 mg/l in the east and west, controlling the location of the irrigation area. Large well yields, up to 500 m ³ day ⁻¹ , are common.
CAMBRIAN BASEMENT	Schists, phyllites and greywackes of the Kanmantoo Group.	Poor aquifer with generally low permeabilities and high salinities in the adjacent Mount Lofty Ranges.

CLIMATE

The area has a mediterranean climate with hot, dry summers and cool, moist winters. Rainfall occurs mainly in the months April to October (Table 2), with erratic storms contributing most of the remainder. The total rainfall is low (about 400 mm) as the area lies in the rain shadow of the Mount Lofty Ranges. The catchments of the Angas and Bremer rivers have somewhat higher rainfall, particularly the Mount Barker Creek catchment which has annual precipitation of 750 mm. The locations of rainfall measuring stations are shown on Figure 44.

An evaporimeter (Class 'A' pan) has been installed at Milang near the lake shore for some years, to estimate lake evaporation (Table 3 and Figure 47). More appropriately average monthly rates of potential evaporation were determined by Holmes and Watson, 1967 in an irrigated area near Murray Bridge.

Figure 16 shows rainfall for Langhorne Creek P.O. plotted with potential evapotranspiration. There is a precipitation surplus of 30 mm from March to July. This is most unlikely to be greater than the soil moisture deficit at the end of the summer, which has been estimated to be about 150 mm by Professor J.W. Holmes (Flinders University of South Australia, pers. comm., 1977).

Recharge of the unconfined aquifer by rainfall is only likely in excessively wet winters or where localized runoff concentrates water for infiltration. High groundwater salinities suggest that these processes are unlikely to contribute significantly to the groundwater resources. River flooding may be important, the water being derived from higher rainfall outside the irrigation area.

TABLE 2
AVERAGE MONTHLY AND ANNUAL RAINFALL (mm)

Station	Years of Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
Langhorne Creek	73	17	20	19	29	41	42	40	40	37	32	27	24	368
Milang	96	18	19	18	33	43	48	47	43	38	34	24	19	384
Strathalbyn	113	21	22	24	40	56	59	64	60	58	44	29	24	496

(Data from Commonwealth Bureau of Meteorology)

TABLE 3
AVERAGE MONTHLY AND ANNUAL PAN EVAPORATION AT MILANG (mm)

(Data from Commonwealth Bureau of Meteorology)

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
174	137	114	57	33	27	29	57	97	118	140	160	1143

AGRICULTURAL PRACTICES

1. General

The area near Lake Alexandrina was first settled in the late 1830's. Since then a variety of agricultural practices have been carried out, particularly the raising of dairy cattle and other livestock, cereal and fodder crops, orchards and vineyards (Plate 2).

Some crops were irrigated by natural flooding near the Angas and Bremer, and by diversion structures (sluice gates, banks and channels). This practice is still carried out. Farmers claim that the frequency and intensity of the flooding down the rivers has decreased, probably in response to changes in land use in the catchments. Most vineyards still rely on Bremer River floods to supplement rainfall.

Since the late 1950's large amounts of lucerne have been grown for stock fodder using groundwater supplies for summer irrigation; this is the dominant use of groundwater in the area.

Some potatoes are grown using lake water, which also provides the water for most lucerne grown near its shore.

Most stock supplies in the area are obtained from groundwater pumped with windmills (Plate 3).

2. Documented Land Use

Irrigated lucerne was mapped in 1971 by members of the local irrigation association (Figure 13), the first attempt at a land use map.

Department of Lands aerial photographs are available for several periods from 1949. Where they were taken during the summer months irrigated lucerne is easily distinguished, and land use plans have been prepared for March, 1949 and

March, 1976 (Figures 14, 15 and 47).

Currently about 2 400 hectares of lucerne are irrigated using groundwater (Appendix 5).

SURFACE WATER RESOURCES

1. Lake Alexandrina

The Lake forms the southern boundary to the area. It is a permanent body of water, fed by the River Murray, and is characterised by a large surface area, small depth (less than 5 metres), an average salinity of 300-400 mg/l and a salinity range of 100-500 mg/l from July 1974 to December 1977.

Since the construction of the Goolwa barrages in the 1930's Lake Alexandrina has been a freshwater impoundment, with pond level maintained approximately 0.75 metres above sea level at Goolwa. This has drowned the mouths of both Angas and Bremer Rivers (Plate 4). Prior to the constructions of River Murray locks the lake was usually fresh to brackish, and its water level only fell in unusually dry periods (information from local farmers).

2. Bremer and Angas Rivers

Two ephemeral rivers cross the area, flowing from their catchments in the Mount Lofty Ranges to discharge into Lake Alexandrina (Figures 17 and 47).

They have not been studied enough for much quantitative information to be available, however their behaviour is understood.

Both have very small baseflows, which disappear near the edge of the Murray Basin, and flow irregularly for most of the winter months reaching the lake on occasions. Short duration floods (a few days at most) occur whenever enough rain falls in their catchments at any time of the year. The

intensity and frequency of flooding is reported by local residents to have decreased markedly over the last 40 years.

The Bremer has the larger and wetter catchment with correspondingly larger flows, longer flood peaks and lower water salinities. Neither river has water salinities below 1 000 mg/l except during short periods of high flow, and salinities may be as high as 3,000 mg/l at times of low flow.

Staff gauging, on a daily reading basis, has been in progress for a few years supervised by Mr. R.G. Hutton, and a more complete statement about the rivers will be available in the future.

The salinities of the rivers have been measured at the gauging sites, to correlate water quality with flow. This will be reported in detail following further work by the E. & W.S. Water Resources Branch, however some data are shown on Figures 18 and 19.

Several towns and industries contribute to pollution in the Bremer River (Deland, 1976). The Angas is probably much less polluted, although data are scarce.

Both rivers are obvious sources of groundwater recharge. They commonly flow only as far as the approximate edge of the basin. Most water disappears in a short distance downstream if flows are relatively low (Plate 5). Flows to the lake are much less frequent than flow into the northern part of the irrigation area.

Mosquito Creek is a distributary of the Bremer River, flowing only when the river floods.

GROUNDWATER RESOURCES
THE UNCONFINED AQUIFER SYSTEM

1. General

The first work in the area (Bowden and Bleys, 1971) stressed the importance of the unconfined aquifer, but little consideration was given to it again until the investigations carried out by A.F. Williams in 1974-5.

Most private drilling has failed to record information about the upper aquifer, because it was known to be useless for irrigation purposes, and the target was the confined aquifer.

The 1975-6 drilling programme began the first thorough study of the unconfined aquifer.

Water is stored in an irregular Quaternary sequence of dominantly fine grained sediments, with some coarser layers.

To the north west the sequence is up to 35 metres thick, and sand and gravels predominate near the subsurface margin of the Tertiary sediments (Figures 11 and 12).

There the aquifer can be regarded as continuous.

In the central zone the sequence is dominantly clay, with minor sand and gravel aquifers which may be discontinuous in part. Generally, lower salinities there suggest active recharge and lateral flow. Occasional high salinities probably reflect isolated zones of more static water, intersected by chance drilling.

To the south and particularly the south-east the aquifer becomes thinner (as little as 10 metres) but the dominance of coarser material probably results in higher transmissivities. The absence of continuous clays low in the Pleistocene sequence in the south of the area means that

there is unlikely to be much hydraulic separation from the underlying confined aquifer.

2. Potentiometric Surface

A network of observation wells has been measured, beginning in May, 1976 to examine potentiometric contours and the response of the aquifer through a complete pumping season.

The configuration is shown on Figure 20 for August 1976, the time of highest water levels since measurements began, and on Figure 21 for March, 1977, the time of lowest water levels.

General flow is towards a cone of depression north of Lake Alexandrina. Flow lines suggest that recharge occurs along the Bremer River and Mosquito Creek, although the latter source is unlikely to be very important, and is interpreted from limited observation well data. The River Angas is likely to be a source of recharge, as diminutions of flow have been observed by the authors and measured by Sinclair (1976). This is not as obvious from the contour plan as the inferred recharge from the Bremer River, possibly because of lower river flows and the lack of observation wells near the river. Lake Alexandrina is probably also a source of recharge, although this has been induced by modern lowering of water levels.

The cone of depression recovers partially during the winter. The configuration is interpreted as the effects of vertical leakage to the confined aquifer, because there is virtually no water extracted directly from the unconfined aquifer, and a near-perfect correspondence in position of the cones of depression in each aquifer. The difference

from the beginning to the end of the irrigation season is an expansion and deepening of the cone of depression during the summer, apparently in response to pumping from the confined aquifer. No other mechanism for loss of water from the aquifer in that area can be found. Figure 22 shows the depth of the water table below the ground surface, suggesting that evaporative losses are unlikely to be responsible. The lucerne is well-irrigated, and unlikely to be depleting soil-moisture.

The vertical leakage has probably prevented the rising water table problems which often beset irrigation areas.

No aquifer tests have been carried out, however work carried out on core samples collected during drilling has provided data from which storage characteristics can be calculated. This work is presented in Appendix 2 and Figures 23 to 25. It shows that the storage coefficient is about 0.1.

No aquifer testing has been carried out, however, it can safely be assumed that hydraulic conductivities are an order of magnitude lower than those in the confined aquifer.

Water level hydrographs for selected wells are shown on Figure 26 with confined aquifer hydrographs where an adjacent well is available.

They correspond closely with fluctuations of the confined aquifer in the southern part of the area, but lag up to 5 months in their response in the northern part. This supports the interpretation of effective hydraulic separation to the north, but near-continuity to the south.

2. Salinity

The pattern of salinity in the aquifer is complicated, laterally and vertically. Salinities range from less than 1 000 mg/l to more than 20 000 mg/l. A general representation is shown on Figure 27, based on salinities from Department of Mines observation wells, and ignoring other private wells which provide a wealth of confusing data. The plan supports suggestions made about recharge from the rivers. High salinities near the lake, where water levels are near the surface, are presumably caused by evaporation, whilst those in the north-east of the area where water levels are deeper are probably an indication of little or no recharge.

Data from private wells shows that the aquifer is even more complex than the observation wells suggest, and future work could be directed towards a better understanding of the system.

THE CONFINED AQUIFER SYSTEM

1. General

The confined aquifer is the main supplier of irrigation water in the area. It occurs throughout, being limited in north-western extent by the Mount Lofty Ranges. To the east and west the aquifer extends far beyond the area of irrigation quality groundwater, and to the south it probably occurs beneath Lake Alexandrina, with deep, infilled erosion channels of the former River Murray incised into it and possibly forming impermeable boundaries. The sediments which comprise the aquifer vary considerably, but production intervals are dominated by fossiliferous limestones. The limestone is cavernous in some (undefined) areas, probably as a

result of pre-Pliocene erosion. This feature improves well yields, but can be a problem to rotary drilling. Most wells develop only the top 10-20 metres of the aquifer, and still provide adequate supplies for irrigation.

Aquifer tests were conducted at two sites (see Figure 47) in 1969, and the results reported in Roberts, 1972. Data was reinterpreted (Appendix 4) to check for evidence of vertical leakage, as the original detailed interpretation had been lost. The results are summarised in Table 4.

TABLE 4
SUMMARY OF CONFINED AQUIFER TEST RESULTS

SITE	TRANSMISSIVITY ($\text{m}^3 \text{day}^{-1} \text{m}^{-1}$)	STORAGE COEFFICIENT	VERT. HYD. COND. OF CONFINING BED ($\text{m}^3 \text{day}^{-1} \text{m}^{-2}$)
NORTHERN	500	2×10^{-4}	0
SOUTHERN	1 500	5×10^{-4} to 1×10^{-5}	3×10^{-2} to 3×10^{-3}

2. Potentiometric Levels

The aquifer is confined because of the high elevation of the recharge zones relative to the area in which it is developed. This in turn is a result of the pre-Pliocene erosion of the limestone, and subsequent covering with relatively impermeable material. Outside the irrigation area to the north-east, the top of the limestone rises above the zone of saturation, and the aquifer is unconfined.

Prior to irrigation on a large scale potentiometric levels were several metres higher than at their modern maximum levels, and wells in low lying areas near the lake were artesian, with standing levels reported to be about 1.5 metres above ground level.

There was a general decline in levels after the commencement of large scale irrigation, however systematic measurements of potentiometric levels have only been made since 1968, at least 10 years later. The contours are dominated by the cone of depression caused by the pumping in the summer months (Figure 28). By winter the maximum recovery is attained (Figure 29), giving the nearest representation of the pre-pumping situation. Recovery is never complete, and the aquifer has clearly been depleted.

The general slope of the potentiometric surface is to the south, suggesting that natural recharge comes from the rivers, which are the only significant source of water in the north. Lateral groundwater flow from the fractured rock aquifers is unlikely to provide significant input, as the permeability of the rocks is low, and the salinities generally (but not universally) at least 2 500 mg/l. The modern lowering of water levels suggests that water now flows into the irrigation area from all directions for the entire year (see flowlines on Figures 28 and 29). The seasonal fluctuations are consistent from year to year, and only the two contour plans from any one year are required to represent the changes that take place. Change in storage can be represented qualitatively by a plot of the area below sea level of the cone of depression versus time, for the contours drawn at the end of the irrigation season (Figure 30). For the period 1969 to 1977 there has not been a significant change in storage (for the end of the irrigation season) when rainfall variations are considered. Provided that the area under irrigation does not increase there is unlikely to be a problem of groundwater supply.

Water level hydrographs are presented on Figure 31. They show marked seasonal fluctuations up to 6 metres in the central and northern parts of the area. To the south the fluctuations are smaller, perhaps because of the damping effect of vertical leakage from the unconfined aquifer. The peak water levels are in approximate correspondence with annual rainfall, which exerts direct influence upon the amount of water used for irrigation, except for observation well BRM 7, which shows a distinct decline. Some depletion may therefore be occurring in the north-west area recharged by the Angas River, but elsewhere there appears to be a stable situation. Monitoring will continue to check this interpretation.

Inelastic response of the confined aquifer to pumping could result in decreased available storage but maintenance of water levels. No evidence would be obvious unless measurable ground subsidence took place.

Aquifer data can be used to study the contribution of water by lateral flow into the irrigation area by flow net analysis. Figure 32 shows the extremes of drawdown and recovery, each of which can be assigned six months flow as a first approximation, with flowlines and values of transmissivity, hydraulic gradient and flowpath width.

Using Darcy's Law, the flow in each flowpath for each six month period can be calculated.

Table 5, below, gives the components of lateral flow into the irrigation area calculated using this method.