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Merredin townsite groundwater pumping and desalination pilot project

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March 2004

Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

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Summary

Townsite salinity affects more than 40 towns in the WA wheatbelt. Waterlogging and salinity are responsible for damage to townsite infrastructure including homes, commercial premises, schools and other public buildings, roads, railway lines, pipelines, cables, as well as sporting and recreational facilities. Merredin townsite has suffered damage to many of these assets due to the impacts of salinity resulting from rising groundwater levels.

In recognition of the severity of the problem and future risk, the Merredin Shire was granted $320,000 by the WA Government's State Salinity Council (now Natural Resource Management Council). The purpose was to investigate the feasibility of groundwater pumping and desalination as a method of preventing salinisation in the Merredin townsite.

The project was supported by the Merredin Shire ($68,000, mainly through donation of land), the Department of Agriculture ($32,000 through the Rural Towns Program) and the WA Water Corporation ($30,000). The project was implemented through a joint Project Management Committee from each of these organisations plus a representative from the Avon Catchment Council.

Two production bores previously installed by the Rural Towns Program, were used to draw 100 kilolitres per day (kL/d)of moderately saline (2,900 mS/m) groundwater from under the townsite. The effect of pumping on groundwater levels and water salinity was monitored for 12 months. Abstracted groundwater was pumped to an evaporation basin which was constructed as part of the project and located approximately 4 km to the west of town. Groundwater levels and water quality were monitored at the evaporation basin site. Saline water evaporation and leakage were also determined.

A desalination plant was hired for six months during the project to test the feasibility of producing potable water from saline groundwater. For the period, 17% of water supplied from the town bores was diverted to the plant. Water quality of the product was monitored for the duration of the trial.

Groundwater pumping resulted in a combined output from the two production bores of 1.6 litres per second (L/s) or a total of 39,478 kL and 345 tonnes of salt over the project. If there had been no pump shutdowns (caused by breakages or other forced stoppages) a combined rate of 2 L/s would be possible from the two production bores.

The average radial impact of groundwater pumping on piezometric head was about 200 m from each production bore. The radial impact of pumping on the shallow aquifer was approximately 100 m. Water chemistry did not change significantly over the 12 months of monitoring. Groundwater salinity, pH and ionic composition were measured as they are important water quality parameters to consider if industries based on saline groundwater production are contemplated.

The Pilot Project demonstrated that in Merredin, groundwater pumping could be effective for lowering groundwater levels and therefore has significant potential for salinity control.

The evaporation basin results were less clear. Routine monitoring revealed groundwater levels increased under and immediately adjacent to the basin when discharge water was pumped into it from the townsite. Although direct measurements of seepage through the basin's clay liner of the basin were not made, it was inferred by inflow and evaporation rate calculations that the basin was leaking.

Leakage appeared to be caused by permeability of basin walls. Construction techniques may also not have been adequate. Groundwater monitoring around the site revealed a groundwater mound was created below the basin within five months of the commencement of pumping.

If evaporation basins are to be constructed using clay liners in similar soil types and wheatbelt terrain, they be a moderate leakage risk. Sites near high value infrastructure should be avoided for evaporation basins if using similar construction technique. Geotechnical investigations need to take greater account of hydrogeological conditions and more permeability tests need to be conducted in moderate to high risk sites. Synthetic basin liners should be considered to reduce leakage risk.

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1. Introduction

1.1 Project background

The Merredin Groundwater Pumping and Desalination Pilot Project was an initiative of the WA Department of Agriculture's Rural Towns Program, the Shire of Merredin and the WA Water Corporation on behalf of the local community. Initiated in October 2000, the project was designed to address the issue of rising water levels under the Merredin townsite.

The project comprised the construction of an evaporation basin to the west of town and installation of piping and pumping equipment associated with two existing production bores within the townsite. Water was pumped 4.5 km from the bores to the evaporation ponds via an 80 mm diameter pipeline. A portion of the bore water bypassed the evaporation basin and was fed to a desalination plant. The reverse osmosis (RO) desalination plant produced a low salt concentration 'product' stream together with a 'brine reject' stream. All of the brine reject stream and most of the water product stream was piped to the evaporation pond. Major ions, organic matter and microbial composition of the water product stream (permeate), were analysed for possible human consumption.

1.2 Project objectives

The project objectives were to:

- test the effectiveness of groundwater pumping in reducing watertable levels in and around townsites or areas at risk from salinity;
- test the sustainable yields from two production bores over 12 months;
- test the effectiveness of the evaporation basin as a means of saline groundwater disposal;
- test the effectiveness of the desalination plant in producing potable quality water;
- monitor the capital and operating cost of the pilot project;
- evaluate the cost of a full scale salinity control and groundwater production scheme;
- demonstrate a model of an integrated salinity control and water supply scheme.

2. Merredin site characteristics

2.1 Landform and climate

The Merredin catchment is located 265 km east of Perth on the Great Eastern Highway. Area is approximately 400 km^2. Topography is characterised by long, low slopes and low relief (109 m of fall over 35 km of catchment).

The climate is semi-arid with hot dry summers and cool wet winters. Average annual rainfall (1901-2001) measured at the Merredin Shire is 328 mm, with 70% falling between May and October. The average long-term pan evaporation is 2,200 mm/yr. Hundred year climatic averages for Merredin are shown in Figure 1.1.

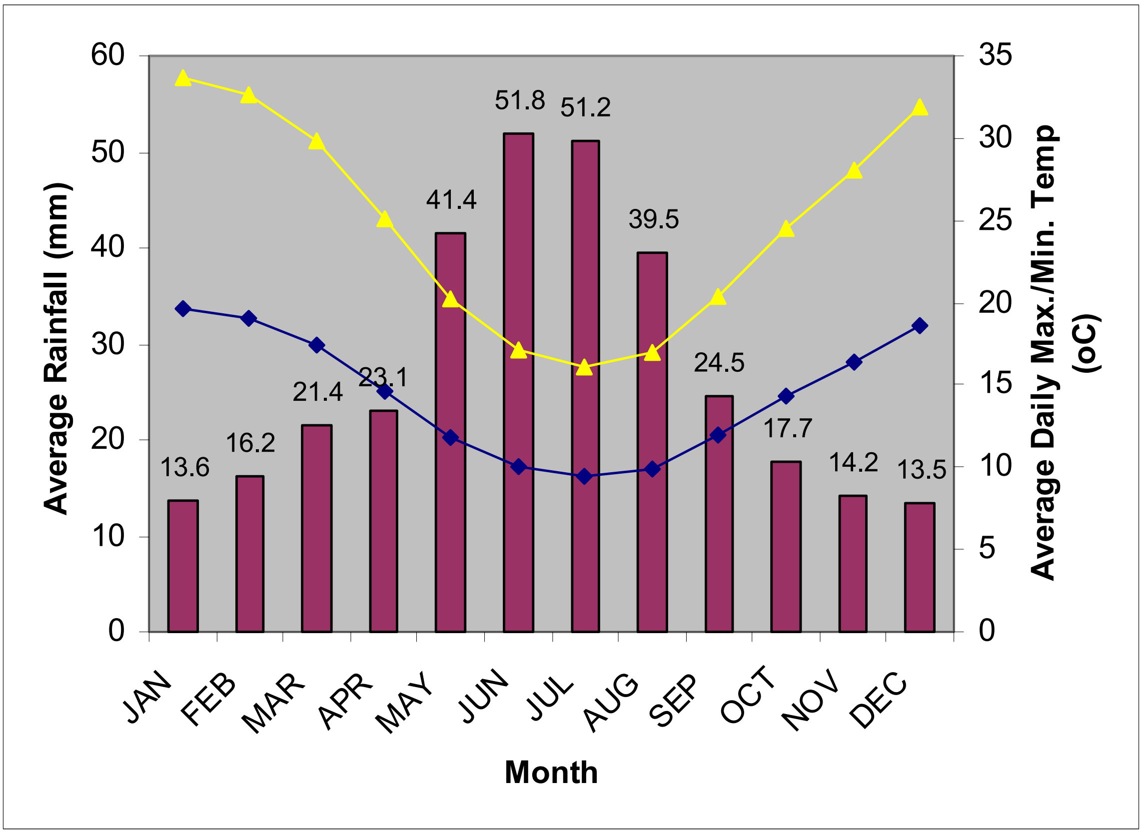

Figure 1.1. Average rainfall, maximum and minimum temperatures for Merredin 1901 to 2001

2.2 Vegetation

Approximately 10% of the catchment retains a cover of remnant native vegetation. Bettenay and Hingston (1964) described the soil-landform units (and vegetation associations), within the Merredin district as: Danberrin (York gum) 9%, Ulva (tamma) 20%, Norpa (grevillea, wodjil) 15%, Booraan (white gum) 20%, Collgar (mallee) 5%, Merredin (salmon) 20% and Nangeenan (morrell) 11%.

2.3 Surface water hydrology

Merredin catchment is located in the Swan-Avon drainage basin. Surface drainage through the townsite is from east to west via Cohn Creek and artificial town drainage systems. The catchment discharges into the Yilgarn River palaeodrainage system at Hines Hill, approximately 20 km from the town centre.

In 1984, 110 km of absorption banks were constructed throughout the catchment, including many upslope of the town to protect it from flooding (often generated by intensive summer thunderstorms), and reduce catchment soil erosion (personal communication, M. Harper). A network of stormwater drains had previously been constructed within the town.

2.4 Geology

The Merredin catchment is underlain by highly weathered Archaean granite and gneissic bedrock. Major lineaments (faults, fractures in bedrock) trend in NNE and ESE directions. Dolerite scree from Proterozoic intrusions and quartz veins are present in the upper, more dissected area of the catchment (George and Frantom 1990).

Above the bedrock there is up to 50 m of clay-rich unconsolidated material derived either from *in situ* weathering of the underlying bedrock or from transported material. The *in situ* weathered profile consists of a poorly weathered saprolite zone underlying a more intensely weathered pallid zone. Sequences of colluvial, alluvial and aeolian sediments derived from erosion of the upper slopes can be found above the weathered profile.

2.5 Hydrogeology

According to George (1992), groundwater occurs in the following aquifer types in the wheatbelt:

(i) Coarse-grained soils overlying pallid sandy clay

(ii) Granite saprolite above bedrock

(iii) Alluvial sediments within major valleys

(iv) Possibly in aquifers deep within the bedrock.

There are two dominant aquifer systems:

- A deep saprolite type (ii) aquifer extends throughout the catchment. Recharge occurs from the highest part through to the valley floor while discharge is at the lowest point (Hines Hill salt lakes) and bedrock highs. Groundwater velocities are very low (0.05 m/day in the mid to lower catchment region).
- Small shallow type (iii) aquifers are found within and west of Merredin town. Water perches on silcrete layers within alluvial sediments.

Shallow type (i) aquifers, controlled mainly by variation in local topography and geology, exist in the upper catchment e.g. sandplain aquifers.

Lee (2001) examined the relationship between acidity and ion concentration in the formation of hardpans, particularly silcrete. Silcrete layers are thought to be hydrogeologically important in the town centre where salty groundwater is mounding above the hardpan. Lee found that town groundwater with pH <4.5 typically contained high concentrations of dissolved aluminium. High silica concentrations were observed in groundwater with pH <5.6. He suggested that some silcretes may have formed after clearing. He found silica concentration was related to both low pH and higher EC groundwater. These conditions were common in bores where a confining or semi-confining silcrete layer separated type (ii) and (iii) aquifers.

2.5.1 Recharge

There are three main mechanisms for recharge in the Merredin district described by George and Frantom (1990) and Matta (2000):

(i) Direct recharge through general infiltration over a wide area (dominant in the east)

(ii) Indirect recharge from concentrations of creek flow along waterways (e.g. Cohn Creek which drains to the west of Merredin) and waterlogging

(iii) Recharge from garden irrigation, septic tanks, leaking pipes, reticulation and other man-made influences.

2.5.2 Depth to groundwater and salinity

Depth to groundwater in the town ranges from 2 to 7 m. In other parts of the catchment, it varies from 0 to 35 m. Groundwater salinity ranges from 630 to 43,930 mg/L or 30 to 4,700 mS/m (Matta 2000).

2.5.3 Groundwater monitoring

A network of piezometers was established to study trends in groundwater levels and salinity (George and Frantom 1990). Groundwater level fluctuations have been monitored at monthly intervals for 19 piezometers since 1986.

Seasonal fluctuations

Aquifers in areas with direct hydraulic contact with creeks show seasonal fluctuations (Nott 2001). Water levels rise during wet periods (usually winter) and fall during dry periods. For example, higher rainfall during the 1991 summer and autumn was reflected by larger water level rise during winter. Conversely, lower rainfall between 1988 and 1990 resulted in smaller water level rises.

Water level fluctuations in piezometers MD3A, MD3C, MD3-pump, MD4, MD4B and MD7 show both recharge and discharge cycles in the annual pattern. Long-term records from piezometer MD3-pump in a replanted area showed that water levels were rising from 1986 to mid-1993 at a rate of 0.04 m/yr, but between mid-1993 and April 1998 fell by about 2 m (at a rate of approximately 0.45 m/yr). Since 1998 the levels have been rising, but if long-term rainfall is taken into account, the overall trend is still downward at a rate of 0.10 m/yr. This is further supported by the bicarbonate analysis of Matta (2000) which showed decreased recharge at MD4 and MD7 between 1986 and 2000.

Constantly rising

In the upper slopes (recharge areas) where the rate of groundwater recharge is high, water levels are rising 0.15-0.54 m/yr (Nott 2001). For example, in cleared sandplain areas the water levels are rising continuously. The situation may be exacerbated by local recharge from level banks in the vicinity. However, piezometer MDB located between MDA and MDC does not exhibit a similar pattern (because this area is heavy-textured and does not have such a high recharge rate). Contrary to established trends, water levels have declined in MDB since June 1994 and then rose in the wet year of 1999.

Piezometers MD2 and MD8 show a steady rise with minimal seasonal response. This is probably due to contribution from a sustained lateral groundwater inflow from the hillslopes.

3. Groundwater pumping

3.1 Introduction

Groundwater pumping has proven effective in lowering watertable levels across the wheatbelt, given appropriate hydrogeologic conditions (Dogramaci 2002). High pumping rates have been achieved from coarse sediments in thick sequences and/or thick bands of coarse saprolite grit. High pumping rates however are not always conducive to the lowering of watertables if connectivity is poor between a regional and shallow groundwater system.

Groundwater pumping was investigated by George and Frantom (1990) as a means of lowering or maintaining groundwater levels in the Merredin townsite. Two short pump tests were carried out at a 17.7 m deep bore, downstream of the town. Although only moderately low discharge rates were achieved for pumping from sandy alluvial sediments, it was estimated that production from weathered saprolite would be higher and useful for controlling salinity in the west Merredin area.

Matta (2000) used a groundwater model (MODFLOW®), to test salinity management options for Merredin, including groundwater pumping, tree planting and a ‘do nothing’ strategy. Modelling based on available groundwater data for the town showed that groundwater pumping could to be effective in lowering watertables. A network of bores 250 m apart, abstracting groundwater at 100 kilolitres per day per well throughout the salt-prone area of town was recommended as a means to control salinity. In practical terms this translated to nine production bores located within the central area of town, each yielding 50 kL/d.

The economics of groundwater pumping are very site specific and depend on drawdown distance (particularly from perched aquifers), cost of pump operation, groundwater disposal and the value of the infrastructure protected. Dames and Moore/URS (2001), using Matta’s (2000) data, predicted that the costs of pumping and disposal to lower watertable for most rural towns in WA would exceed the financial benefits. This conclusion was based on conservative estimates of the area of land potentially protected and did not assume any cost recovery derived from use of pumped groundwater. A pumping trial using a borefield like the one suggested by Matta (2000) for Merredin was conducted by the Wagga Wagga City Council using a field of 10 production bores to lower groundwater below a 230 ha urban centre (Wallett *et al*. 2001). The method had an impact on only a limited area, but nonetheless was economically viable given the high value of urban infrastructure (including a hospital) that was protected.

In the Merredin groundwater modelling report, Matta (2000) recommended that a network of piezometers and observation wells be installed within the townsite to improve the understanding of townsite geology and groundwater dynamics. In 1999-2000 the Merredin Shire and Rural Towns Program undertook drilling of 17 deep piezometers and shallow monitoring bores, along with two fully cased production bores, at selected sites. During this same period Cooperative Bulk Handling (CBH) provided funding for drilling two deep and one shallow piezometer at the Merredin grain facility. The two town production bores were test pumped for yield and drawdown. Both bores gave sustainable yields in excess of 50 kL/d and indicated a potential drawdown of approximately 200 m radius (unpublished data; Matta, Catlin and Lacey).

Analysis of drilling logs and Matta’s work suggest that Merredin has a semi-confined aquifer, separated from a sedimentary aquifer by a leaky silcrete layer of variable thickness. Dogramaci (2002) suggests that abstraction from a deep aquifer of this type may have significant impact on hydraulic head, but minimal impact on watertable. George and Nulsen (1985) described a similar pumping experience from weathered granite site near Dalwallinu, where abstraction rates of 3 L/s resulted in impacts on deep aquifer head four times greater than impacts on the shallow watertable.

The current project aimed to expand production bore test pumping initiated by Matta *et al.* in 2000, in order to determine sustainable production yields and to test the effectiveness of pumping on decreasing groundwater levels. Determining sustainable yields was also important information for the Merredin Shire as it enabled it to plan future ventures involving productive use of town groundwater.

3.2 Methodology

3.2.1 Unpublished geological data

Field logs from 17 piezometers and two production bore sites collected by Matta and Lacey in 2000 were entered into a geological software package (WINLOG®). Where necessary; unlogged piezometers sites were logged from historic drill sample material. The logs were used to create a town hydrogeologic cross-section to supplement the catchment long-section presented by George and Frantom (1990).

3.2.2 Pipeline layout and flow rate measurement

Groundwater was conveyed from production bores 1 and 2 to the newly constructed evaporation basin via 4.5 km of 80 mm polythene pipe. The basin was constructed with two compartments of 0.5 and 1.5 ha. Figure 3.1 illustrates the passage of groundwater through town to the disposal and reuse site.

The reticulation system was designed and installed by the Water Corporation in locations convenient to public infrastructure. Within the main street area the pipe was buried 0.3 m below ground, while outside of town it was laid on top of the ground in an open drain then a roadside ditch along the Great Eastern Highway. At the evaporation basin site, water was discharged into partitioned sections. Feed water for the desalination unit was fed directly to the plant. Reject and unused desalinated water was returned to the evaporation basin.

Figure 3.2 illustrates the planned daily water yields from the pumping and desalination pilot project. A total of 100 kL/d was to be delivered to the evaporation basin from two production bores each yielding 50 kL/d. Of this, 83 kL/d would be delivered directly to the evaporation basin while 17 kL/d would be fed to the desalination plant. The desalination plant was expected to deliver 10 kL/d of fresh permeate water and 7 kL/d of waste brine to be disposed of in the evaporation basin. Aquaculture trials involving saline groundwater and or brine were possible add-ons to the scheme illustrated in Figure 3.2, but not part of the pilot project.

3.2.3 Monitoring points

Flow meters were installed at critical points in the pilot system to monitor efficiencies of pumping and desalination components. Critical points included groundwater output at each production bore, water into the evaporation basin directly from town and permeate and brine outputs from the desalinator. Each flow meter was read daily during week-days and recorded against time. Daily volumes were calculated at each flow meter and compared to the expected volume distributions of water for the duration of the desalination trial.

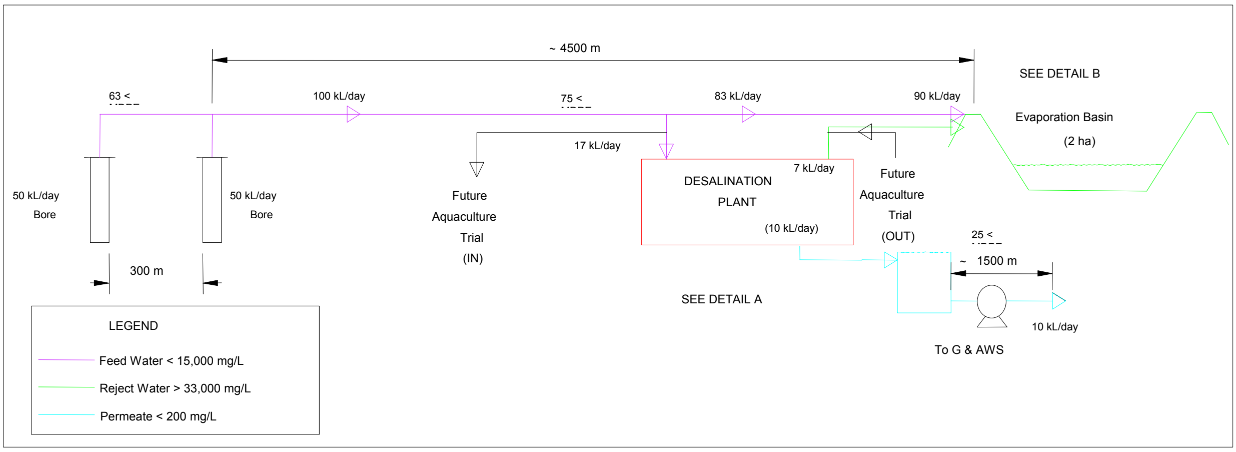

Figure 3.2. Diagram of daily groundwater distribution

3.2.4 Water level measurement

The piezometer network within the townsite was used to monitor water level changes due to pumping from the two production bores. The layout of town bores is shown in Figure 3.3. Six data loggers were used on selected bores for the duration of the project. Three of these were placed in piezometers adjacent to each production bore to obtain detailed data for production analysis. All bores in the immediate vicinity of PB1 and PB2 were monitored weekly while all other town bores were monitored monthly. Figure 3.3 indicates the location of bores which were monitored weekly and monthly. Water level was analysed using HARTT.xls; a program for statistically estimating trends in groundwater levels (Ferdowsian *et al*. 2001). HARTT was not used where the data showed erratic responses to pumping.

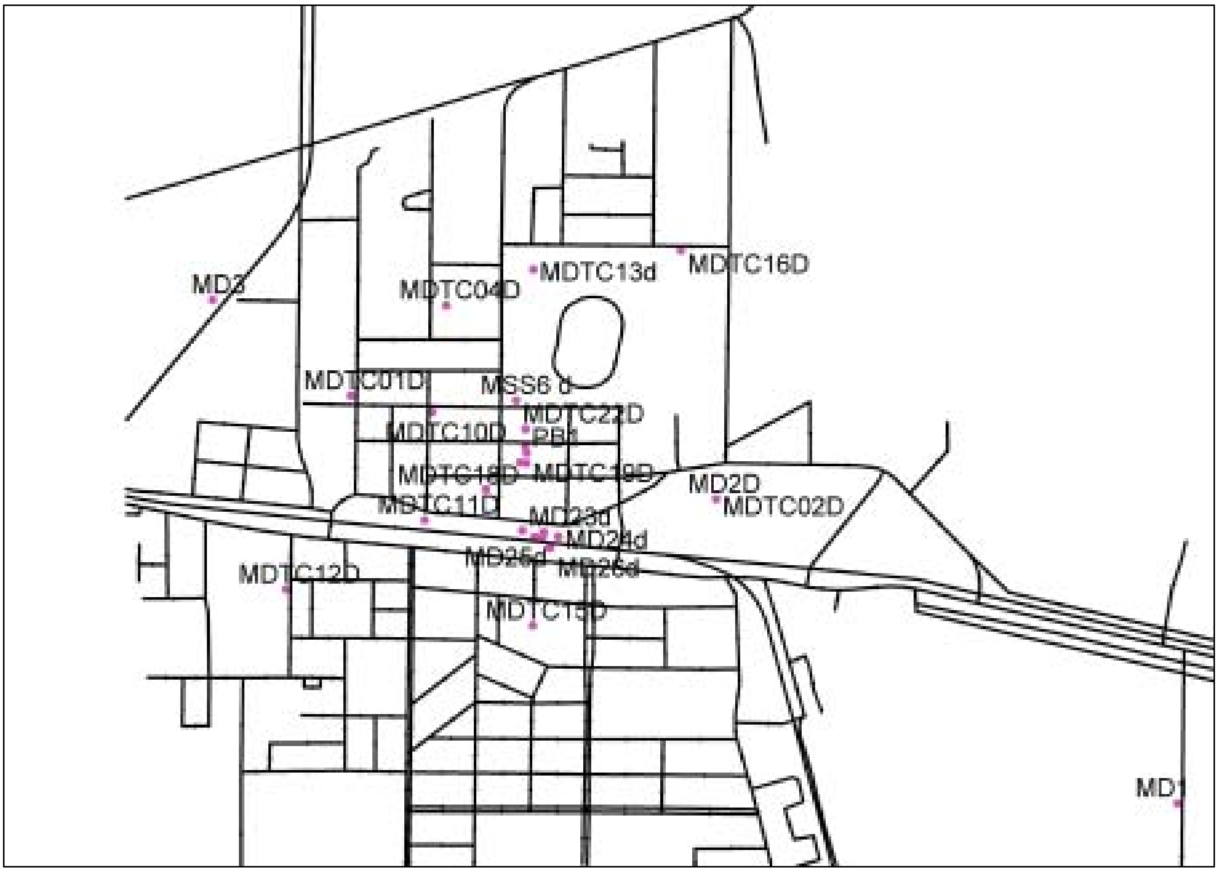

Figure 3.3. Distribution of bores in Merredin townsite

3.3 Results

3.3.1 Geological data

Geological logs from two production bores and 19 piezometers within the townsite are presented in Appendix 1. All drill sites indicated a weathered granite regolith overlain by sediments. Regolith depth was typically 40-50 m in the valley, decreasing to a few metres near rock outcrops. The upper granite saprolite layer usually contained highly weathered kaolinitic clay pallid zone. This generally overlayed a zone of variable thickness containing coarse grained gritty saprolite material comprising quartz, feldspar, mica and often, whole granite chips.

The production bore sites were selected where gritty saprolite bands were in excess of 12 m thick. Regolith profiles such as those found at MDTC01 would not make suitable production bore sites because of large sections of kaolin clay and relatively small bands of the gritty saprolite. The granite saprolite at all drill sites is overlain by 5-14 m of predominantly fine grained sediment.

The areas surrounding production bores 1 and 2 contained bands of silcrete within the sediments. It is likely these silcrete bands formed on a previous watertable that existed in low lying areas. Water dissolved silica compounds which then hardened once the watertable receded. These layers however are not continuous or confining. The more elevated areas of town, such as piezometer sites MDTC12 and MDTC16, do not contain any silcrete bands. Figure 3.4 shows a cross-section through the Merredin town, indicating the likely distribution of silcrete formations across the low-lying area.

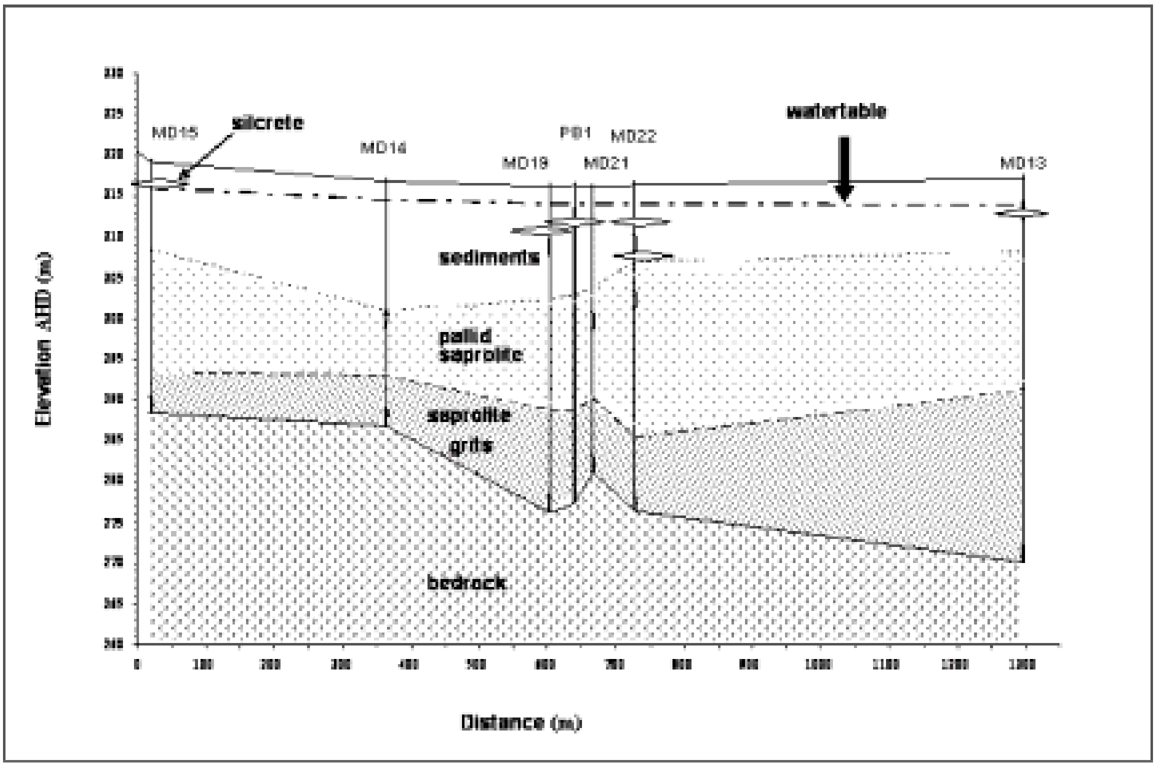

Figure 3.4. North-south hydrogeologic cross-section of Merredin town

3.3.2 Flow rate measurement

Pumping commenced from both PB1 and PB2 on 2 November 2001. Pumping ceased on 6 May 2002 for PB1 and 13 September 2002 for PB2. Results of pumping during this period are shown in Table 3.1. The volume of water which could be safely disposed of in the evaporation basin was calculated as 100 kL/d, based on basin size, evaporation rates and expected salinity. The yields indicated were flows read from meters at each production bore. Neither bore operated for the full 10-month pumping period due to various installation and set-up problems. Problems included: pumps set at incorrect depths in the bore to sustain the planned flows; low water level switches not fitted, power blackouts and pipe failures. Both electric submersible pumps were damaged and had to be replaced in the 10-month period as a result of one or more of system failures.

Pumping was interrupted for several weeks at PB2 during January 2002 for maintenance. This pump was then shut down on 13 September 2002, when routine monitoring detected excess vertical leakage from the evaporation basin. Some piezometers at the evaporation basin site had risen up to 2 m above the original watertable level prior to pumping due to leakage. The Project Management Committee decided to suspend pumping into the evaporation basin until the leakage problem was resolved. PB1 operated between 2 November 2001 and 6 May 2002 when pump failure caused shutdown.

Table 3.1. Pumping results for PB1 (2 November 2001 to May 2002) and PB2 (2 November 2001 to 13 September 2002)

Bore No.	PB1	PB2	Total	Average
Planned pumping rate (L/s)	0.58	0.58	1.16	
Actual pumping rate (L/s)	0.60	0.98	1.59	0.79
Volume pumped (kL)	9,037.57	21,635.62	30,673.19	15,336.60
Pump hours	4155.95	6099.47	10255.42	5127.71
Average pumping rate over period (L/s)	0.33	0.80	1.13	0.56
Average salinity (mg/L)	19,084	16,650		17,867
Total salt discharged (T)	172.47	360.23	532.70	266.35

Table 3.2. Pumping results for PB1 and PB2 (4 December 2002 to 14 February 2003)

Bore No.	PB1	PB2	Total	Average
Planned pumping rate (L/s)	0.58	0.58	1.16	
Actual pumping rate (L/s)	0.57	1.04	1.60	0.80
Volume pumped (kL)	3357.46	5446.92	8804.38	4402.19
Pump hours	1642.91	1460.95	3103.86	1551.93
Average pumping rate over period (L/s)	0.54	0.87	1.41	0.71
Average salinity (mg/L)	19,800	16,600		18,200
Total salt discharged (T)	66.48	90.42	156.90	78.45

The actual pumping rates for PB1 (0.60 L/s) and PB2 (0.99 L/s) indicate how efficient the pumps were for respective working hours, while average pumping rates indicates the efficiency of the pumps over the duration of the project. Despite PB1 being shutdown for four months and PB2 for two months, the average pumping rate from the two bores was close to the planned rate when they were working. This was achieved by operating both pumps at rates greater than 0.58 L/s. In fact, PB1 seemed to be able to sustain 0.8 L/s for an indefinite period, whilst PB2 was able to sustain 1.2 L/s. It appears that a total of 2 L/s could be abstracted from the two production bores if water disposal problems are rectified.

Salinity of the two bores was measured regularly during the pumping period. The average salinity was 19,084 and 16,650 mg/L for PB1 and PB2 respectively. Using the average discharge volume from each bore, the total mass of salt discharged from the Merredin town was calculated using the formula:

$$\text{Salt discharged (t)} = \text{Salinity (mg/L)}^{*}\ \text{Volume Water Discharged (kL)}/10^{6}$$

A total of 532.7 tonnes of salt was abstracted during the 10-month period. This is a small fraction of salt in the Merredin town regolith. George and Frantom (1990) calculated that the salt store at MD02 for a 60 m profile was 3800 t/ha.

Table 3.2 shows results of pumping between 4 December 2002 and 14 February 2003. This pumping period was used solely to determine evaporation basin leakage rates. The only interruptions to pumping occurred during power blackouts before and immediately following Christmas Day. Average pumping rates during this phase were above the design rates due to fewer pumping hours lost. Actual pump rates from both bores exceeded 0.58 L/s.

Weekly calculations were made of total water volume delivered into the evaporation basin and out of the desalination unit to determine the efficiency of the downstream water delivery component. These figures were compared to expected weekly volumes, shown in Figure 3.2. Expected and actual water delivery through each flow meter is shown in Figure 3.5.

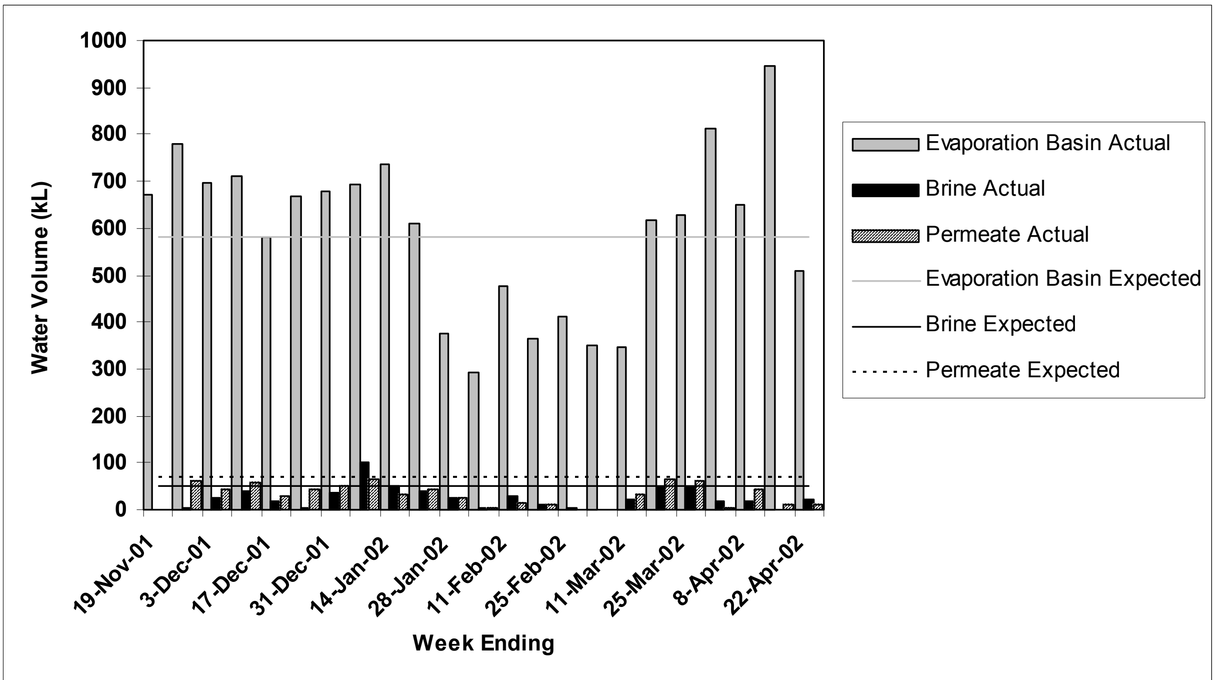

Figure 3.5. Predicted and actual water delivery

The actual water volume delivered to the evaporation basin is directly related to the efficiency of water delivery from the production bores, as shown in Table 3.1. Water delivered to the evaporation basin did not reach the predicted volume of 581 kL/week between late January and March. This corresponds to a period of pump failure at PB2. A similar pump failure occurred at PB1 in mid-April. Permeate output from the desalination unit only reached the expected weekly output of 70 kL on two occasions. Brine volumes discharged into the evaporation basin were thus also lower than predicted. Efficiencies and operating problems related to desalination are described in detail in Chapter 5.

3.3.3 Water level analysis

Table 3.3 shows piezometer responses to groundwater pumping. Groundwater levels before pumping commenced in September 2001, are compared with groundwater levels after a period of pumping. Significant water level responses were observed in both deep and shallow aquifers within a 50 m radius of both production bores. Within a 100 m radius, deep aquifer water levels were observed to drop over 10 m, whilst there was minimal influence on the surficial aquifer.

At some sites (MDTC11, MDTC18 and MSS6), reductions in surficial aquifers levels of 0.8-1.3 m and corresponding deep aquifer reductions up to 2 m, were recorded at distances to 150 m from a production bore. An unconfined aquifer at MDTC15, over 350 m from PB2, indicated water level reductions of over 2 m. Piezometers in excess of 350 m from a production bore (e.g. MDTC 12 and 16) showed little to no effect of groundwater pumping.

Hydrographs from representative piezometers are shown in Figures 3.6 to 3.10. Some additional hydrographs are shown in Appendix 2. HARTT hydrograph analysis results for a two year period from June 2001 and May 2003 are shown within these figures.

Figures 3.6 and 3.7 indicate deep and shallow water level responses to pumping at PB2. Positive and negative fluctuations in water level correspond to pump fluctuations. A major shutdown in PB2 occurred in late January 2002 for six weeks. Figure 3.6 shows that the response of the deep aquifer to cessation of pumping resulted in rapid water level recovery. Shallow aquifer recovery (shown in Figure 3.7) however was slower, taking over four weeks for groundwater to return to original levels. Both figures indicated that site MDTC23, north of PB2, is the most reactive of all piezometers located within 40 m of the production bore. No obvious difference appeared in the geological log to indicate site MDTC23 should be more transmissive than 24, 25 or 26. It is slightly closer to PB2 than the other piezometers.

Table 3.3. Merredin piezometer responses to groundwater pumping

Piezometer	Location	Depth (m)	Distance from bore (m)	Aquifer type	Date drilled	SWL Sep 01 (m) bgl	Max SWL (m) bgl	Change in SWL (m)
MDTC01d	Roy Little Park	45	650	(ii)	Feb. 2000	-2.03	-2.71	0.68
MDTC01s	Roy Little Park	5.5	650	(iii)	Feb. 2000	-2.13	-2.80	0.67
MDTC02d	Old Military Mus.	60	180	(ii)	Dec. 1995	-5.29	-5.61	0.32
MDTC02s	Old Military Mus.	4	180	(iii)	Jan. 1996	-3.41	-3.73	0.32
MDTC04d	Goof's House	42	220	(ii)	Feb. 2000	-3.15	-3.78	0.63
MDTC04s	Goof's House	5.5	220	(i)	Feb. 2000	-1.00	-3.00	2.00
MSS6d	Duff Drain	?	150	(ii)	?	-3.13	-4.82	1.69
MSS6i	Duff Drain	?	150	(iii)	?	-2.04	-4.05	2.01
MSS6s	Duff Drain	?	150	(iii)	?	-1.98	-2.89	0.91
MDTC10d	NMPS	38.5	350	(ii)	Feb. 2000	-1.85	-2.66	0.81
MDTC10s	NMPS	5.5	350	(iii)	Feb. 2000	-1.99	-2.69	0.70
MDTC11d	West Carpark	41.5	150	(ii)	Feb. 2000	-2.37	-3.33	0.96
MDTC11s	West Carpark	5.5	150	(iii)	Feb. 2000	-2.54	-3.86	1.32
MDTC12d	Albury St	32.5	360	(ii)	Feb. 2000	-5.92	-6.56	0.64

Table 3.3 continued …

Piezometer	Location	Depth (m)	Distance from bore (m)	Aquifer	Date drilled	SWL Sep 01 (m) bgl	Max SWL (m) bgl	Change in SWL (m)
MDTC13d	Rec Ground	47	655	(ii)	Feb. 2000	-2.82	-3.53	0.71
MDTC13s	Rec Ground	5	655	(iii)	Feb. 2000	-3.10	-3.50	0.40
MDTC14d	Dewsons Park	30	80	(ii)	Feb. 2000	-2.25	-5.90	3.65
MDTC14s	Dewsons Park	8	80	(iii)	Feb. 2000	-2.15	-4.50	2.35
MDTC15d	Basketball Court	31	350	(ii)	Feb. 2000	-3.30	-5.47	2.17
MDTC16d	Golf Rd	15	750	(ii)	Feb. 2000	-11.90	-11.90	0.00
MDTC18d	Newfields Park	28	150	(ii)	Feb. 2000	-2.29	-3.64	1.35
MDTC18s	Newfields Park	7	150	(iii)	Feb. 2000	-2.32	-3.15	0.83
MDTC19d	Cummins Theatre	38	37	(ii)	Feb. 2000	-2.20	-23.65	21.45
MDTC19s	Cummins Theatre	8.5	37	(iii)	Feb. 2000	-2.22	-5.88	3.66
MDTC21d	Cummins Theatre	35	25	(ii)	Feb. 2000	-2.20	-7.77	5.57
MDTC21s	Cummins Theatre	17.5	25	(iii)	Feb. 2000	-2.15	-5.59	3.44
MDTC22d	N of Coronation	40	113	(ii)	Feb. 2000	-2.28	-13.31	11.03
MDTC22i	N of Coronation	15	113	(iii)	Feb. 2000	-1.95	-5.39	3.44
MDTC22s	N of Coronation	8	113	(iii)	Feb. 2000	-2.32	-2.69	0.37
MDTC23d	Nth PB2	40	25	(ii)	July 2000	-2.24	-12.57	10.33
MDTC23s	Nth PB2	8	25	(iii)	July 2000	-2.28	-7.61	5.33
MDTC24d	East PB2	40	35	(ii)	July 2000	-2.17	-6.93	4.76
MDTC24s	East PB2	8	35	(iii)	July 2000	-2.16	-6.94	4.78
MDTC25d	West PB2	40	40	(ii)	July 2000	-2.20	-9.59	7.39
MDTC25s	West PB2	8	40	(iii)	July 2000	-2.20	-6.72	4.52
MDTC26d	Sth PB2	40	40	(ii)	July 2000	-2.26	-6.77	4.51
MDTC26s	Sth PB2	8	40	(iii)	July 2000	-2.30	-6.84	4.54

Aquifer type: (i) = perched sand over clay, (ii) = saprolite, (iii) = sedimentary

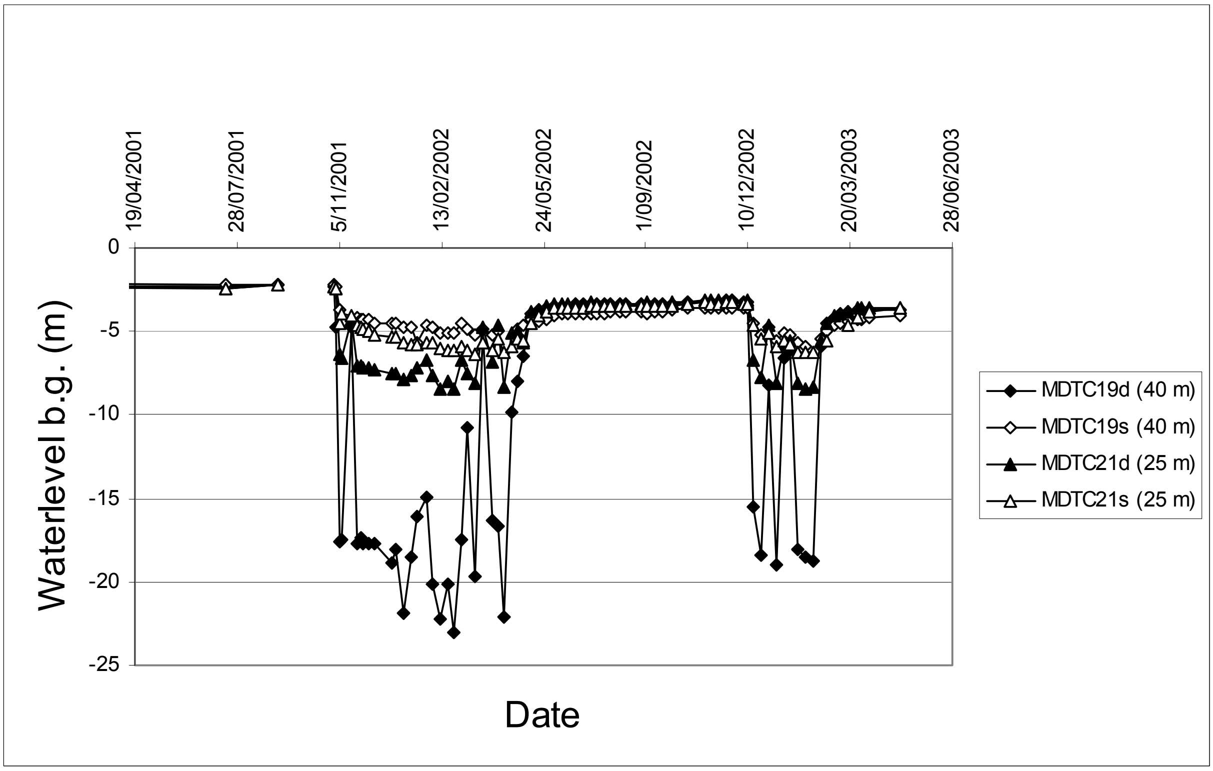

Figure 3.8. Deep and shallow aquifer water level response to pumping at PB1

Figure 3.8 indicates water level responses to pumping in deep and shallow aquifers at PB1. The deep regolith is more transmissive to the south of PB1 (MDTC19) than to the north (MDTC21), dropping 21 m compared to 8 m. Geological logs indicate slightly coarser saprolite at depth at MDTC19 compared to 21. Recovery was also more rapid at the coarser site. The shallow aquifer at both sites responded quickly to pumping from PB1, with water level dropping over 1 m in four days.

Responses of deep and shallow water levels to groundwater pumping at distances of 80 and 150 m from PB2 and PB1 are shown in Figures 3.9 and 3.10 respectively. At bores 80 m from PB2 water level dropped 4 m in the deep aquifer and 0.2 m in the shallow aquifer. At bores 80 m from PB1 water level dropped 10.5 m in the deep aquifer and 4 m in the shallow aquifer. Smaller water level responses were seen at 150 m as a result of groundwater pumping. The furthest response to pumping was observed in MDTC15, 350 m to the south of PB2, where water level dropped 2 m. Recovery in this shallower aquifer was slower than deeper aquifers closer to the production bores.

3.3.4 HARTT analysis of trends

HARTT analysis of groundwater trends conducted between June 2001 and 2003 for bores MDTC01, 04 and 12, is shown in Appendix 2. It was calculated that these bores were falling at 0.17 m/yr (R^2 = 0.93 to 0.98). It is unlikely that this fall is due exclusively to groundwater pumping as below-average rainfall was experienced. Rainfall and evaporation for the period is shown in Figure 3.10. The total rainfall for 2002 was only 247 mm. Bores at the CBH facility west of town were falling at 0.18 m/yr, as shown in Appendix 2.

Bores MDTC16d and MDTC11s showed little trend (-0.055 and 0.016 m/yr respectively) throughout the monitoring period, indicating that dry conditions and a possible pumping effect at MDTC11s, were balanced by local recharge. Recharge is likely to have come from saprolite water moving from Merredin Rock at MDTC16 and sprinkler watering near MDTC11. MDTC11d (shown in Figure 3.9) shows a minimal drawdown trend (0.07 m/yr) for the two years, indicating an effect of groundwater pumping.

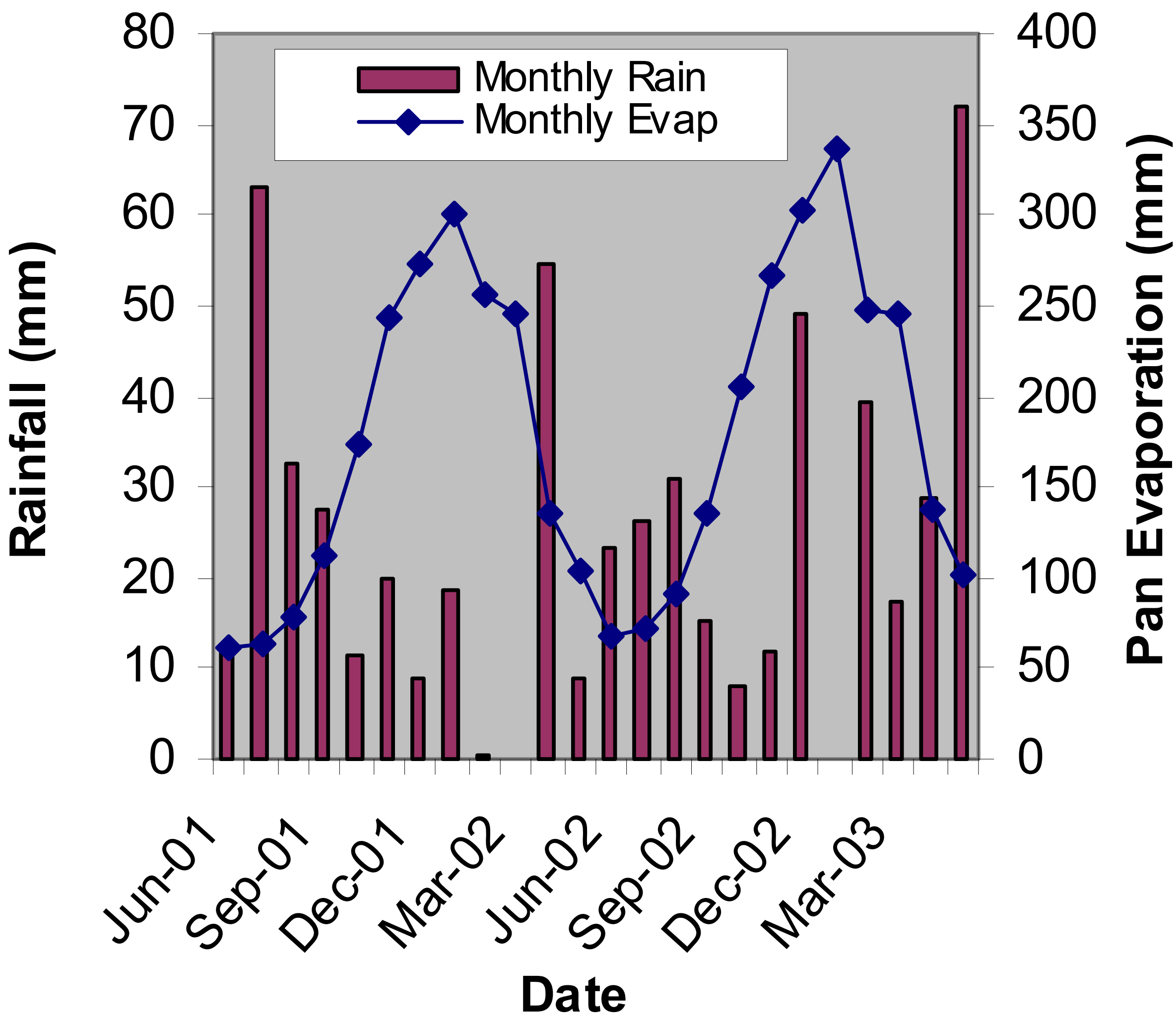

Figure 3.11. Merredin rainfall and evaporation, June 2001 to May 2003

MDTC02D and MDTC02S (Appendix 2, Figure c), show small downward and upward trends in water level. Matta (2000) suggested that water level behaviour at this site was due largely to local recharge from the Merredin Rock.

Minimal data was collected from the three bores at the CBH site to the west of Merredin town (shown in Appendix 2, Figure e). Trends over the two years indicated water levels falling at 0.185 m/yr (R^2 = 0.92-0.98). In normal rainfall years, these bores are likely to have a rising trend due to on-site recharge and run-off from large bitumen and concrete surfaces.

Sites MDTC15, 18 and 14 (shown in Figure 3.9 and Appendix 2, Figure b) showed falling groundwater trends of 0.22, 0.11 and 0.47 m/yr respectively. It is likely that all three of these sites were affected by local watering from council sprinklers. However, all three also show hydrograph patterns consistent with pumping periods. Thus it is difficult to separate proportional contributions to water level changes due to rainfall recharge, sprinkler recharge and pumping extraction at these sites.

The spatial effect of groundwater pumping is shown in Figures 3.12 (deep aquifer) and 3.13 (shallow aquifer) where a) shows water level before pumping and b) during pumping. The colour scale of Figures 3.12 and 3.13 varies from dark to light for the highest to lowest groundwater contour. Prior to pumping deep groundwater moved from east to west and from south to north towards the creek. A groundwater mound was present to the south of the Great Eastern Highway. This mound was centred near MDTC15d; adjacent to the Shire Swimming Pool. Water moved out from this mound influencing the town centre. No data was available for the area to the south of the mound.

During pumping, deep groundwater movement was generally still east to west for the catchment, but in the town centre movement was towards the pumps due to drawdown. Approximately 200 ha of land were influenced.

Figure 3.13 shows the spatial effect of groundwater pumping on the shallow aquifer before and during pumping. Before pumping, shallow groundwater moved from east to west in a similar direction to surface water flow. No mound was evident south of the Great Eastern Highway. During pumping the drawdown area for the shallow aquifer was 71 ha.

3.4 Discussion

The project aimed to test the sustainable production volumes achievable from the two town production bores. Previous drilling by the Rural Towns Program in the town centre located a thick coarse-grained saprolite. Production bore sites PB1 and PB2 were chosen from sites showing gritty saprolite in excess of 12 m. Another site (MDTC10) outside the influence of the production bores also has regolith containing coarse thick saprolite. At time of drilling, MDTC10 was estimated to yield 0.5 L/s, half the capacity of PB1.

The conservative pumping rate from both production bores was found to be 2 L/s (0.8 L/s from PB1 and 1.2L/s from PB2). Piezometer readings found that deep aquifer water was decreasing during pumping at distances up to 200 m from each production bore, and in one situation 350 m from the production bore. Surfer® analysis found that groundwater from approximately 200 ha of land was moving towards the production bores. Shallow groundwater responses during pumping however were only observed in bores within 100 m of the production bores. Surfer® analysis found that shallow groundwater was moving towards the production bores from a 71 ha area. For practical townsite salinity management, significant reduction in watertable levels needs to be maintained indefinitely.

While these results are encouraging from a production perspective, the economics of the continuous disposal of saline water in small rural towns is still in question. Dames and Moore/URS (2001) suggested that financial benefits from land recovery in the Merredin townsite would not cover the costs of a groundwater pumping and disposal scheme as suggested by Matta (2000).

The negative return on investment was due to the very high cost of constructing sufficient evaporation basins (the only disposal option considered during the economic analysis). However, if four or five other sites producing 1 L/s were found in the townsite, groundwater could be used for productive purposes. If much of the groundwater was utilised rather than simply being removed, it would dramatically reduce the area of evaporation basin required. Revenue generated from groundwater, coupled with savings made on preventing damage to infrastructure, might actually generate a positive return on the investment.

Groundwater movement in the townsite, determined from the Surfer® analysis, was from east to west as suggested by George and Frantom (1990) A large groundwater mound south of the Great Eastern Highway near MDTC15 however was causing local flow north towards the town centre and possibly also in other directions. The Surfer® image of this mound illustrates the importance of recharge from leaking infrastructure and artificial surfaces. MDTC15 is located in a low area between the Shire Swimming Pool and Basketball Courts. The upper regolith of predominantly deep yellow sand is conducive to rapid recharge from a leaky pool and run-off from an undrained bitumen area.

Only small differences in water level between deep and shallow aquifers occur across the town centre. Exceptions to this generalisation are sites MDTC02, MDTC04 and MSS6 where large downward gradients exist. As a result the shallow aquifer is significantly fresher than the underlying deep aquifer, suggesting transient recharge through a permeable upper profile. During pumping the deep aquifer is drawn down faster than the shallow aquifer creating a downward gradient from the sediment to the saprolite. Recovery of shallow aquifers takes several weeks due to the movement of water through clay-rich sediments, compared to several days for the deep aquifer. In terms of salinity management this means that pumping needs to be continuous to prevent an increasing watertable, but short pumping stoppages can be sustained due to the longer recovery time of the shallow aquifer.

4. Groundwater chemistry in Merredin townsite

4.1 Introduction

Detailed groundwater sampling of the Merredin catchment was first conducted by George and Frantom (1990) in 1986. Twenty observation bores in different zones of the catchment were sampled for salinity, pH, EC and major ions. Groundwater salinity and EC were generally found to be lower in upslope and valley floor recharge areas and higher in active and potential discharge sites. Groundwater stratification was noted in bores within and downslope of the town. Bores screened in weathered or sedimentary clays were typically more saline than those screened in sand sediments and coarse saprolite.

George's hydrogeologic cross-section indicated a granite basement high downslope of MD3. The deep bore at MD3 contained high salt concentrations, while the deep bore downslope at MD4 was relatively fresh. Matta (2000), in similar analysis to George and Frantom plotted the distribution of chloride in groundwater as an indicator of salinity. This plot suggested the accumulation of highly saline groundwater in a basin upslope of the basement high. It is this saline basin which extends back into Merredin town.

Ionic analyses of both chlorides (George and Frantom 1990) and bicarbonates (Matta 2000) indicate high recharge along the Cohn Creek channel between MD4 and MD7. In the 13 years between these studies, recharge significantly decreased at MD4 and MD7, indicating a positive impact of tree planting in the discharge site. The only town groundwater samples taken in both the George and Matta analyses were from MD2. At this site the shallow bore samples were more saline than those from the deep bore. Matta (2000) noted that in the shallow bore, bicarbonate ratios and hence recharge, had increased over the 13 year period, while the deep bore was unchanged. This suggested the presence of an increasing source of fresher water from Merredin Peak as postulated by George and Frantom (1990).

During 2000, the Merredin town centre was drilled by the Rural Towns Program. Lee (2001) sampled a selection of deep and shallow piezometers for groundwater EC, pH and major ions. Acid groundwater from shallow aquifers was found to overlie more neutral water in the majority of deeper town bores sampled. Alkaline and low salinity shallow water at borehole MDTC11s was seen as an indicator of local recharge from adjacent fresh water sprinklers. Sampling of groundwater pH and EC at a regional level was conducted by Gray (2002). When pH was plotted against salinity, regional groupings appeared which related to geology and climate. Eastern wheatbelt sampling was limited, but groundwater had consistently low to neutral pH and moderately high salinity. Saline lakes sampled from the eastern wheatbelt were all acid.

Recent discussions have focused on the productive uses of groundwater from wheatbelt valleys. George and Coleman (2001) reviewed the use of groundwater for mineral harvesting, aquaculture, algae production, energy and desalination. The main physical limitation to the use of each of these technologies appears to be available groundwater supply and water quality, especially salinity and pH. The Merredin Shire has expressed interest in finding alternative productive uses of its groundwater to offset the otherwise high cost of abstraction and disposal (Dames and Moore/URS 2001).

A brief study of groundwater chemistry was conducted to evaluate the existing water resource for desalination and other potential uses. Previous studies in the catchment did not sample the Merredin townsite (George and Frantom 1990, Matta 2000), or did not sample the full range of townsite bores (Lee 2001). The aims of the groundwater chemistry study were to:

- evaluate pH, EC and salinity levels across the Merredin town, compared to outside town;
- determine water chemistry changes after a year of groundwater pumping;
- evaluate pH, EC and salinity levels in deep compared to perched aquifers; and
- compare the groundwater chemistry of PB1 and PB2 to previously analysed catchment groundwater and seawater.

4.2 Methodology

Prior to commencement of groundwater pumping, one litre water samples were collected from the pump outlet pipes of PB1 and PB2 after pumping for over one hour. Samples were sent to analytical laboratories for chemical analysis. Prior to this, PB1 had been analysed only once; at the completion of drilling in early 2000. Post pumping analysis was conducted for PB1 and PB2 on 4 January 2002. A complete chemistry analysis was included at this sampling including pesticides and industrial hydrocarbons. A subsequent analysis of PB2 was conducted eight months later (13 September 2002). PB1 was not sampled at this time due to pump failure. During 2002, one sample from each production bore was collected for a Microtox® test. This is a bioassay that uses luminescent marine bacteria (*Vibrio fischeri*) to assess toxicity to higher organisms such as fish. Reduction in light from the bacteria after five minutes is seen as a measure of toxicity.

All piezometers, observation bores and production bores were sampled every four to six weeks over an 18 month period from November 2001 to May 2003. Salinity, pH and EC measurements were made at the Department of Agriculture's Merredin laboratories.

4.3 Results

4.3.1 Merredin townsite pH, EC and salinity

Average pH, EC and salinity levels over 18 months may be seen in Appendix 3. No obvious changes occurred as a result of groundwater pumping. Electrical conductivity and salinity changes are generally observed following significant recharge events. The monitoring year from late 2001 through 2002 had below-average rainfall. As observed by George and Frantom (1990), salinity and EC increased from east to west and from upslope to downslope. This may be observed in Figure 3.1 where recent average EC from the Merredin town and catchment EC readings obtained by Matta (2000) have been plotted.

Shallow bores with lower EC levels are consistently found in areas of localised recharge, especially from scheme water irrigation. Bores MDTC04s, 03s, 11s, 14s, 18s, 22s, 22i, 23s and 25s are all screened in shallower aquifers above silcretes in the central area of Merredin. All have EC levels <1000 mS/m. Town bore sites with similar geological conditions but which receive no sprinkler irrigation (e.g. MDTC02s and 10s), have higher groundwater EC. The pH ranges from slightly acid to alkaline at these sites and does not seem to be related to water origin (rainfall or scheme). One slightly alkaline bore (MDTC11s) was noted by Lee (2001) to also have low chloride content, indicating a higher level of recharge.

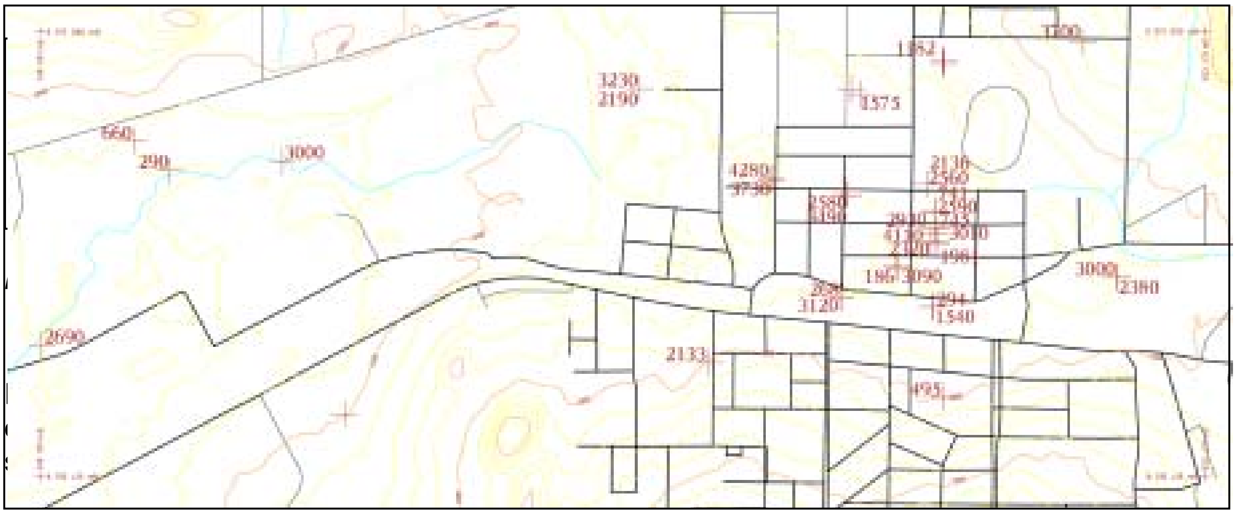

Figure 4.1. Distribution of electrical conductivity in deep aquifer for Merredin town and immediate catchment

Figure 4.2 shows the relationship between pH and EC for town and catchment bores from deep and shallow aquifers. Shallow bores generally have lower pH than deep bores of the same salinity.

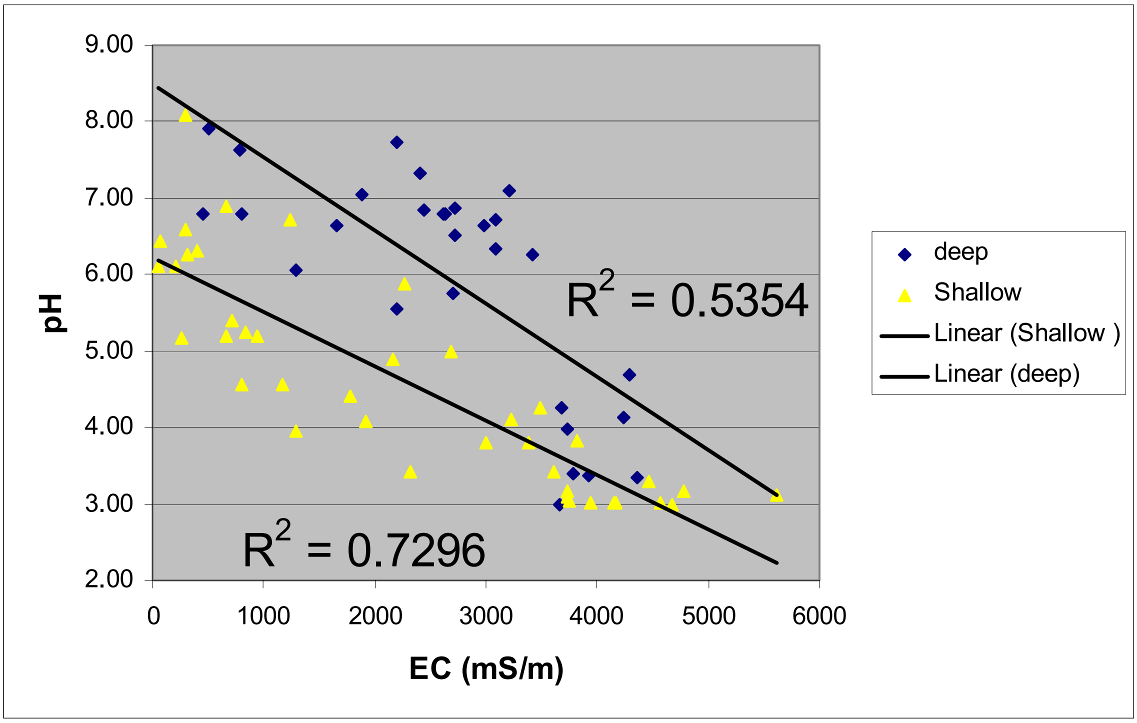

Figure 4.2. Relationship between pH and EC for Merredin town and catchment bores

4.3.2 Groundwater chemistry of PB1 and PB2

A summary of groundwater analyses from four sampling periods for PB1 and PB2 is in Appendix 4. Compared to the analysis of bores predominantly downstream from the townsite (George and Frantom 1990), groundwater from the two production bores had lower concentrations of magnesium, sodium, potassium, chloride and silica ions, while higher in calcium and nitrate. The higher concentrations measured in the townsite, particularly the nitrate, may be due to regular fertilising of shire and residential gardens. High nitrate concentrations (5-10 mg/L) in the Wagga Wagga urban groundwater study (Cook *et al*. 2001), were attributed to garden fertiliser or sewage leaks. The lower concentrations of magnesium, sodium, potassium, chloride and silicon may be due to local recharge from fresh scheme water.

Ions which pose problems for desalination include aluminium and silica, both of which can foul membranes in reverse osmosis desalination plants. Ions found in concentrations higher than stipulated in drinking water standards included sodium, chloride, manganese, fluoride, aluminium, manganese and iodide. No problematic heavy metals or pesticides were detected in water samples from either production bore.

Table 4.1 shows the average concentration of major ions compared to seawater for the two production bores. Ions which were significantly different to seawater may pose problems for seawater aquaculture. Ions that may cause problems for growing fish in Merredin groundwater due to high concentrations included copper, fluorine, iodine and manganese.

The Microtox® test found that PB1 was non-toxic but PB2 was slightly toxic. Further investigation is required to establish whether the Merredin water is suitable for aquaculture.

Table 4.1. Average concentration of major ions from production bores compared to seawater

	Sea water	Average Merredin bore water	Ratio of Merredin water to seawater
Chloride	19,000	9,008	0.474
Sodium	10,500	5,050	0.481
Magnesium	1,350	485	0.359
Sulphur	885	1,428	1.614
Carbon	400	8.3	0.021
Potassium	380	97	0.255
Nitrogen	15	5.4	0.360
Fluoride	1.2	2.3	1.917
Iodide	0.06	0.63	10.500
Copper	0.03	0.195	6.500
Aluminium	0.01	0.35	35.000
Iron	0.01	0.09	9.000
Manganese	0.002	1.49	745.000

4.4 Discussion

Compared with other rural towns in the eastern wheatbelt, Merredin townsite groundwater is significantly less saline. For example Mukinbudin, Kellerberrin and Narembeen all have groundwater salinities one and a half to twice as high as Merredin (Lewis 2000, Nott 2000, Cattlin 2000). Groundwater pH of Merredin townsite bores was also less acid than that many eastern wheatbelt towns. While salinity has to be within a desirable range, most productive uses of saline water (particularly those involving aquaculture) rely on neutral pH. Merredin town groundwater has a pH >6 at most sites. This compares to a pH <3.5 in bores further downstream in the catchment and other low lying wheatbelt towns. Apart from landscape position, one likely cause of the difference in water quality is scheme water inputs to the shallow groundwater system. Scheme water delivered to the Merredin area is predominantly alkaline with pH 7-9 and salinity 30-100 ppm (mg/L). There appeared to be a reverse relationship between groundwater pH and EC for Merredin town, indicating possible ion reactions driven by pH, as suggested by Matta (2000) and Lee (2001). Groundwater depth also appeared to be a factor in pH/ EC relationships, as shown in Figure 4.2.

Groundwater chemistry analysis does not suggest any major water quality issues which may limit desalination or aquaculture. No ion concentrations appeared to change significantly with groundwater pumping. Appendix 4 shows major ionic composition of groundwater compared to water samples taken from MD02D in 1990. Apart from nitrate nitrogen and sulphate concentrations, which are currently higher in the production bores, most ion concentrations from the production bores are similar to those analysed from MD02D over 10 years ago.

Both nitrate and sulphate are ions are typically concentrated in urban areas due to leached fertilisers, septic systems and run-off from bitumen roads. Several deep bores in the vicinity of PB2 and the railway line (e.g. MDTC26D, 25D, 14D and 11D) had groundwater which gave off sulphurous odours during pumping. Sulphur in the Merredin production bores is over 1.5 times the concentration of seawater. This will not pose a problem for most aquaculture.

Nitrogen in groundwater can be a problem for some fish culture, causing the growth of algae. Aquacultural businesses deal with this by using a serial system approach where excess nitrogen in source water is stripped using seaweed or algae which will become fish food.

5. Evaporation basin

5.1 Introduction

Prior to 1998 there had been only a few isolated cases where earthen evaporation basins had been used to dispose of saline water from agricultural or urban catchments in WA. Excess water from pumping or drainage was typically disposed of in natural drainage systems such as creeks or salt lakes. JDA (1998) referred to the potential environmental problems resulting from uncontrolled discharge of highly saline groundwater. More recently awareness of highly acid groundwater (pH <3) from many wheatbelt areas (Nott 2001, Gray 2002), has emphasised the need for constructed evaporation basins to dispose of saline and acid groundwater discharge from pumps and deep drains where off-site problems may arise.

Although used extensively in some other States, JDA (1998) found very few uses of, or research into earthen evaporation basins outside of the mining industry in WA. The only study of a constructed evaporation basin in the wheatbelt was reported in Otto (1994) at Quairading, where a small basin was constructed in a saline area to enhance discharge. Water was pumped from the middle of the basin and allowed to leak back to the sandy clay aquifer. No attempt was made to prevent leakage.

A case study earthen evaporation basin was developed for the property of Mr E. Abe of Corrigin (JDA 1998). This property had already groundwater pumped for a four years between 1993 and 1997. Approximately 100 ML/yr was pumped to a drain discharging into the Lockhart Salt River system prior to installation of the ponds. Minimal water level reduction was evident during monitoring of shallow piezometers during the four years of pumping. Using soil and hydraulic data from the Abe site and climatic data from the Corrigin Shire, an evaporation basin was designed to cater for all the pumped groundwater. The site was also used for development of a series of design criteria and monitoring principles to be incorporated into the 'Evaporation Basin Guidelines for Disposal of Saline Water' manual (JDA and Hauck 1999). This manual was used by Golder Associates (2001) in determination of site and evaporation basin size for the Merredin Townsite Groundwater Pumping and Desalination Pilot Project.

More intensive studies of earthen evaporation basins have been carried out by CSIRO in the Murray-Darling Basin. This predominantly irrigated area has traditionally used evaporation basins for community waste water disposal, but more recently on farms to dispose of saline water. In 2000, approximately 20 on-farm evaporation basins, between 1 and 14 ha in size, existed in the Riverine Basin alone (Leaney and Christen 2000). These basins are designed to remove water from agricultural systems, whilst minimising leakage (Jolley *et al*. 2000). High evaporation rates and minimal leakage are thus critical to their success.

Evaporation depends on:

- basin water salinity (higher salt concentrations produce decreasing evaporation rates);
- basin size and shape (increasing volume, area and depth of ponds equates to reduced evaporation rates);
- temperature and solar radiation levels (increasing temperature increases evaporation rates); and
- wind velocity and humidity (higher speeds of warm dry air increases evaporation rates).

Leakage through an evaporation basin floor is driven by:

- distance between water in the basin and the watertable; and
- basin floor permeability.

Water from a leaky basin will move down and out rapidly (a plume) whilst the soil beneath the basin remains unsaturated. Once the groundwater connects to the basin floor, lateral flow will increase due to the creation of a direct hydraulic connection. Potential environmental problems due to basin leakage and contamination of underlying groundwater bodies may be anticipated in sites where soils below the basin are unsaturated. This will be of particular concern where underlying groundwater systems are relatively fresh. Where underlying groundwater systems are saline, the concern would be that increases in groundwater level which could accelerate local salinisation due to the formation of a saline groundwater 'mound' under the basin.

The leakage rate for small basins (<5 ha) is typically 3 mm/d. Leakage rates >3 mm/d occur if the material in which the basin is constructed is sandy textured, inadequately compacted or was allowed to dry out. A desirable leakage rate suggested for the Murray-Darling area is 0.5-1 mm/d (Singh and Christen 1999). Basins with leakage rates >1 mm/d should be designed to incorporate either an interceptor drain around the basin, sub-surface tile-drainage below the basin or recovery wells downslope. It was hypothesised by Jolley *et al*. (2000) however, that recovery pumping could result in increased leakage. In most evaporation basins a safe leakage level will be considered as a trade-off between minimal leakage and reduced evaporative disposal capacity, and high leakage at the expense of environmental risk to the basin surrounds. Observation of leakage and groundwater flow patterns was described by Leaney and Christen (2000) for a 2 ha basin in the Murrumbidgee Irrigation Area. Initial groundwater level at this site was >6 m below ground level. Immediately after filling the basin, vertical leakage was high and the underlying watertable reached the floor of the basin within five months. As a groundwater mound formed, hydraulic gradients increased and lateral flow became the dominant leakage vector. The leakage plume eventually affected another 1-2 ha of land around the basin and the previously 6 m deep watertable rose to within 1-2 m of the surface.

Given the likelihood of leakage from evaporation basins and the potential environmental problems, site investigation needs to be considered before construction commences. Site investigation should be ranked with equal importance to basin design (Christen *et al.* 1998). In the Evaporation Basin Guidelines for Disposal of Saline Water manual (JDA and Hauck 1999), site investigation principles were based on those used in the Murray-Darling area. Appropriate soil investigations however are inadequately covered in the manual, and do not consider leakage risk factors such as hydrogeological properties or distance to important infrastructure. For example, watertable depth may place a site at high risk, warranting more detailed on-site soil investigations. Dowling *et al*. (2000) used a GIS approach to assess land suitability for evaporation basins based on soil permeability, groundwater depth and quality and proximity of the proposed basin to infrastructure and other high value features. They define a site which has a watertable depth of 5-10 m and groundwater salinity >3000 mg/L, as only marginal suitability for evaporation basins because of potential plume development and increased hydraulic gradient. Jolley *et al*. (2000) stressed the importance of implementing monitoring regimes at sites to ensure basin integrity plus functionality and that environmental impacts are contained within acceptable limits.

Monitoring of a basin should include:

- input water quantity and quality;
- water quantity and quality within the basin storage area;

- watertable depth and groundwater quality under and immediately surrounding the basin;
- evaporation from the site; and
- leakage rates - may be measured directly with a seepage meter or derived from water or salt balance calculations.

The project aimed to test the effectiveness of a small (2 ha), evaporation basin as a mechanism for disposing saline groundwater pumped from under the townsite. Secondary objectives were to measure the integrity of the basin and monitor any environmental impacts. A disposal point close to the townsite was important to success as costs of transporting water to natural salt lakes, over 20 km away, were likely to be prohibitive and complicated by regulatory requirements. A further reason to monitor the site was that no evaporation basin in the WA wheatbelt had been intensively monitored for effectiveness and environmental impact, making this information important to the improvement of evaporation basin guidelines. The type and distribution of the various monitoring apparatus are indicated in Figure 5.1.

The land on which the evaporation basin was constructed was provided by the Merredin Shire and situated between the Great Eastern Highway and Crooks Road. Design and installation of the reticulation system between the production bores and evaporation basin were undertaken by the Water Corporation. Design and supervision of the construction of the evaporation basin were undertaken by Golder Associates (a contracted engineering company) and based on the *Evaporation Basin Guidelines for Disposal of Saline Water* manual (JDA and Hauck 1999). Two alternative evaporation basin sites were discussed in the initial stages of the project: the saline area upslope of the bedrock high (George and Frantom 1990) and further downslope within Department of Agriculture land. No site investigations were ordered for the alternative sites. A consultancy was issued for a geotechnical investigation of the site chosen for the evaporation basin in December 2000. The objectives of the geotechnical investigation were to:

- assess sub-surface soil conditions across the site;
- assess suitability of *in situ* materials to form a clay liner for the basin; and
- recommend appropriate site preparation procedures for construction.

5.2 Methodology

5.2.1 Site testing and basin construction

Site testing at the basin site consisted of:

- excavation of 18 test pits (1.5 to 3 m deep) and soil texturing of excavated samples;
- selected pit sampling for six particle size analysis tests, six Atterberg limit and linear shrinkage tests, two compaction tests, two permeability tests, two Emerson crumb tests and two clay mineralogy tests;
- performance of four *in situ* infiltration tests at varying depths using 300 mm square pits (Golder Associates 2001).

All of these procedures were suggested methodology of the *Evaporation Basin Guidelines for Disposal of Saline Water* manual (JDA and Hauck 1999).

Based on geotechnical testing of the basin site, construction specifications were provided to the construction company. The design of the basin called for construction of two bays of 1.5

and 0.5 ha in area (Figure 5.1). The compartmentalisation of the basin would enable future concentration of brine in a bay separate to the main evaporation area.

Earthworks including topsoil removal, excavation, batter reworking and compaction commenced in January 2001.

5.2.2 Groundwater level and quality

Prior to completion of the evaporation basin construction, a network of piezometers was installed around the basin perimeter to measure groundwater levels and water quality. The piezometers were drilled and logged in June 2001. The piezometers locations are shown in Figure 5.1. Twelve piezometers were drilled to a depth of 12-15 m in and around the basin. These were cased with class 9, 50 mm PVC pipe, slotted for the bottom 2 m and sealed with bentonite plugs. Sites EB9 and EB10, inside Bay 2 and Bay 1 respectively, were sealed with additional bentonite gel at the top of the hole to prevent leakage past the seal and down into the underlying watertable. Data from an older piezometer (MDX) in the Merredin catchment monitoring project (George and Frantom 1990), was used to compare historical groundwater levels and quality (1986-2001), with bore data from the evaporation basin monitoring network.

A larger diameter bore designed to be used as a recovery bore, was drilled and cased at the western end of the basin. This was installed immediately downslope of the basin as a precaution, and was intended to be used for groundwater recovery should a plume develop. This recovery bore (PB3) was drilled to bedrock (48 m), downslope of the basin and adjacent to EB1. This bore was cased with 100 mm PVC and slotted casing from bedrock to 5 m.

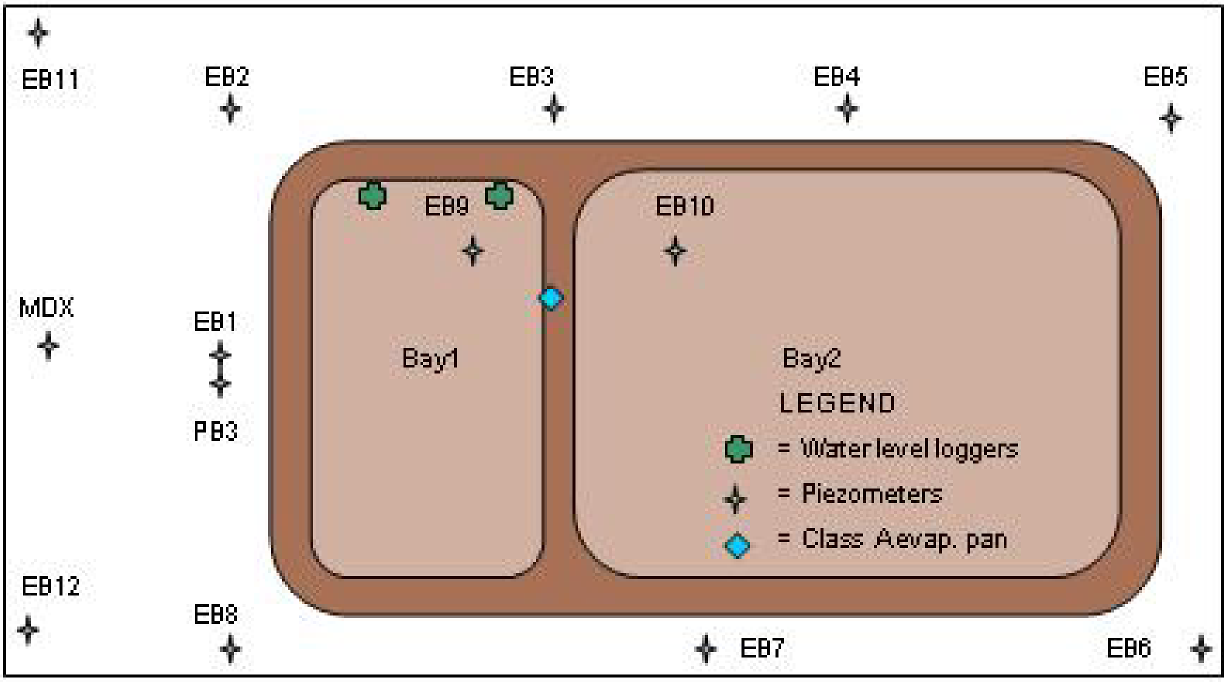

Figure 5.1. Monitoring locations at evaporation basin

Groundwater levels were measured weekly from all piezometers and the production bore for the duration of the project. Water level data loggers were used in some bores for short periods. Groundwater levels were plotted with time to determine changes due to leakage. Piezometer water was sampled for EC, salinity and pH every four to six weeks. Water quality results were examined for changes due to leakage of higher salinity pond water.

5.2.3 Monitoring pond inflows

As noted in Section 2.2.2, water flow into each basin bay was measured daily during week-days, including inputs from the desalination unit. Input water quality and basin water quality were measured every four to six weeks in conjunction with piezometer water quality sampling.

Rainfall was logged at the adjacent Dryland Research Institute and daily evaporation was obtained from the Merredin town weather station. An evaporation pan with logger was also installed on the basin wall to determine microclimate influences on evaporation.

5.2.4 Evaporation and leakage

A more intensive leakage monitoring exercise was conducted between 4 December 2002 and 4 May 2003. Pumped water was directed solely into Bay 1 and allowed to fill to a depth of 1 m. Two water level data loggers were installed into this bay, along with a data logger in piezometers EB9 (within bay) and EB1 (downslope of basin). Rainfall and evaporation were recorded during this period. After the bay water level had reached 1 m in depth, pumping ceased, with the only input water coming from rainfall. Leakage was calculated in mm/d based on average water level changes. Exact water volume changes were unable to be calculated due to unevenness of the basin floor.

The water balance equation:

$$\Delta WL = R + P - E - L$$

where ΔWL = change in water level, R = rainfall, P = input water to basin, E = evaporation and L = leakage, was used to calculate leakage. Further explanation of this method is described by Leaney and Christen (2000). Evaporation from the basin was also calculated using methods described by these authors. Basin area influence (oasis effect) was accounted for using the formula:

$$F = 1 - 0.029 \times A$$

where F = evaporation fraction and A = area. Salinity effect was accounted for using the formula:

$$F = 1.025 - 0.0246 \times EXP(0.00879 \times S)$$

where S is salinity in g/L.

Salinity and pH in the basin were measured on 11 occasions. A salinity/pH meter was fixed to a styrofoam float to obtain a standard reading depth. Up to 20 replicated readings were averaged from around the perimeter of the 0.5 ha water surface area.

5.2.5 Water temperature

A small ‘Tiny Talk’ logger was placed inside the outlet pipe to determine temperature of water entering the basin. Changes in temperature were examined over time and within a 24 hour period as temperature affects evaporation.

5.3 Results

5.3.1 Site testing and basin construction

The geotechnical site investigation report (see Appendix 5) recorded soil conditions at the site. Soils varied from heavy cracking sandy clays of high plasticity (on the western side), to predominantly sandy clays and clayey sands on the east (Golder Associates 2001). Of the 18 pits excavated to 2 m on site for the geotechnical investigation, no groundwater was encountered. Sandy zones were found in two pits and clayey sand zones were found in a further three pits extending from the north-east to the central part of the site. No further groundwater investigations were conducted on site and no reference was made to previous hydrological investigations by George and Frantom (1990).

Infiltration tests at four pit sites indicated unsaturated permeability of $<10^{6}$ m/s. Laboratory falling head permeability tests on two samples indicated k values $<10^{9}$ m/s. Although particle size, Atterberg limits and linear shrinkage tests were completed and presented in the report, no comment was made in the discussion related to these results. The geotechnical investigation concluded that *in situ* site materials could be used for a compacted clay liner, but a synthetic liner was suggested for the basin walls.

Construction of the basin commenced in January 2001 and was completed by October 2001. A Perth-based construction company was used for all earthmoving, compaction and bank formation. A major problem was the small but extensively scattered pockets of sand found at the eastern end of the site. As a result, the finished size of Bay 2 was 1.37 ha, instead of the expected 1.5 ha. Another problem was the short working hours of the construction company which extended construction to seven months. A four-day working week meant that compacted areas were drying out and sometimes cracking during the extended weekends of warmer months. Subsequent investigation of the basin floor using an auger revealed that compaction of the reworked clay blanket was inadequate. The compacted layer was less than 0.3 m thick and was easily augered when wet.

5.3.2 Groundwater changes at the evaporation basin site

Geological logs from the 12 piezometers and recovery bore at the evaporation basin site are shown in Appendix 6. An historical log (MDX), from George and Frantom (1990) which was used for water level and water quality sampling, is included. The production bore (PB3) was the only hole drilled to bedrock. The weathered granite regolith was 48 m deep, with 23 m of predominantly red clay and sandy clay sediments. The saprolite comprised 15 m of pallid kaolinitic clay and 10 m of saprock of increasing grit size. Estimated yield from PB3 was thought to be in the order of 0.5-1 L/s. Thin silcrete and ferrecrete layers were found between 6 and 13 m.

The 12 piezometers were drilled to 12-15 m. All 12 sites intersected sediment of mixed grain size and had silcrete or ferrecrete bands between 6 and 13 m. At the western end of the site, fine-grained sediment dominated the top 4-5 m of profile. This was generally calcrete-rich clay or sandy clay. To the eastern end, 1-2 m thick layered sands or clayey sands were common in the top 5 m. The most obvious of the layered sand sites were EB04 and EB05. Coarse sand to clayey sand was also evident at EB09, EB06 and EB08. The range of sand colours and particle sizes at EB04 and EB05 especially, indicates they are a result of alluvial creek bank sedimentation. George and Frantom (1990) noted alluvial sand formations along Cohn Creek, approximately 100 m from EB05. They estimated that recharge in these sandy deltas would be 0.15 -0.30 mm/yr compared to 0.07-0.15 mm/yr in Merredin sandy clay soils.

Weekly changes in water level at piezometers around the evaporation basin are shown in Figures 5.2 to 5.6, with accompanying HARTT analyses for selected bores. HARTT analysis was only used for the period in which water was pumped to the site. Hydrographs of historical bores MD07 and MD10 were analysed using HARTT and plotted in Figure 5.7 for the two year measurement period from June 2001 and May 2003 as an offsite comparison to piezometers influenced by the evaporation basin. Figure 5.2 shows the water level response of piezometers located to the west of the evaporation basin. Groundwater rose at 0.97 m/yr from the commencement of pumping until September 2002. After pumping ceased, water level declined (1.12 m/yr) and then rose again in response to water inputs into bay 1 between December 2002 and February 2003. Further west at a site located within the grounds of the Department of Agriculture, the water level rose at an average rate of 0.67 m/yr (Figure 5.3). Similar responses to the presence of water in the evaporation basin were observed to the south, north and east, with water level rising at 1.84, 1.82 and 0.43 m/yr respectively for piezometers EB07, EB03 and EB05, shown in Figures 5.4 and 5.5. Water level response directly below the evaporation basin is shown in Figure 5.6, where rate rise was 2.46 and 3.10 m/yr for EB09 and EB10.

All bores immediately surrounding the evaporation basin have increased as a result of inflow of pumped groundwater. Rates of response varied with distance from the ponded water. Figure 5.7 shows two bores located in similar landscape position to the pond, but away from basin influence. These bores show groundwater trends over the two years remained constant or had a slight downward trend - like many other eastern wheatbelt monitoring bores for 2001-02 (Nott 2002). All hydrographs shown in Figures 5.3 to 5.8 indicate that basin leakage added significantly to groundwater recharge at that site and that in the 12 months ending September 2002, a hydraulic gradient or groundwater mound under the basin, was created.

Prior to pumping, water levels were relatively static with only gradual groundwater movement to the west and south, and towards the creek at the eastern end of the basin. The reaction time for water level change varied with distance from the ponded water. Piezometers EB09 and EB10, within the basin, started to show water level rise within days of water inputs. The closest bores outside the basin showed water level rises within four to six weeks, while those further away (e.g. EB06, EB11 and EB12) did not show significant rise until five months.

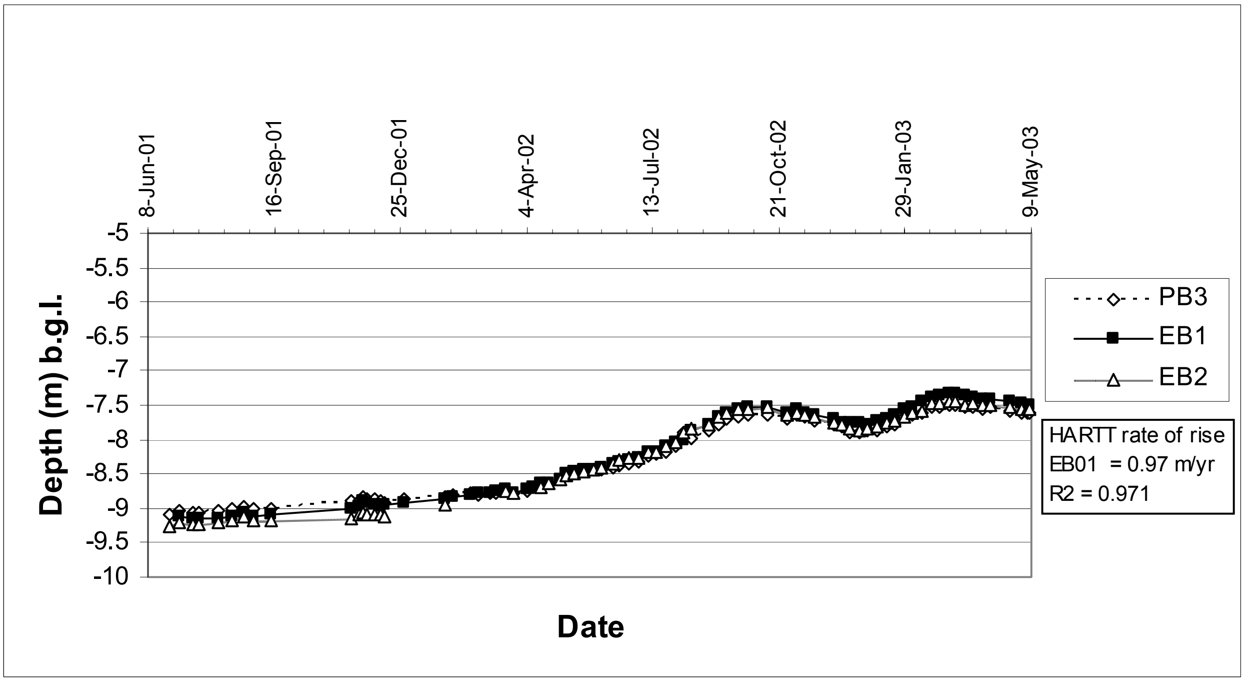

Figure 5.2. Monitoring bore water level response to inflows to evaporation basin, western side

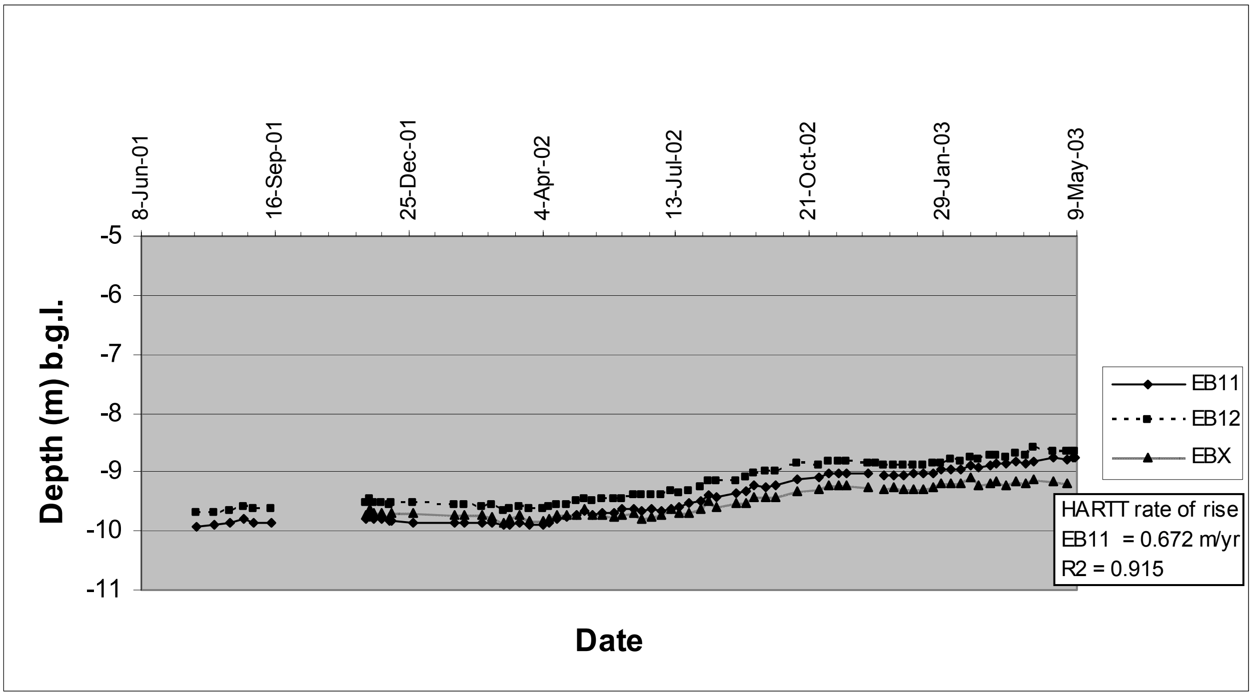

Figure 5.3. Monitoring bore water level response to inflows to evaporation basin - Department of Agriculture grounds

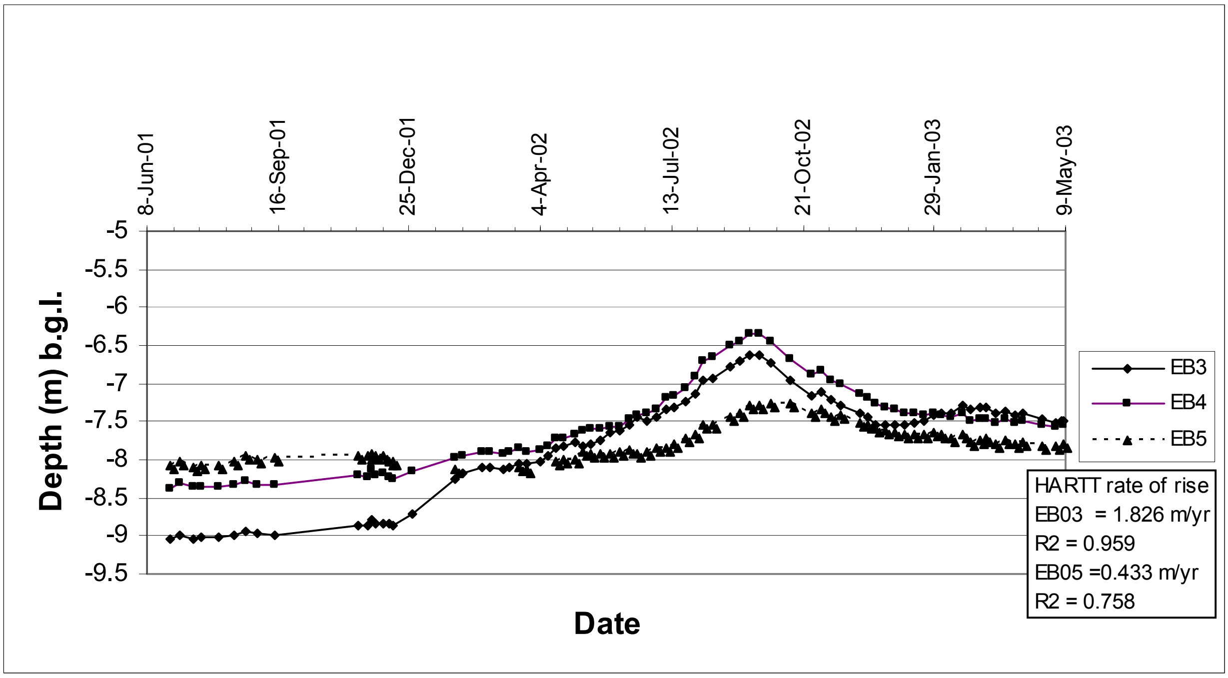

Figure 5.4. Monitoring bore water level response to inflows to the evaporation basin - northern side

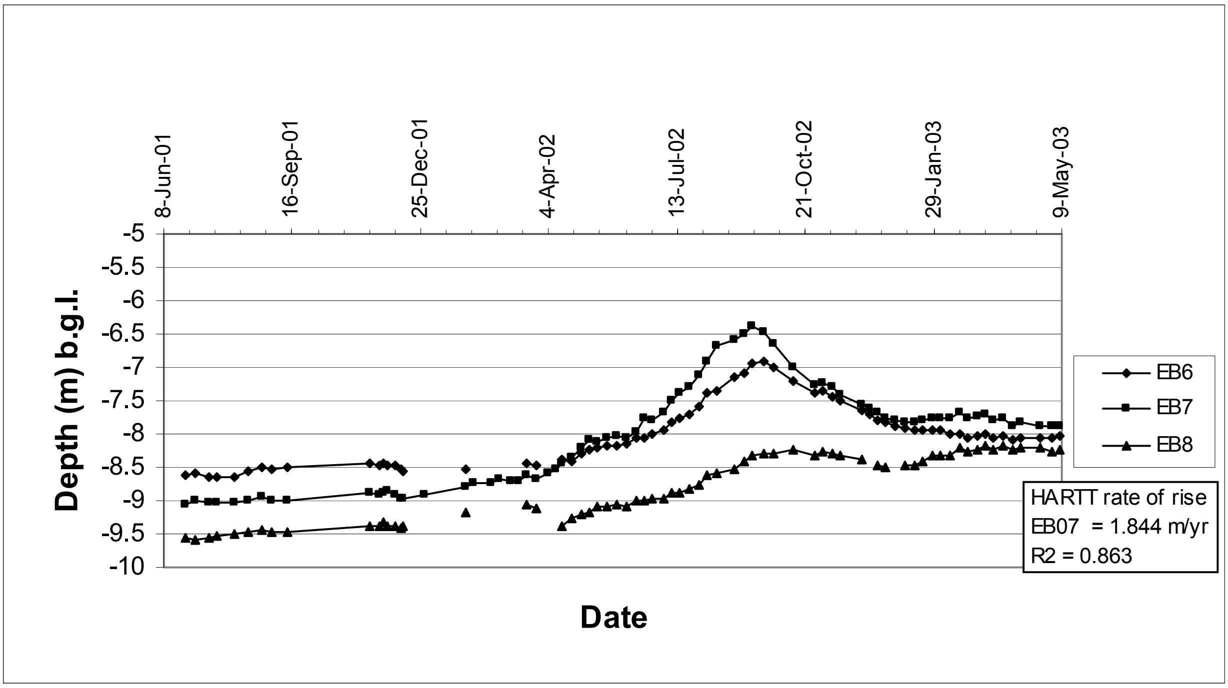

Figure 5.5. Monitoring bore water level response to inflows to the evaporation basin - southern side

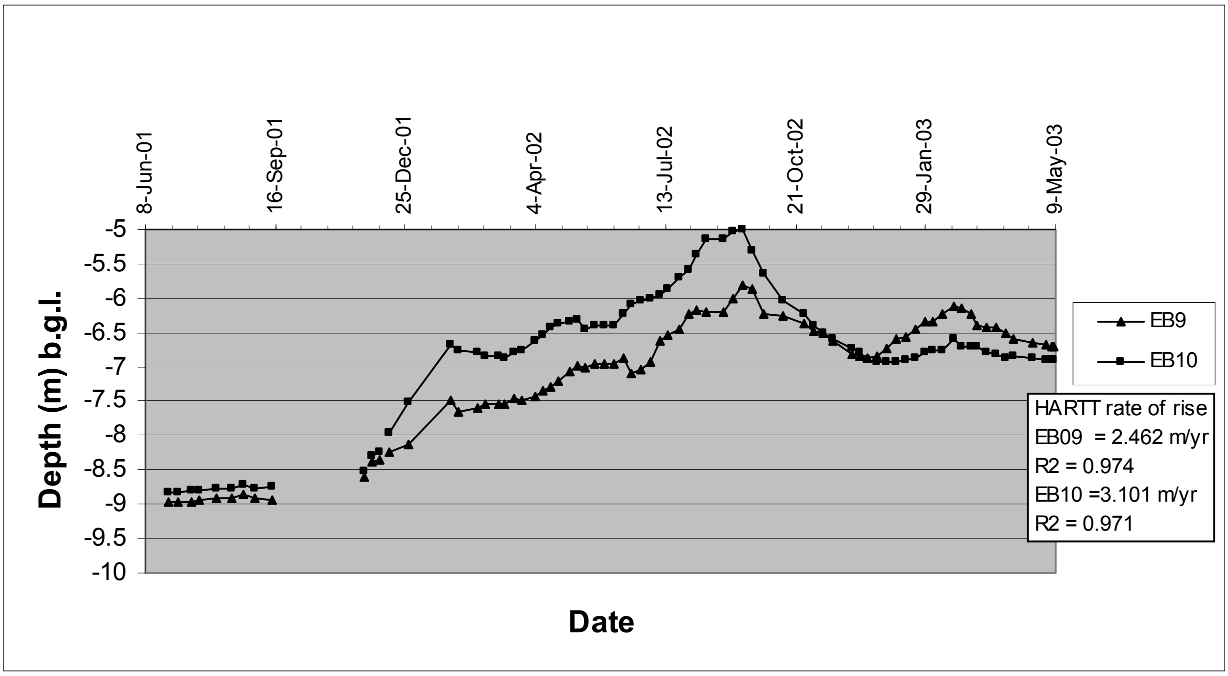

Figure 5.6. Monitoring bore water level response to inflows to evaporation basin - below basin

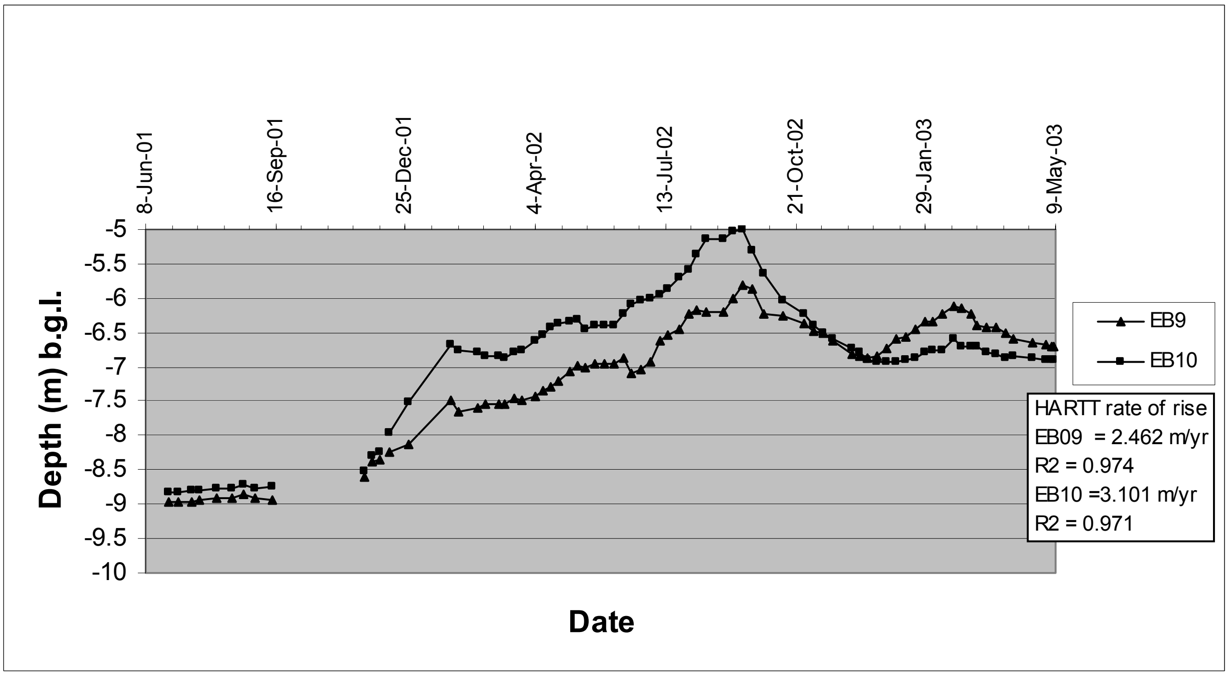

Figure 5.7. Monitoring bore water level response to inflows to evaporation basin - away from the influence of evaporation basin

Average piezometer groundwater chemistry measurements are shown in Appendix 7. No significant changes in pH, EC or salinity occurred during the 18 month period of water inflows to the evaporation basin. The inflow water into the evaporation basin had an average EC of 2,914 mS/m and pH of 6.32. It is unlikely that water quality impacts on watertable would be observed in the short monitoring timeframe of this project.

5.3.3 Monitoring evaporation basin inflows

A simple weekly volumetric water balance was developed for each bay using inputs from town bores, the desalination unit and rainfall, plus known outputs from evaporation. Leakage from the basin was not measured directly and was therefore as a derived component of the water balance equation. Rainfall volume was calculated from daily rainfall at the adjacent Dryland Research Institute and bay areas (5,000 m^2 for Bay 1 and 13,700 m^2 for Bay 2). Evaporation volume was calculated from a fresh water evaporimeter pan on-site, a salinity factor and bay areas.

In total, over 26,000 kL of moderately saline water (2,900 mS/m) was pumped into Bay 2 and over 11,000kL into Bay 1. Rainfall input into the evaporation basin over the 18 months was 283 mm or 1,413 kL and 3,872 kL into Bay 1 and Bay 2 respectively. A comparison of rainfall and calculated true evaporation (adjusted for the salinity of the water in the basin), is shown in Figure 5.8. Cumulative evaporation during the period was 3,373 mm. The volume of water evaporated could not be calculated as the base of each bay was not level. As it was difficult to obtain water coverage of the basin floor due to high evaporation, pump shutdowns and leakage, evaporated water volume could not be determined by water height difference. Leakage thus could not be determined using the water balance equation based on basin area.

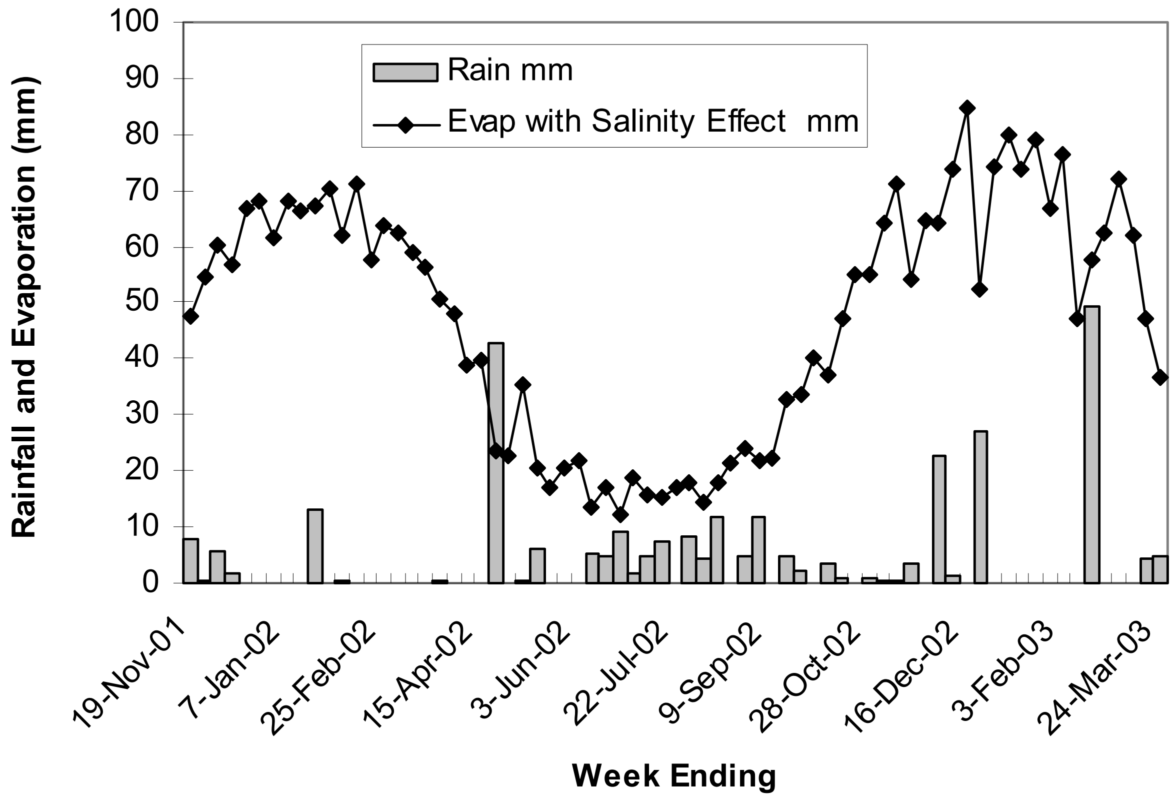

Figure 5.8. Weekly pan evaporation and rainfall - November 2001 to March 2003

5.3.4 Evaporation and leakage

For an evaporation basin of 1 ha or less the ‘oasis’ effect on evaporation is negligible (Leaney and Christen 2000). Pond salinity however was found to increase throughout the short experimental period, and thus evaporation needed to be adjusted. Water entering the basin had an average EC of 2900 mS/m and pH of 6.32. By early May basin water levels had risen to 7170 mS/m and pH 8.0. Changes in water quality for the period of the leakage experiment may be seen in Appendix 7. Electrical conductivity increased with evaporation from the basin. Fluctuations are likely to be due to dilution from large rainfall events and leakage of salts through the base of the pond. Water pH increased rapidly in the basin and then stabilised around 8. Surface soil at the basin site contains small nodules of calcrete (calcium carbonate). It is possible that carbonate reactions increased the water pH. This effect has been observed at other wheatbelt evaporation basin sites, where acid water has been placed in a basin of high pH soil.

Electrical conductivity changes through the monitoring period were used to calculate the salinity evaporation factor. Although resulting in minimal reduction in evaporation, the adjusted evaporation figures were used for water balance computations of leakage.

Accurate water balance calculations were only possible after a complete coverage of the basin floor was reached. This enabled an estimate of water input in millimetres of input water from known input volumes in cubic metres and a known basin floor area of 5000 m^2 for Bay 1. Errors in water level measurement did not enable the calculation of leakage in daily time steps. Despite the collection of high frequency basin water level data, there appeared to be high variability in the data due to measurement accuracy of the loggers and water fluctuation from wind movements. Thus two extended time periods were selected from the logger data for leakage estimation; period 1; after bay water coverage had occurred (13/1/03 to 17/2/03), and period 2; after water input to the basin had ceased (18/2/03 to 31/5/03). A summary of the water balance for these two periods is shown in Table 5.1.

Table 5.1. Summary of water balance from January to May 2003

	Period 1	Period 2
Δ Water Level (**ΔWL**) mm	402.00	-670.00
Evaporation - adjusted for salinity factor (**E**) mm	354.20	576.80
Rainfall (**R**) mm	27.10	130.60
Water Input (**P**) mm	877.80	0
Leakage (**L**) mm	148.70	223.80
No. of days	*36*	*103*
Leakage/day mm/d	4.13	2.17

During the first period of 36 days, the water level in the pond rose 402 mm. This was due to water inputs of 24 mm/d from pumping and <1 mm/d from rainfall. Calculated evaporation losses were over 9.8 mm/d. Leakage was calculated as 4.13 mm/d. In the second water balance period (103 days), water level dropped 670 mm. The only input water was rainfall (1.27 mm/d). Evaporation loss had decreased to 5.6 mm/d and leakage to 2.17 mm/d

5.3.5 Water temperature

Temperature of the input water to the evaporation basin was logged in Bay 2 during late January and early February 2002 when the desalination pilot plant was operating. The maximum water temperature reached was 58.8°C, on 30 January 2002. High water temperatures did not have any measurable impact on evaporation. Higher temperatures did have a significant impact on the operation of the desalination plant and the effects of temperature on reverse osmosis are discussed in Chapter 6.

5.4 Discussion

The Merredin groundwater pumping and desalination pilot project highlighted the importance of geotechnical investigation for determining suitable evaporation basin sites in the eastern wheatbelt. Existing guidelines for evaporation basin design in Western Australia (JDA and Hauck 1999) describe planning, site investigation, design, construction, monitoring and maintenance for saline water storage and disposal purposes. These guidelines however do not consider the environmental consequences of basin leakage and therefore did not analyse the risk of failure in evaporation basin design and construction, as was undertaken for the Riverine Plain (Christen *et al*. 1998). On-site leakage assessment criteria were more explicit in the Riverine Plain geotechnical evaluation report compared to the WA guidelines. Christen's assessment included hydrogeology investigation (shallow aquifer depth, extent and transmissivity, piezometric level and water salinity). He also recommend a leakage assessment using a variety of tools including: an EM31 grid survey and 3 m auger holes to determine variations in soil texture, soil salinity and sodicity, watertable depth and salinity, surface soil moisture infiltration, undisturbed core permeability and *in situ* vertical permeability at 0.5, 1.5 and 2.5 m, as part of an overall site assessment.

Problems were encountered at the evaporation basin site as the geotechnical/soils investigation was done prior to the hydrogeological investigation and without reference to previous hydrological data. Piezometer drilling in June 2001 found a sedimentary regolith of over 20 m overlying a similar depth of weathered granite. The sediment across the site was predominantly the Merredin Province (Bettenay and Hingston 1964) of red sandy clay loams. To the east of the site sand bands were more common and thicker due to alluvial depositions. Hydrogeological logs from piezometers should have been used as a guide to assist in designing the number and location of soil pits. The watertable depth (7-9 m) alone should have been adequate justification for deeming the site of marginal evaporation basin suitability due to potential for increased hydraulic gradient, as suggested by Jolly *et al.* (2000).

An inadequate number of *in situ* infiltration tests was done on the site based on the variation suggested by the geological logs and soil pits. No *in situ* infiltration tests were done using saline supply water. Only four pit infiltration tests were conducted on-site during January 2001; which was insufficient to statistically eliminate measurement error and account for vertical and horizontal soil variation. No reference was made to previous hydrogeological investigations by George and Frantom (1990) which logged soils at site MDX and gave a rising watertable trend from 10 m depth. Detailed soil descriptions were conducted in pits through the centre of the evaporation basin site. Pits displaying larger bands of sand and sandy loam soil were not used for the *in situ* infiltration tests, and average k values are thus likely to be higher than those indicated by the geotechnical report.

Acceptable rates of leakage from evaporation basins suggested by Leaney and Christen (2000) are 0.5-1 mm/d. Leakage is more likely to be tolerated to prolong the basin life if the sole objective is water disposal. In basins where salt harvesting is the main objective, 1 mm/d leakage may not be tolerated due to the loss of the productive resource. In the Merredin Townsite Groundwater Pumping and Desalination Pilot Project, the objectives included water utilisation by desalination and water disposal by evaporation. Thus a leakage rate of 0.5-1 mm/d from the evaporation basin is an acceptable loss, given there is minimal loss of surrounding land. Calculated leakage from the Merredin evaporation basin however was 4.13 mm/d for a 36 day period (between 13/1/03 and 17/2/03), which was 41 days after commencement of water input to the site, and 2.17 mm/d between 18/2/03 and 31/5/03 (when there was no further water input). The reduced leakage may have been a result of soil expansion and bacterial sealing after a period of wetting a dry, cracked basin floor. Watertable rise was calculated at 2.46-3.10 m/yr below the basin and over 0.6 m/yr in Department of Agriculture grounds approximately 80 m away. This rate of water level rise is not acceptable for a site surrounded by high value infrastructure such as main roads, public buildings and land, fuel depots and railway lines.

6. Desalination

6.1 Introduction

This section of the report is limited to the performance of the pilot desalination plant:

- Operating performance with analysis of the reverse osmosis-treated water for use as potable water.
- Project economics for a larger scale RO plant are discussed with 'lessons learnt'. These lessons should be incorporated in the design of any future projects of this nature.

6.2 Effectiveness of the reverse osmosis plant

6.2.1 Plant specifications

Osmoflo Pty Ltd, a South Australian-based water treatment company, was contracted to supply a trailer-mounted reverse osmosis (RO) water treatment plant (plant). The plant included a pre-treatment section and RO unit comprising:

1. A filter feed pump with a 450 kpa capacity driven by 0.6 kW motor
2. Multi-media 23 micron filter
3. Five and one micron cartridge filter
4. A high pressure pump with a 4,200 kpa capacity driven by a 2.2 kW motor
5. Mains electricity power supply
6. A reverse osmosis block containing three membranes with a permeate flow capacity of 10 kL/d at a 60% recovery rate
7. A design capacity of 10 kL/d treated water output.

The plant was designed and constructed in Adelaide specifically for the Merredin site. The pilot plant was rented for a six month period. Appendix 8 details the technical and commercial brief for the pilot plant with respect to:

- process design;
- equipment supply;
- on-site commissioning.

A process flow chart for the pilot plant is attached in Appendix 8.1. The pilot plant was delivered to site in September 2001 and the equipment commissioned in November 2001. The plant was returned to Osmoflo in April 2002.

6.3 Evaluation of field performance

The pilot plant showed that small quantities of potable water could be produced from Merredin groundwater. Some issues would need to be resolved before permanent installation of a full-scale plant was contemplated. The technical issues were:

- High feedwater temperatures to the RO plant were experienced due to solar heating of the black polyethylene transfer pipe. The pipe had been laid on the surface as it was considered uneconomic to bury it for the expected 12 month duration of the project. This initially forced daytime shutdown of the plant as high feedwater temperatures can permanently damage the RO membranes. The problem was solved by installation of a feedwater storage tank next to the RO unit. Sufficient bore water for 24 hour operation would fill the tank overnight, thereby avoiding day time transfer of hot bore water.

As a longer term solution, burying the pipe would significantly reduce heat absorption whilst pumping water through the pipeline in daylight hours during summer. It would be preferable to bury the pipeline even for shorter projects if pumping during summer.

- The poor mechanical performance of the pilot plant high-pressure pump resulted in repeated shutdowns of the plant and eventual replacement of the pump.
- High membrane fouling rates resulted in high operating pressures and shutdown of the plant for chemical cleaning of the RO membranes. Site attendance by the Osmoflo technical staff was required for this critical step. High levels of SiO_2 (50 ppm), in the bore water were thought to contribute to the abnormally high fouling rates. Advice from various suppliers of RO equipment was that injection of alternative anti-scalants to the feedwater should eliminate this problem.
- Failure of the plant's high-pressure switch resulted in shutdown of the plant when this instrument was replaced.
- It was originally envisaged that the Water Corporation staff would visit the plant daily to monitor and record the operating parameters. However operational problems required 'hands-on intervention' outside the skill set of local staff. Regular phone contact with Osmoflo usually resulted in resolution of the problem. However, this issue highlighted the advantages and importance of installing remote monitoring and control facilities for RO units to enable easy review and trouble shooting by external technical specialists. Any future operating plant will need to consider the training needs of local staff.
- The yield of RO treated water was significantly below the design figure supplied by Osmoflo. However, no attempt was made to optimise performance to achieve higher water recovery rates. The objective of the trial was to demonstrate the feasibility of RO technology to treat Merredin bore water and not to maximise treated water yields. Discussions with Osmoflo indicated that the plant could be optimised to achieve better operating performance.

6.4 Water quality

6.4.1 Bore water samples

Laboratories produced a comprehensive water chemistry report for each production bore. Analysis of samples taken in January 2002 showed that the test samples were free of pesticides, herbicides and industrial hydrocarbons. The salt concentration of the samples averaged 17,900 mg/L (2,900 mS/m), which was consistent with earlier testing. The pH of samples averaged 6.3. Water chemistry analyses of feedwater samples are recorded in Appendix 4.

6.4.2 RO-treated water samples

A series of RO-treated water samples was collected in March/April 2002 and fully analysed. These were tested against the National Health and Medical Research Council Guidelines.

The samples were consistent with drinking water standards (1996). The exception was pH, which averaged 5.3; outside the target range of 6.5 to 8.5. Iodide was also outside the standard minimum of 0.1 mg/L, with levels averaging 0.14 mg/L.

The total soluble salts of the treated water samples ranged from 180 to 298 mg/L, which is equivalent to typical Perth scheme water. Water quality analyses of RO treated water are recorded in Appendix 9.

6.5 RO-treated water - re-use options

Among a number of utilisation/re-use options for RO-treated water, injection into the town drinking water supply offers the most attractive option.

The data collected from this trial indicate that the treated water could be piped to the Merredin town water supply system pending resolution of the low pH and high iodide quality issues. However, if the treated water is to be used for drinking then it will have to be monitored to comply with the standards set by the WA Health Department.

6.5.1 pH treatment

Injection of RO-treated water into the Merredin Reservoir at low volumes has been contemplated. Daily water consumption at Merredin ranges from 1500-3000 kL/day. Blending a small quantity of slightly acid RO-treated water with a large volume of slightly alkaline scheme water will overcome the low pH problem.

6.5.2 Iodide treatment

The higher than acceptable levels of iodide in the treated water were discussed with Osmoflo. The analysis of test results indicated that iodide rejection was typically 80% of the iodide level in the feedwater. Average iodide levels were 0.72 mg/L compared with treated water level iodide levels of 0.14 mg/L. The suppliers of the plant indicated that a higher iodide rejection rate (typically 97%), could be achieved with certain RO membranes and any future plant trials should test the performance of alternative membranes. Requirements for water testing are summarised in Appendix 10.

6.6 Economic evaluation of RO plant

The hired pilot plant at Merredin was a small-scale unit designed to demonstrate that RO technology could be used to produce drinking quality water from groundwater under the Merredin townsite. However, the RO plant used was less efficient than a full-scale commercial unit. Consequently operating costs should not form the basis for any economic analysis for the desalination of bore water in country regions.

Data are available for a 100 kL/d desalination plant, which was operated for several years at a minesite near Ravensthorpe in the south coastal region of WA. The quality of the feedwater to this plant was similar to Merredin bore water. Apart from the size of the plant a major difference between the Ravensthorpe and Merredin units, was that the Ravensthorpe plant was remotely monitored and controlled by the supplier. The operating equipment was set in a transportable container and delivered to site and hooked up to the local facilities.

The capital and set-up costs (capex) of the Ravensthorpe plant was approx $280,000. Daily operating charges (opex) resulted in a desalination water product stream at a cost of about $2/kL. Capex recovery costs (assuming a 20 year project life) would add approx $1.10/kL to the cost of the treated water.

Operating and capital costs for desalination plants are highly site specific and further detailed design work would be required at the Merredin site. Assuming installation of a similar sized desalination plant to the Ravensthorpe unit, it would be expected to incur the above typical capex and opex charges. Hence treated water product from a medium scale RO plant at Merredin would cost about $3 per kilolitre. In 2002, the total cost to the Water Corporation to supply water to Merredin to meet the township demand was approximately $1 per kilolitre. However, it has been estimated that additional water supply to Merredin above the current demand would cost around $2 per kilolitre.

Comparison of these costs shows that the provision of desalination facilities at Merredin to supply drinking water is expensive compared with the delivery via the G and AWS pipeline. The cost of supplying additional water to Merredin (the marginal cost) will be higher due to the requirement to upgrade the supply system.

7. Communications

7.1 Introduction

The Groundwater Pumping and Desalination Pilot Project was promoted to stakeholders and interest groups. These included the local Merredin community, other WA rural communities dealing with rising groundwater and salinity issues, and key funding and decision-makers involved in natural resource management.

Interest from both the local and wider community, has been high. The level of interest reinforced the need for a coordinated communications strategy including media releases, brochures, signage, informal site tours and information days.

7.2 Project launch

The Ministers for Primary Industries and Water Resources officially launched the project in Merredin on 5 December 2000. The purpose was to publicise that the project would demonstrate the feasibility of pumping water from beneath towns to lower the watertable and processing the water to make it drinkable.

If successful, the project could give many towns throughout the agricultural region an effective tool in the fight against rising watertables and townsite salinity. Rising groundwater levels, a hazard which currently threatens the townsite, might be turned into a resource.

The venue was the Merredin town centre which offered several visual opportunities such as the effects of salinity damage on town infrastructure, community responses to a serious threat and demonstration of groundwater pumping.

7.3 Signage

A sign was prepared and placed on the Great Eastern Highway in mid-2001 to inform the community of the GWPDP Project during construction of the evaporation ponds. The sign (which faces both directions of traffic) names the project partners and the State Salinity Council as the major funding provider (Figure 7.1).

Figure 7.1. Sign on Great Eastern Highway promoting the project

7.4 Information bay

An information bay was constructed in March 2002 to enable the community and passers-by, to obtain a quick overview and basic understanding of the project. The information bay (Figure 7.2) provided a brief outline of the project, its objectives, and where to obtain further information.

There is room for a two-sided sign to be added which summarises the final research results. This will allow the site to continue being a useful educational site for natural resource management.

Figure 7.2. Information bay and signs outlining the project

7.5 Pamphlets

A pamphlet summarising the essential details of the project was released in March 2002. The pamphlet was handed out at project information days, during informal site tours and the Merredin Agricultural Show, as well as to people who visited the Merredin Landcare Centre, Merredin Shire Offices, and Merredin Tourist Bureau. The pamphlet was also sent to all shires participating in the Rural Towns Program along with an invitation to visit the pending information days.

7.6 Site visits

Project staff hosted numerous informal site visits for scientists, students and farmers on request.

Several organised tours of the project sites have been conducted. Tours have been arranged for groups such as the Avon Working Group and Swan Catchment Council, Tambellup Shire Council. The tour was also included in the 2001 Annual Dryland Research Institute Field Day. Representatives from communities such as Tambellup have visited the sites to see what aspects may be relevant to them.

7.7 School excursions

St Mary's Primary School and South Merredin Primary School participated in tree planting activities around the evaporation pond site in July 2002 for Planet Ark National Tree Day. One hundred school kids were given an overview of the project, participated in the salty liquorice game and planted approximately 500 trees around the evaporation pond fencing. Due to adverse seasonal conditions the survival rate was low, but the school children enjoyed the activities and learnt about the groundwater issues in Merredin.

7.8 Community and technical open days

Two information days were help in April 2002 to inform the public about the project and its progress. Topics concerning Merredin's water supply history and reasons for undertaking this type of project were included.

The Community Open Day was to cater for members of the public who had little or no previous knowledge of the project or salinity issues in general. The Community Open Day also hosted a 'second' opening to promote the fact that the scheme was fully operational.

The Technical Open Day was aimed at people who were more informed about groundwater and salinity issues and wanted a better understanding of the technical aspects of the project. The day gave them opportunities to discuss technical questions with the specialists who had worked on the project.

Both Open Days had approximately 50 attendees and feedback was generally positive. Overall desire was expressed to be kept informed and for another information day to be held once the final results had been compiled.

7.9 General publicity

A number of articles and media releases were prepared for the AgMemo (Department of Agriculture publication circulated to farmers and agribusiness), and regional press (newspaper and radio) throughout this project. The main effort was concentrated during the time of the open days, to encourage attendance and to heighten awareness in the 12 month period that the project was fully operational.

National publicity was gained through two national magazines, including an article in *Focus on Salt,* the newsletter of Australia's National Dryland Salinity Program, and in *Salt* magazine.

7.10 Pictorial record

A simple pictorial diary of the project has been maintained throughout. This was undertaken to provide visual material for project presentations and to demonstrate to the community the steps and workings of the project.

8. Project costs

The project capital and operating costs are summarised in Table 8.1. In-kind contributions, including evaporation site and Department of Agriculture, Merredin Shire and Water Corporation salaries, ***are not included*** in the summary.

Table 8.1. Capital and operating expenses

Expenditure schedule	Budget	Actual	Variation
PLANNING AND ADMINISTRATION			
Project planning and management	$16,028	$8,014	$8,014
Operations management and monitoring	$675	$0	$675
Communications	$11,000	$10,171	$828
Headworks design	$5,241	$5,421	-$180
BORES			
Drill, develop and test bores	$22,300	$27,715	-$5,415
Electrical services	$12,100	$4,915	$7,185
Western Power connections	$22,200	$0	$22,200
Pump installation	$5,500	$4,461	$1,039
Headworks installation	$5,500	$5,885	-$385
Install pressure transducers	$5,720	$0	$5,720
RETICULATION			
Pipe delivery	$14,407	$22,628	-$8,221
Mains pipeline installation	$11,349	$14,022	-$2,673
Desalination pipework installation	$2,176	$0	$2,176
DESALINATION PLANT			
Desalination plant installation	$31,500	$39,365	-$7,865
Electrical services installation	$6,600	$0	$6,600
Clearwater tank installation	$2,090	$349	$1,741
Clearwater transfer pump installation	$1,725	$1,925	-$200
FENCING			
Supply and erect security fence	$11,025	$16,558	-$5,533
EVAPORATION BASIN			**$0**
Earthworks design and specifications	$12,013	$34,306	-$22,293
Evaporation basin construction	$107,877	$111,734	-$3,857
OPERATIONS AND MAINTENANCE			
General operating costs	$13,498	$10,120	$3,378
Repairs and maintenance costs	$0	$2,932	-$2,932
Total	**$320,524**	**$320,524**	**$0**

The project overall was completed on budget. However this was only made possible by cash injections from the Department of Agriculture's Rural Towns Program, the Shire and Water Corporation.

In addition, some savings made by judicious use of limited resources were used to offset over-expenditure in some areas."

9. Conclusions and recommendations

9.1 Groundwater pumping

The Merredin Town Groundwater Pumping and Desalination Pilot Project showed that groundwater pumping is an option for management of shallow groundwater and townsite salinity. Where Merredin-type pumping responses (or better) are achievable in other towns, groundwater abstraction should have application in protecting high value infrastructure. Protection of town infrastructure at risk is particularly beneficial where costs of pumping can be recovered through productive uses of the water. However, the results of the Merredin Project cannot be transferred without appropriate knowledge of hydrological conditions.

Groundwater pumping in Merredin from the two bores produced an average 1.6 L/s of water for the duration of the project. The potential maximum yield was 2 L/s or 63 ML/yr (assuming no shutdowns). The response of pumping on local groundwater levels was a lateral impact of 200 m in deep aquifer and 100 m in the shallow watertable. This area of watertable response however would not justify further immediate investment in pumping infrastructure for the town which included expensive evaporation basins (Dames and Moore/URS 2001).

Groundwater pumping will not be feasible in all rural towns affected by salinity. The decision to pump will be determined by several factors:

1. Water quality: hyper-saline or highly acid water may create too many water use or disposal problems, and prove too costly to replace corroded pump parts.
2. Draw-down distance: high pumping rates do not always produce the desired response in groundwater levels.
3. Value of the assets at risk.
4. Level of support for a truly integrated system which may only prove cost effective if multiple benefits are capitalised upon and spread across the entire project.
5. Technical preference for engineering solutions over other options such as plant-based recharge control or internal water use efficiency improvements.

9.1.1 Borefield extension

One solution to the problem of low economic benefit caused by high disposal costs may be to reduce pumping costs. This could be achieved by integrating deep pumping wells with shallow aquifer pumping wells operating from solar power. Alternatively, using solar power to phase pump groundwater from the deep aquifer may be sufficient to lower the watertable in Merredin given that shallow bores took six weeks to recover after pumps were turned off.

A second solution to the problem of negative economic benefit is producing groundwater for commercial purposes. This would obviate the need for many hectares of evaporation basin and would also offset the high pumping costs. A working scale desalination plant would require approximately 1 ML of water per day, or nearly six times the potential yield from PB1 and PB2. The volume of 1 ML per day would require another 9-10 bores producing 1 L/s continuously; a volume which is optimistic if abstraction only from within the area at risk of salinity is considered. From drilling work undertaken throughout the town, only one site (MDTC10), at the North Merredin Primary School, may yield enough groundwater to make pumping viable. Sites which have not been investigated but may be worth drilling for water abstraction include:

- the area bounded by the Wesfarmers building, Merredin Club and Uniting Church;
- the south end of Roy Little Park, near council chambers; and

- the western end of the town bounded by Nungarin Road, town drain and railway line.

A few sites around town also contain fresh to brackish water, which may be used for domestic purposes. For example, MDTC15 has an electrical conductivity of 570 mS/m, which is low enough for irrigating salt-tolerant tree crops.

9.1.2 Lessons from the Merredin project

Several lessons were learned from the Merredin Townsite Groundwater Pumping and Desalination Pilot Project that could improve the project design and operation for Merredin and other towns implementing similar pumping schemes in the future. These included:

1. Appropriate hydrogeological advice should be obtained regarding aquifer properties and likely groundwater responses before deciding on critical factors such as setting pump depths and determining monitoring regimes.
2. Pumps need to have speed controllers, low water cut-off switches and easily readable gauges and flow meters to prevent the possibility of motor burnout.
3. Where electricity is used as the main power source, battery back-ups are required in the event pumps shutdown due to power failure or fluctuation.
4. For a full scale pumping project, it is important that contractors be trained in pump maintenance and flow rate monitoring to ensure a constant water supply is maintained.
5. All head works (pumps) should be located within a security fence area for protection against accidental damage or vandalism.
6. Head works including monitoring equipment could be set below ground or with a lockable steel lid to eliminate the need for a security fence.
7. In a full scale pumping and desalination project, the desalination plant should be located in a secure area within the townsite to reduce the volume of water pumped to an out-of-town disposal site. This would also enable permeate water to be used close to where it is produced.
8. The pipeline from the bores, at least as far as the desalination plant, should be buried to avoid high temperature disrupting reverse osmosis membrane function. Burying the entire pipeline is preferable in order to avoid damage from mowers and fire.

9.1.3 Aquaculture

Twelve months of groundwater monitoring revealed no changes to major aquifer chemistry due to pumping. Water from the Merredin production bores appears to be suitable for a range of aquacultural activities, which may generate income to assist with off-setting costs.

Monitoring both salinity and pH of Merredin groundwater indicates it may be suitable for growing several fish species, including snapper, bream, trout, giant tiger prawn and possibly barramundi if temperature can be controlled (George and Coleman 2001). Further trials need to be undertaken to confirm the suitability of the groundwater for these species. It is suggested private investment be encouraged to research, develop and market aquacultural industries in the central wheatbelt region.

Although salinity levels and pH of Merredin water are favourable for aquaculture, groundwater in other rural towns may be limited by water quality, particularly pH. Most aquaculture enterprises using saline water require a neutral to slightly alkaline pH. Studies by Gray (2002) and Lee (2001) showed a predominance of low pH in groundwater and playas in the eastern wheatbelt.

9.2 Evaporation basin

9.2.1. Evaporation basin performance

Based on the crieteria of Dowling *et al*. (2000), the site selected for the evaporation basin was only marginally suitable, due to a pre-existing watertable between 5-10 m and salinity above 3000 mg/L. The site was also surrounded by high value infrastructure, so the possibility of leakage should have been given greater emphasis.

Dowling's site criteria and land classification for the Riverine Plain need to be adapted to the Western Australian wheatbelt as a tool to aid future evaporation basin design and site selection. The *Evaporation Basin Guidelines for Disposal of Saline Water* manual (JDA and Hauck 1999), also needs to be updated to include new information regarding evaporation basin design from the Riverine Plain.

Further monitoring at other basin sites is needed to establish how widespread basin leakage is in Western Australia. In the absence of hard evidence, leakage rates may be inferred by correlating known design and construction techniques with soil properties at a given site.

In high risk locations, such as the Merredin evaporation basin site, where valuable infrastructure surrounds the basin, monitoring should be undertaken to measure the extent to which groundwater recharge and contamination is occurring. Measures to prevent or at least minimise leakage may include:

1. Full lining of the evaporation basin with an artificial membrane. This option may only be justified if mineral harvesting, aquaculture, construction of a solar pond or other high value activities were to be undertaken.
2. Installation of coil drains or external deep drains to collect leakage water and recycle it to the basin.
3. Production bores and scavenge pumps to collect and return seepage water to the basin. Recovery pumping may be an option if costs are less than pumping to an alternative evaporation basin site.
4. Decommissioning of the existing site and establishing another evaporation basin elsewhere. Two alternative sites for Merredin might be a basin further downstream near the Hines Hill salt lakes or above the granite high where the watertable is less than 2 m bgl as recommended by George and Frantom (1990). The lower catchment option would have less chance of undesirable environmental impacts from leakage, but would result in higher pumping costs to transport the water. The mid-catchment (granite high) option would be less costly for water transport, but may have environmental risks for CBH and railway infrastructure if located on the south side of the catchment.
5. Repair and re-treatment of existing clay liner using a combination of soil conditioners, substitute clay material, water binding, compaction and care in filling the basin.

9.2.2. Additional basin uses

Additional uses of evaporation basins to assist with adding value to saline water resources need to be further explored for the wheatbelt. So far only limited uses and markets have been found for harvested salts, aquacultural products and electricity from saline water (George and Coleman 2001). Products which grow in saline to hypersaline water need to be investigated for potential integration with existing wheatbelt industries and social structures.

PPK (2001) suggested brine shrimp, algae and seaweed were all potential products grown in seawater through to hypersaline water in warm climates, providing environmental issues can be addressed. Growth trials of these products need to be undertaken in Merredin or other wheatbelt towns wishing to use local saline groundwater.

9.3 Desalination plant

The pilot project demonstrated that drinking quality water could be produced by the desalination of Merredin groundwater. However, there were a number of operational and mechanical issues that impacted directly and indirectly on the performance of the plant.

Whilst drinking quality water could be produced from the desalination of Merredin bore water, the quality and performance problems encountered during the operation of the small-scale pilot plant could be technically resolved. Regular testing of the raw and treated water could permit the inclusion of small amounts of desalinated water product stream into the Merredin Reservoir where it would be mixed with scheme water and further treated prior to distribution to the town drinking water system. Should a full scale plant be installed, it must include facilities to permit remote control and monitoring to reduce the time burden placed on local technical staff.

Water supply to the Merredin townsite from the existing scheme is significantly cheaper than desalinated water. Installation of a larger capacity desalination plant cannot be justified unless the costs of water supply are subsidised under arrangements similar to the existing ‘Community Service Obligation Scheme’.

The cost of water supply using desalination technology is site specific. The economics for each new project must be fully evaluated on a site by site basis in order to determine the feasibility and viability. Whereas a desalinated water supply to Merredin cannot be economically justified on the above analysis, an integrated water management system could be viable if it produced multiple economic benefits from a scheme which combined the protection of townsite infrastructure from the effects of salinity, with commercial gains from production of salty water.

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